European Commission

Community Research

Studies

Third European Report on Science & Technology Indicators

2003

Towards a Knowledge-based Economy

Interested in European research?

RTD info is our quarterly magazine keeping you in touch with main developments (results, programmes, events, etc).
It is available in English, French and German. A free sample copy or free subscription can be obtained from:

European Commission
Directorate-General for Research
Information and Communication Unit
B-1049 Brussels
Fax : (32-2) 29-58220
E-Mail: research@cec.eu.int
Internet: http://europa.eu.int/comm/research/rtdinfo_en.html

EUROPEAN COMMISSION

Directorate-General for Research — K - Knowledge-based economy and society;
K3 - Competitiveness, economic analysis and indicators

Contact: Mrs Fotini Chiou

European Commission, Office SDME 11/16

B-1049 Brussels — Tel: (32-2) 296 90 26 - Fax (32-2) 296 28 40
E-mail: fotini.chiou@cec.eu.int

EUROPEAN COMMISSION

Third European Report on Science & Technology Indicators

2003

Towards a knowledge-based economy

Directorate-General for Research
Knowledge-based economy and society
Competitiveness, economic analysis and indicators

2003

EUR 20025 EN

A great deal of additional information on the European Union is available on the Internet.
It can be accessed through the Europa server (http://europa.eu.int).

Cataloguing data can be found at the end of this publication.

Luxembourg: Office for Official Publications of the European Communities, 2003

ISBN 92-894-1795-1

Printed in Belgium

PRINTED ON WHITE CHLORINE-FREE PAPER

EUROPEAN COMMISSION

RESEARCH

Commissioner : Philippe Busquin

Directorate-General for Research

Director General: Achilleas Mitsos

The Directorate-General for Research initiates, develops and follows the Commission's political initiatives for the realisation of the European Research Area. It conceives and implements the necessary Community actions, in particular the Framework Programmes in terms of research and technological development. It also contributes to the implementation of the "Lisbon Strategy" regarding employment, competitiveness at international level, the economic reform and the social cohesion within the European Union.

The Directorate K "Knowledge-based economy and society" (Director : Jean-François Marchipont) contributes to the realisation of the European Research Area in the fields of the social sciences, economic, science and technology foresight, and the respective analyses. To this end, it monitors and encourages science and technology foresight activities, conducts the economic analyses necessary for the work of the Directorate-General, and co-ordinates policy as regards the relevant political, economic, human and social sciences. It prepares the European reports on science and technology indicators, and it contributes to the development and implementation of the Framework Programmes in these fields. It monitors the progress made in the implementation of the Lisbon strategy. It is responsible for encouraging investment in research and technological innovation. To this end, it develops policies and measures to improve framework conditions (e.g. Intellectual Property Rights) for private investment and the effectiveness of public financing instruments.

The Unit K3 "Competitiveness, Economic Analysis and Indicators" (Head of Unit: Ugur Muldur) contributes to the Directorate General's policy conception and analysis. It is also responsible for the development and implementation of the related research actions in these fields (Action CBSTII of the 5th Framework Programme) and ensures the publication of DG reports like the ***Key Figures : Towards a European Research Area*** and the ***European Reports on S&T Indicators*** and conducts the analyses necessary for the benchmarking of national policies and the mapping of excellence in economics. The members of the Unit K3 are :

Fotini Chiou, Fabienne Corvers, Henri Delanghe, Vincent Duchêne, Angela Hullmann, Kai Husso, Marie Jonkers, Dermot Lally, Gaëtane Lecocq, Marianne Paasi, Ian Perry, Viola Peter, Brian Sloan, Bénédicte de Smet, Anastassia Vakalopoulou and Lise Vanneck.

Contact : Fotini Chiou : e-mail: fotini.chiou@cec.eu.int; tel. (32-2) 296 90 26; fax. (32-2) 296 28 40

URL : www.cordis.lu/rtd2002/indicators/home.html

PREFACE

In recent years there has been an increasing recognition of the vital role played by research in the modern economy. Citizens are becoming more and more aware of the impact of science and technology on their daily lives. Enterprises appreciate the growing importance of research and new technologies for their competitiveness. Expert analysts recognize that knowledge is a key driver of growth, employment and improvements in the quality of life. Policy makers are now accepting that measures to stimulate research and the exploitation of knowledge must play a more central role in government policies.

This heightened emphasis was particularly visible at the recent summits at Lisbon and Barcelona where EU governments affirmed the status of research policy as a central pillar of Europe's strategy towards the knowledge-based economy. Research policy will therefore be crucial for Europe in the coming years, and this is the reason why, in the preparatory debate on the future of Europe, it has been cited among the core missions of the Union.

Meeting these challenges requires nothing less than a restructuring of the research landscape in Europe. This was the reason I launched the initiative on the European Research Area, which had as its core message the need to overcome the traditional fragmentation and compartmentalisation of research efforts in the EU through better coordination and cooperation.

On the one hand, a greater coordination of national research policies and European policy is needed so that they complement each other better and form a more coherent whole – a matter which has become all the more pressing with the imminent enlargement of the Union.

On the other hand, there must be a strengthening of cooperation between different research actors across Europe. In this regard, the recently launched 6th Framework Programme for Research and Technological Development will make an important contribution – with its innovative structure and new instruments such as networks of excellence and integrated projects. It will provide a powerful new tool to stimulate cooperation, promote scientific excellence, and integrate and strengthen the European Research Area.

In order to improve the coordination and effectiveness of research policies in Europe, it is essential that policy makers have at their disposal a common information base about European research trends and performances. The European Report on Science and Technology plays a valuable role in this respect, providing a shared information resource which presents policy-relevant S&T indicators and analyses. The in-depth analyses in this report are intended to complement the more compact Key Figures publication which DG Research also produces every year.

This 3rd edition of the European Report has changed in content and layout compared with its predecessor. The new structure focuses on Europe's investment and performance in the knowledge based economy, and pivots around the policy challenges emerging from the Lisbon and Barcelona summits. The analyses are generally based on the latest internationally comparable data, but there is a permanent need to develop new and better indicators, and with this in mind we have tried to introduce some innovative measures (for example the new composite indicators for the knowledge-based economy).

The messages arising from the report are of critical importance for the future of Europe:

- It is now widely understood that Europe needs to invest more in research, particularly if it is to attain its objective of becoming the most competitive and dynamic knowledge-based economy in the world by 2010. Results in this report indicate a widening gap in R&D spending between the EU and the US, and confirm the importance of the Barcelona European Council's call to raise EU research expenditure to 3% of GDP by the end of the decade. Forecasts presented in the first part of this Report indicate that, if no major changes are made in national and regional R&D and innovation policies, and the 3% target is not reached, then the gap in 2010 will be much more significant. This is why we need a real and coordinated commitment to this objective from all policy makers in the EU Member States.

- However, it is not just about spending more. Where and how we invest in research are also important factors. We need to target financing on those key areas and technologies that will be vital for our future, such as nanotechnology and biotechnology, while at the same time developing new and efficient instruments for supporting research. Industry is particularly well-placed for channelling more investment into commercially promising research and innovation activities. This is why the European Council has called for raising private R&D to 2/3 of total R&D spending by 2010. The European Commission will try to inject further momentum into this process in the form of an Action Plan to boost R&D investment and innovation, based on the lessons learned and best practices from on-going national efforts. It will be presented to the Council and the European Parliament later this year.
- Investing in people will also be crucial for Europe's future. People both produce and convey knowledge. Researchers in particular form a key element of the modern knowledge-based economy. While the EU education system currently produces more S&T graduates than the US and Japan, it still has fewer researchers per capita. Further efforts must be made to attract young people to scientific careers, to create more opportunities for highly qualified scientists – especially in the business sector –, to better exploit the enormous potential of women to provide resources for S&T, and to encourage mobility of researchers between countries as well as between university and industry.
- Europe remains a world class scientific power. The EU is now the largest producer of scientific papers, outstripping even the US. However, its most important challenge remains the exploitation and commercialisation of science in order to boost growth and employment and improve social conditions. This cannot be done simply through greater levels of investment, or the strengthening of research policy. It also requires the effective coordination of a range of complementary public policies that can all contribute to this goal – including taxation, employment, enterprise, competition and education policies, as well as research and innovation policies. It is only by the modernisation and integration of its structural policies that the EU can be the most competitive and dynamic knowledge-based economy in the world.

It is still too early to say whether Europe will meet its ambitious goals in 2010. However, I am convinced that if it continues on this new dynamic, then, just as it was at the forefront of the industrial revolution at the turn of the 19th century, so it will be well-placed to lead the knowledge revolution in the 21st century.

All policies need to be based upon a vision of the future. My vision is of a Europe that has made the successful transition to become the most competitive knowledge-based economy in the world, with better jobs and improved social conditions: a Europe where most employment is in skilled well-paid jobs in knowledge-based sectors; where the majority of production is in high tech, knowledge-intensive goods and services; where growth is sustainable and based on clean technologies; where protecting inventions is cheaper and easier than anywhere else in the world; where women play an equal part in research at all levels; where science is the most popular career choice for young people; and where the best researchers and the most competitive firms from across the world want to come and work.

I hope that this Report, by setting out where Europe is in relation to S&T at the start of the 21st century, will provide a solid basis of quantitative and qualitative information on which we can build and strengthen our policies so as to reach this goal.

Philippe Busquin

AUTHORS AND ACKNOWLEDGEMENTS

The *Third edition of the European Report on Science and Technology Indicators* has been published, at the request of Philippe Busquin, member of the European Commission in charge of Research and the Joint Research Centre (JRC), by the Directorate General for Research, Director General Achilleas Mitsos.

Directorate K *Knowledge-Based Society and Economy*, under the direction of Jean-François Marchipont, was responsible for producing the report. It was prepared, under the leadership of Ugur Muldur, by members of Unit K3 *Competitiveness*, *Economic Analysis and Indicators* between 2000 and 2003: Jean Bourlès, Fabienne Corvers, Henri Delanghe, Vincent Duchêne, Angela Hullmann, Kai Husso, Marianne Paasi, Ian Perry, Viola Peter, Brian Sloan and Richard Torbett. Technical assistance was provided by Fotini Chiou, Dermot Lally, Timo Hirvonen and Anastassia Vakalopoulou. Bénédicte de Smet, Marie Jonkers, Gaëtane Lecocq and Lise Vanneck were in charge of its layout and provided secretarial support.

Through work under study contracts mainly placed as part of the *Common Basis of Science, Technology and Innovation Indicators (CBSTII)* section of the *Improving Human Research Potential* specific programme of the *5^{th} Framework Programme for Research and Technological Development* a number of European institutes and experts contributed significantly to the report: Luke Georghiou (PREST), Chapter 2, part of Section III on European Research Centres; Geert Steurs (Idea Consult), Massimo Colombo and Paola Garrone (Politecnico di Milano), Chapter 3, section on mergers and acquisitions; Philip Marey, Andries de Grip and Frank Cörvers (ROA), Chapter 4 part on Employment scenarios; Wendy Hansen (MERIT), Chapter 4, part on mobility of S&T personnel; Bart Clarysse, section on SMEs and Dossier II on spin-offs; Rosella Palomba, Dossier III, Women in Science; Robert Tijssen (CWTS), the bibliometric indicators used in Chapter 5; Fulvio Naldi and Ilaria Vannini Parenti (Biosoft), Chapter 5, part on patent and publication indicators by gender; Svante Lindquist (The Nobel Museum), Dossier IV on the Importance of Nobel Prizes as S&T Indicators; Rémi Barré, Françoise Laville (OST) and Ulrich Schmoch (Fraunhofer-ISI), the patent indicators used in Chapter 6; Knut Blind, Jakob Edler and Ulrich Schmoch (Fraunhofer–ISI), Dossier V on Patents in Services; Arnold Verbeek and Koen Debackere (INCENTIM-KUL), Dossier VI on S&T linkages. Copies of the full reports prepared by these institutes are available on request.

The authors of this report gratefully acknowledge the guidance given by other staff of DG Research and in particular: Michel André, Paraskevas Caracostas, Nicole Dewandre, Fabio Fabbi, Elie Faroult, Marge Fauvelle, Marshall Hsia, Bianca Nativel, Jacques Removille, Christine Tricot and Pierre Valette, and from Eurostat: August Götzfried, Ibrahim Laafia, Jean-Louis Mercy, Richard Ragnarson and Harald Sonnberger.

Also the authors would like to thank the following external experts who played a key role in the reviewing the text of the Report: Luke Georghiou, Wolfgang Glänzel, Dominique Guellec, Wendy Hansen, Sybille Hinze, Martin Meyer, Mario Pianta, Brigitte Preißl, Ulrich Schmoch and Robert Tijssen. They would also like to acknowledge the assistance with preparing the final text given by Alister Scott and colleagues from The Knowledge Bridge.

EDITOR'S NOTE

Much has happened in science and technology since the very first European Report on Science and Technology Indicators saw the light of day in 1994. Research and innovation policies have evolved considerably, and so too has our understanding of innovation and our capacity to measure it.

This third edition of the Report reflects many of these changes, in its form as well as in its content. Yet its core mission remains the same as it was nearly a decade ago: to provide those involved in S&T policy with reliable indicators and comparative analyses of S&T trends in Europe. Over the years, feedback from the research community has confirmed that the Report responds to a clear need for information, and occupies a special niche. First and foremost, it is of course a *European* report, centred around S&T trends in the European Union and their relationship to current policy developments at the EU level and in the Member States. Few other reports of this kind provide this intensity of focus on European issues. Secondly, it is fashioned as a *policy-oriented* report, rather than a classical compendium of statistics. The Report's value added derives from exploiting the work of statisticians and economists and transforming it into a product that can be readily understood by policy users and that responds to what they want to know about S&T in Europe.

While its aims remain the same, the structure of the Report continues to evolve. The revised structure of the third edition reflects recent policy developments in the EU, in particular the heightened emphasis on Europe's transition to the knowledge-based economy – called for by the Lisbon European Council – and the objective agreed by EU governments at Barcelona of increasing R&D spending to 3% of GDP by 2010. Strongly linked to this is the initiative to create a true "European Research Area" launched by Commissioner Philippe Busquin which aims at a coherent restructuring of the European research system through greater coordination and cooperation. Finally, one should mention the emergence of "benchmarking" of research policies – of which indicators are an important component – as one of the tools for implementing the new "open method of coordination" of policies which was established at the Lisbon summit. These developments run like a thread throughout the Report linking together the different sections, acting as a unifying backdrop to the discussion and providing a recurrent focal point for the analyses.

It had been hoped to publish this third edition sooner than now, but its appearance has been delayed owing to need to devote resources to a number of new policy activities – including the preparation of the initiative on the European Research Area and the launching of the 6th EU Framework Programme for RTD, as well as the new exercises in benchmarking and mapping of excellence in research. Nevertheless, we have tried in the meantime to provide summary updates of S&T indicators in our Key Figures publication which now comes out annually, and which we will continue to publish each year. We also plan in the near future to produce some more targeted work on certain themes which we were not able to include in this edition of the Report.

The abiding principles of the Report have not changed. It tries wherever possible to compare the EU with its main global partners using official statistics from harmonized international sources. In some cases national sources have been used if no international data were available. An effort is also made to highlight methodological issues and disparities where important. Such a report could not have been made without the ongoing efforts of national and international statistical agencies to collect and harmonize data, and in this respect, a special mention should be made of the work of Eurostat, the OECD and the UN (and their member countries). Moreover, these same agencies are also responsible for significant improvements in recent years in the quality and range of statistics available for analysing S&T trends.

In addition to exploiting "classical" data from the official statistical system, the Report incorporates some new approaches in the analysis and measurement of S&T, especially in certain key areas where established indicators are lacking. Some of these innovative approaches derive from projects funded from the 5th EU Framework Programme for Research and Technological Development (FP5), under the activity "Common Basis of Science Technology and Innovation Indicators", which has been active in stimulating the development of new S&T indicators.

Part I of the Report examines Europe's investment in knowledge, and makes extensive use of classical statistics of R&D expenditure, government research budgets, education and human resources in S&T, which respect harmonized definitions agreed at international level (e.g. those in the Frascati and Canberra Manuals). Part I also includes some complementary material based on innovative approaches or new sources of data, including:

- in chapter 2, a section describing the characteristics and recent trends of research centres in Europe;
- in chapter 3, an analysis of the effects of mergers and acquisitions on R&D, in addition to material on international research joint ventures, information on the top EU and international companies in terms of R&D spending, and an analysis of venture capital investment in high tech start-ups;
- in chapter 4, results of a Eurobarometer survey on public knowledge and perceptions of S&T, a section on the migration of skilled human resources, and an analysis of data relating to women's participation in research – a theme which is developed in more detail in a dedicated dossier on "women in science" (dossier III).

Part II of the Report goes on to look at the EU's performance in producing and exploiting knowledge. Indicators of scientific publications, patents and high-tech trade are analysed in detail. Unlike trade statistics, bibliometric and patent data are not produced by the official statistical system, but over the last decade they have more or less established themselves as "classical" S&T indicators. Part II also integrates the following new material:

- the results of a pioneering approach for measuring S&T outputs by gender (scientific publications and patents) (chapter 5);
- a dossier on European performance in terms of Nobel Prizes (dossier IV);
- an analysis of input and output indicators relating to two key technology fields, biotechnology and nanotechnology (chapter 6), which responds to the increasing demand of policy makers to evaluate performance in specific domains or disciplines of critical importance for the future;
- a dossier on patenting in the service industries (dossier V);
- a dossier tracing the linkages between science and technology using indicators of citations to science in patent documents (dossier VI).

Another innovation in this edition is the use of two new "composite" indicators in order to assess the progress of the EU towards the knowledge-based economy: one which measures investment in the knowledge-based economy, and the other performance in the knowledge-based economy. The complex, multi-dimensional nature of the knowledge economy means that many indicators need to be presented in order to cover its different aspects. The aim of these composite indicators is to distil this information so as to obtain an overview, or a "big picture", of trends across a number of related indicators. The results of this innovative measurement approach are presented at the end of chapter 1.

Unlike the previous two editions, the Third European Report on Science and Technology Indicators contains no statistical annex. This was decided partly in an attempt to limit the physical weight and bulk of the report (a common complaint of users who wished to carry it around without risking physical injury), but more importantly in recognition of the advances made in access to data via the internet. The majority of the data used in the report can now be found quite easily on the websites of Eurostat (http://europa.eu.int/comm/eurostat) and the OECD (www.oecd.org), which offer fuller breakdowns and longer time series, while some of the indicators and detailed studies cited can be accessed on the S&T indicators website of DG Research of the European Commission (www.cordis.lu/indicators).

Finally, we would be happy to receive feedback from readers of the Report so that we can continue to improve our products in the future, and in order to help us in our ongoing aim of strengthening the link between users and producers of science and technology indicators.

U. Muldur

TABLE OF CONTENTS

CHAPTER 1
Facing the challenges of the 21st century

Europe at the crossroads in a changing landscape

Europe is facing a crucial period in its history. It is confronted with a number of major, and sometimes very conflicting, challenges and choices, and the various paths it decides to follow will crucially affect the future shape of European society and its role in the world:

- Given the increasing competition in a globalised world, will Europe be able to combine higher competitiveness and social cohesion?
- In the transition to a ‘knowledge-based society’, will Europe be able to prevent the emergence of a ‘digital divide’?
- In macro-economic policy, will the emphasis of fine-tuning be on inflation or unemployment? And is a cautious, restrictive budgetary policy aiming for macro-economic stability still appropriate?
- At what pace will the enlargement of the Union proceed? And what kind of governance model are we going to adopt? Will enlargement lead to more or less convergence between European regions?
- In the international order, will we have a continuing American leadership or will there be a more multipolar structure? And how important a role will Europe play?

These issues must be addressed against the backdrop of a completely new environment created by globalisation, technological change and an ageing population, which will have major consequences for the fundamentals of the welfare state. Globalisation means that companies, regions, nations and continents are competing to attract investment, which depends increasingly on the general conditions influencing business competitiveness. Business competitiveness, in turn, relies more and more on the capacity to answer just in time to the specific needs of customers. This means managing a larger amount of knowledge through the intensive use of information technologies (Rodrigues, 2002). Of course knowledge per se is not a new asset; it has always been a basis for human activity. However, what is radically new is the pace of its creation, accumulation and diffusion resulting in economies and society following a new knowledge-based paradigm. Working and living conditions are being redefined; markets and institutions are being redesigned under new rules and enhanced possibilities for the exchange of information. Moreover, knowledge is not only becoming the main source of wealth for people, businesses and nations, but also the main source of inequalities between them. In other words, while knowledge is the key to increased competitiveness, it could also lead to a reduction in social cohesion and increasing economic disparity between regions, countries and continents. And since knowledge is the key resource, the human capital in which much of it is embodied takes on an ever-increasing importance. This in turn leads us to a crucial question: to what extent can the input of new, highly-skilled human capital compensate for the ageing of European populations?

Europe’s leaders already acknowledge that the transition towards a knowledge-based economy involves a fundamental structural change, and that all the challenges facing Europe need to be reconsidered in the light of this new paradigm. At the Lisbon European Council of March 2000, they adopted a new strategic goal to transform the Union by 2010 into *“the most competitive and dynamic knowledge-based economy in the world, capable of sustainable economic growth with more and better jobs and greater social cohesion”*[1]. However, in this transition to a knowledge-based economy, Europe is already lagging somewhat behind the US, and can learn a lot from the US experience. The aim should not be to imitate the US, but rather to seek to define the European way to the knowledge-based economy. As the Lisbon Conclusions state: *“The Union must shape these changes in a manner consistent with its own values and concepts of society”*[2].

Scientific and industrial research, as the main resource for the creation of new knowledge, is at the core of the transitional process towards the knowledge-based economy and therefore represents a crucial input for the strategic goals set at the Lisbon Council. This report gives a detailed and analytical overview of the main indicators of scientific and technological research, by comparing the different European countries with the US and Japan. The strategy chosen at the Lisbon European Council will be a key theme recurring throughout the report, but the Lisbon strategy itself is a product of a number of broader developments. The aim of this first chapter therefore is to set the scene for the rest of the report by presenting the wider perspective of the global economic, social

[1] *Council doc. 100/1/00 Rev. 1, paragraph 5.*
[2] *Lisbon Conclusions, op cit., paragraph 1.*

and political context of Europe and the challenges that it faces.

The remainder of this chapter is structured as follows. The next section addresses the first -and probably most striking- issue: the fundamental and unavoidable transition to the knowledge-based economy. The chapter then goes on to analyse the main demographic, social, economic and political challenges that Europe will face in the coming years. A next section examines Europe's response to these challenges – the Lisbon strategy – and its consequences for research policy. The final section then presents the latest indicators on investment and performance in the knowledge-based economy. It shows how Europe and its Member States have progressed in the last few years.

The emerging knowledge-based economy (KBE)

Knowledge as a strategic asset

Since the beginning of the 1970s, the most advanced economies in the world have been undergoing structural change, turning them from industrialised economies based on labour, tangible capital and material resources into economies based more and more on the creation, diffusion and exploitation of new knowledge. One of the fundamental characteristics of this shift is the structural intensification of research activities. In the emerging 'knowledge-based economy', also called 'learning' economy, economic growth depends more directly on investment in knowledge, which increases productive capacity, than on traditional factors of production (Lundvall and Johnson, 1994). In other words, knowledge raises the returns on and the accumulation of other types of investment (Nelson and Romer, 1996). In a production function where knowledge becomes the primary factor, human capital and professional skills play an even more essential role. Human capital is the key element in the creation of new knowledge and its dissemination and assimilation in broad sectors of industrial, commercial and social life.

However, new knowledge elements and their successful exploitation have always been the source of great economic progress in the past. The importance of knowledge for economic growth has been recognised in much economic thinking and writing in the last two centuries. Economists, just like historians, have always been aware of the crucial importance of knowledge accumulation for long-term growth (see for example the work of classical economists such as Marx and Schumpeter). According to Abramovitz and David, the importance of intangible investment even grew substantially in the long term. In the second half of the 19th century, growth of physical capital per hour worked accounted for two-thirds of labour productivity growth; at the end of the 20th century it represented only one fifth of it (Abramovitz and David, 1996).

What is new now is the pace of knowledge production and dissemination. There has been a fundamental change in the nature of knowledge production, accumulation and diffusion processes, and this has had much more than just technical or economic implications. Without pretending to be exhaustive, one could describe the transition to a knowledge-based economy under three headings (Lundvall, 2001; Rodrigues, 2002; Soete, 2002; Viginier, 2002):

- the impact of new key technologies on the process of knowledge production, accumulation and diffusion, and consequently also on economic growth;
- the intensification in the production, diffusion and implementation of technological, organisational and institutional innovations;
- the widespread impact of the transition on almost all aspects of society.

Impact of new key technologies

New technologies and their successful dissemination have always had an important impact on economy and society. Three new key technologies are nowadays at the core of the transition to a knowledge-based economy. Firstly, there are the Information and Communication Technologies (ICT), which already came to the fore in the 1980s. More recently, biotechnology has shown a huge potential and widespread impact on many domains of economic and social life. A third key technology for the 21st century is nanotechnology. These key technologies have revolutionary characteristics. Technically speaking, a 'key technology' is one that gives rise to new technologies and deeply influences existing ones; in other words, they may have a 'horizontal' effect on many industry sectors, with consequences for the whole economy. It can be a catalyst for radical technological progress, leading not only to substantial changes in firms' innovation processes, but also having a significant impact on society. ICT, bio- and nanotechnologies seem to possess all the characteristics of key technologies in that they may prove to be strategically influential in terms of new products, processes, and employment.

Indeed, ICT already plays a prominent role as a basic means for the collection, storage and dissemination of (codified) knowledge. It makes human communication and knowledge exchange far less dependent on constraints of time and space. It increases the efficiency of knowledge production and thus speeds up its accumulation. Bio- and nanotechnologies too have a deep 'horizontal' impact across practically all industries. They are generating technologies incorporated into a broad range of products and processes, like new nanoscale semi-conductors that will revolutionise the computer industry. Moreover, these key technologies seem increasingly to interact with each other, forming new fields and new applications like bioinformatics (e.g. IT providing tools for gene sequencing) or nanobiotechnology. Their increasingly common use in many scientific and technological fields has led to a blurring of technological boundaries, making it more and more difficult to distinguish between these technologies and redefining products and innovation processes.

Thus, the upswing in the use of these key technologies has significantly changed the perception of the innovation process over the past decade. Generally speaking, many authors now consider innovation capability less in terms of the ability to discover new technological principles, than the ability to exploit systematically the effects produced by new combinations within the existing stock of knowledge (David and Foray, 1995). Access to state-of-the-art knowledge becomes increasingly important, enabling innovators to draw upon the work of other innovators. In the knowledge-based economy, the science and technology system is evolving towards a more complex 'socially distributed' structure of knowledge production. As Soete put it, the former system was much more based "*on a simple dichotomy between, on the one hand, deliberate learning and knowledge generation (R&D labs and universities) and, on the other hand, activities of production and consumption where the motivation for acting was not to acquire new knowledge but rather to produce or use effective outputs*" (Soete, 2002, p. 38). In the knowledge-based economy, this dichotomy is (partially) collapsing. In other words, there is now a proliferation and a much greater diversity of 'learning organisations' with the production and absorption of knowledge as explicit goals (David and Foray, 1996; Smith, 2002).

Technological, organisational and institutional innovations

It is clear then that the emergence of a 'knowledge-based economy' is much more than a temporary intensification in the production of technological innovations in a few sectors. A wider change is taking place in all sectors of activity, from services to manufacturing, and even agriculture, under the pervasive effect of new key technologies. Technological innovations are invading all sectors of the economy and modifying our lives. Moreover, this change is not only technological, but also includes fundamental institutional and organisational innovations since it reshapes the rules that determine how companies, businesses, institutions and markets operate, due to the new possibilities of exchanging and exploiting knowledge. Knowledge management becomes a key component of corporate strategic management, activating the relationship between marketing, research and production, and modifying the way organisations function. Beyond these organisational innovations, the extension during the 1990s of intellectual property protection to new actors and new types of knowledge appears to have been a crucial institutional innovation, since it made investments in new high-tech products and companies much more attractive[3]. In the US, it supported -and even stimulated- the development of software and biotechnology industries, the market in high-tech shares and the creation of start-ups by university researchers. In this context, the development in the US of an effective venture capital market, which can provide additional or complementary resources for investment in knowledge creation and accumulation, appears to have been a crucial institutional innovation in the 1990s, and shows a greater readiness by the private financial sector to invest in new, knowledge-based activities.

From a knowledge-based economy to a knowledge-based society

Obviously the transition to a knowledge-based economy has many technological, economic and institutional dimensions. But there is more: the transition is having a significant impact on almost all aspects of society and represents a very complex process. It requires new competencies, is changing working and living conditions and having an effect on inequalities between population groups.

In a knowledge-*driven* economy, the availability of well-educated human capital is crucial. Even if ICT offers huge potential for accessing competitive knowledge, there are wide local variations in the local capacity or competence to access, understand and use such knowledge. Thus, new technologies enable a higher 'new' growth path only if they are coupled with long-term availability of highly skilled manpower -not only scientists and engineers, but more generally so-called 'knowledge workers'. Doubtlessly, this is having important effects on how labour markets function, and on education and training policies. Too little investment in human resources often becomes a limiting factor in relation to innovation and economic success (OECD, 1998).

However, speaking about more investment in human resources definitely goes beyond the general trend towards higher qualifications or re-skilling. Education and training policies need to emphasise particular forms of (new) knowledge and new combinations of intangible assets, new skills and new competencies. Digital knowledge, polyvalence, social and management competencies, quality consciousness and creativity are some of the characteristics that are becoming crucially important. A fundamental change in the way work is organised is taking place and workers are facing an increasingly unstable environment. As Schienstocks put it,

[3] *During the 1990s, the European and American patent offices have been progressively enlarging the concept of 'invention' that may be protected by a patent, including new fields like life sciences. Since 1995, the US Patents and Trademarks Office (USPTO) allows applications for patents on gene sequencing. During the 1990s, there has been a progressive recognition, in the US and to some extent in Europe, of the right to patent software (computer programme without any 'physical embedding'). In the last few years, the intellectual protection has also been extended to 'business methods' (Viginier, 2002, p. 148-152).*

"*the average worker is confronted with new tasks and problems and has to develop new skills and competencies more frequently than ever before*" (Schienstocks, 2001, p. 165). Therefore, to be able to cope with new problems and different situations, they need to learn how to learn.

Increasing pressure for more adaptability has – at least – two important consequences. Firstly, it leads to a greater individualisation of work in the labour process, and consequently to more generalised flexibility and multifaceted working conditions (Castells, 1996). This requires new working arrangements that may improve workers' quality of live, but, at the same time, may lead to increased job insecurity. This new trade-off between job flexibility and insecurity will be an important challenge for employment policies. Secondly, there is the emerging danger of growing social exclusion. Since education and knowledge are key resources giving people access to flexibility and wealth, they also constitute the main source of inequalities between them. Slow learners, among them the unskilled, handicapped and elderly, will have more difficulties keeping up with the new, rapid pace of change. It is a huge – but unavoidable – task for education and training policies to build a 'learning society' as a pre-condition to having a knowledge-based society (Lundvall, 2001).

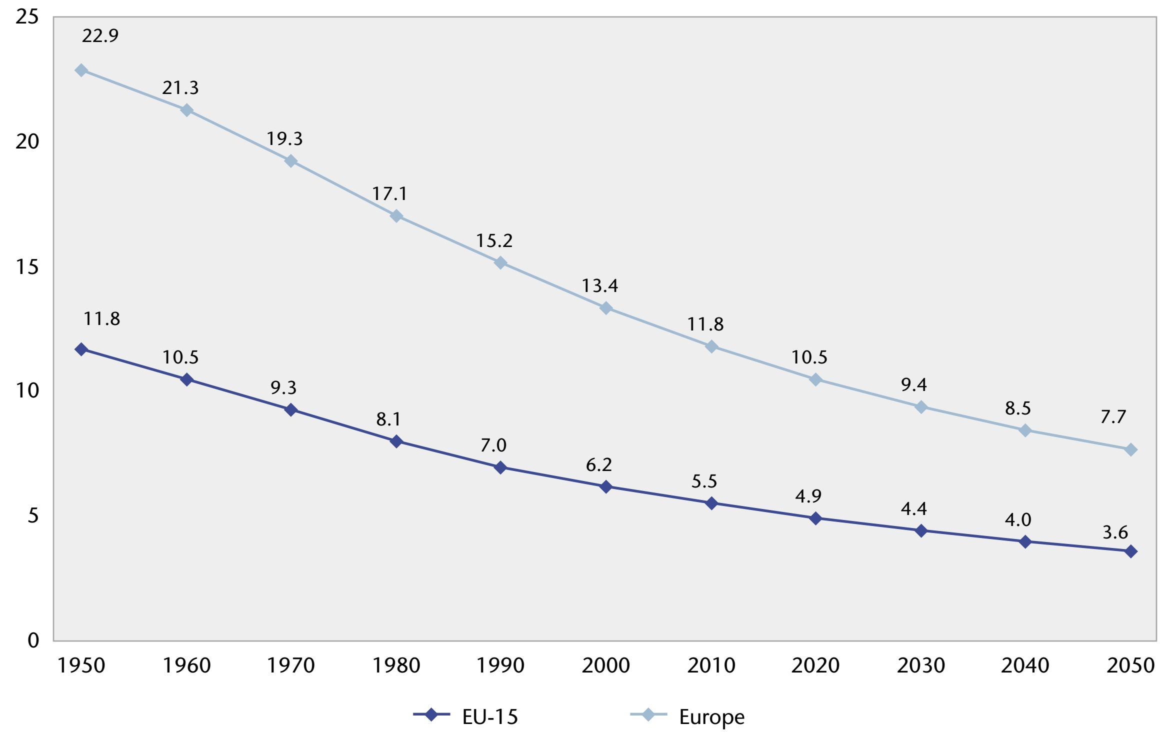
In other words, while there is reason to be optimistic about the huge potential benefits from developing human resources in combination with new technologies and new forms of organisations, one should, however, be aware that the knowledge-based society may not be sustainable if left to itself. Its effects on multiple fields must be dealt with through a multi-dimensional and combined effort at the European, national and regional level. Moreover, in different areas Europe is facing great challenges and also seems to be ill-prepared to adapt successfully to the rapidly changing landscape. Demographic, social and economic challenges need to be reconsidered in the light of this fundamental transition. Let us move on to the demographic challenges.

Europeans: a world minority with an ageing population

Against the background of this fundamental transition towards a knowledge-based economy, the demography of the European continent, and particularly its future population trends, are likely to have a very significant impact on the future of Europe. Europe's policy-makers must take account of two important developments: the unprecedented low share of Europeans in the total world population on the one hand, and the ageing of the European population on the other hand.

In demographic terms, Europe has always represented a substantial part of humanity. From the dawn of Christianity to the

Figure 1.1 European share of world population, 1950-2050 (%)



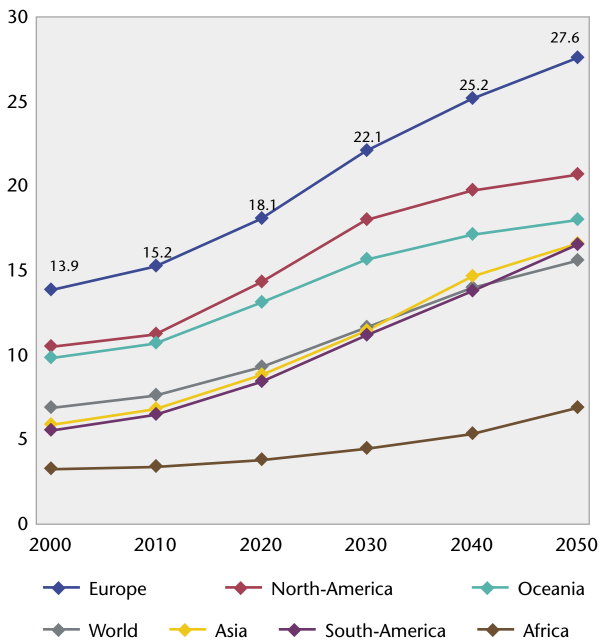
Source: DG Research
Data: United Nations
Note: Europe = EU-15 + EFTA + Candidate Countries + Other Europe (see glossary of country grouping in Annex)

Third European Report on S&T Indicators, 2003

end of the 18th century, Europeans accounted for between 15% and 20% of the world population (between 9% and 13% in the case of the 15 EU Member States). By way of exception, the share increased in the 19th century to 28% on the eve of the First World War. Only in the second half of the 20th century did a structural and, according to certain experts, irreversible decline take place. Whereas in 1950 Europeans still represented almost a quarter of humankind, they now account for only 13% of the global population, a unique phenomenon given long-term trends. With regard to future trends, the forecasts of international institutions in this respect are pointing in the same direction: whatever the scenario, in the first half of the 21st century the relative decline of Europe's population will continue, and it will even fall to below 10%. In 2050, Europe will account for less than 8% of the world population, with the present 15 Member States of the European Union representing barely 4% of the world population.

The population trend in other regions of the world is quite different. North America, whose share of the world population was practically insignificant until the beginning of the 19th century, has increased from slightly more than 3% in 1820 to 13.8% in 2000. The general opinion is that it will stabilise at around 13.5% by 2050. By contrast, Asians have always constituted the vast majority of the inhabitants of the earth. Two thousand years ago, around 75% of the world's population lived in Asia. This percentage declined slightly over subsequent centuries, reaching 65% in 1700 and 55% in 1950.

Figure 1.2 Proportion of the elderly (65 and over) in the total population by continent, (2000-2050) (%)



Source: DG Research
Data: United Nations
Note: for legend, see glossary of country grouping in Annex.
Third European Report on S&T Indicators, 2003

From this date, the proportion of Asians of the total population began to increase. Today Asians are estimated to account for around 59% of the world's population. This is expected to be more or less unchanged by 2050.

This quantitative change could have significant repercussions in qualitative terms. Will the economic and political weight of Europe suffer as a consequence of its demographic weight loss? Whatever the answer, it is not possible to consider the future of Europe without taking account of this variable.

In addition to the overall decline, there is a marked ageing of Europe's population. The forecasts are unequivocal and in complete agreement (figure 1.2). Europe is not only the continent with the highest proportion of over 65s in the population, it will also have the fastest rate of ageing over the next few decades. This phenomenon may also be present in other regions of the world, but nowhere is it as marked as in Europe. The proportion of the elderly (65 and over) in the total population in Europe will have doubled to reach some 28% in 2050 (29% for the EU-15). By 2010, for the first time in its history, the European Union will have more elderly (65 and over) than young (0-15) people.

This chapter is not aimed at discussing the underlying demographic and socio-economic factors that explain the ageing phenomenon. It is important, nonetheless, to highlight the long-term consequences of ageing for the European Union. They are discussed under four headings.

New, bipolar demand patterns

The ageing of the population changes the very nature of the demand for consumer goods. In the second half of the 20th century, the development of domestic markets and mass consumption were mainly stimulated by an increase in the number of families and their combined incomes. Therefore, the mass market which was developed in the West was until recently geared mainly to demand from the young. As a result of ageing, the rate at which families are established will continue to slow down, although this trend would be offset by mass immigration of young people. The mode of consumption over the next decade will probably be defined increasingly by the elderly. Even more likely, it will be geared to a bipolar mass market divided between two groups of consumers with very different needs: on the one hand the elderly of whom most are natives; and on the other hand young people with very varied geographical, ethnic and socio-economic backgrounds.

The resulting increasing pressure on public finance and the provision of welfare services

The impact of the ageing process is already being felt in terms of public finance. The slowdown in the rate of increase in the working population and the increasing dependency rate of the elderly population over the next few decades will not be limited to the European continent. It will occur in most industrialised countries, but the repercussions for public finances will be more severe in Europe than elsewhere. On the one hand, European countries currently have the highest dependency rates in the world. Whilst on the other hand, compared with other continents, the European social model provides for relatively broad state coverage in terms of social security (unemployment, healthcare and pensions).

These effects on public expenditure are expected to be significant. Some calculations project an increase in retirement expenditure under European public schemes from 3% to 5% of GDP over the period 2010-2050, with increases in some Member States to as much as 6% (Netherlands), 8% (Spain) and 12% (Greece)[4]. For the majority of European countries, this means at least a 50% increase between now and 2050 in the proportion of GDP spent on pensions. In terms of healthcare, increases of 1% to 3% of GDP are forecast over the same period (European Commission (2001d); European Commission (2001b)). Will it be possible to sustain this pressure with annual economic growth of 2% to 3%? What are the implications in terms of social security? Will Europe be able to combine such an extended social protection system with budget deficits restricted to less than 3% of GDP?

Mass immigration and labour markets reform as solution?

Faced with a shrinking working population, the vast majority of European countries will be forced to resort to mass immigration of skilled young people. Some forecasts point to the scale of such a movement. The highly reputable *Deutsches Institut für Wirtschaftsforschung* in Berlin estimates that by 2020, Germany will have to bring in one million young people of working age each year simply to maintain its potential labour force. Many other European countries supply figures on the same scale in relative terms. In Japan, mention has been made of bringing in around 500 000 Koreans per year for the same reasons (Drucker, 2001; OECD, 2001).

In Europe, disregarding the large population movements at the end of the Roman Empire, migration on this scale is a unique historical phenomenon and creates therefore unprecedented challenges. It is leading to a widespread feeling of unease, sometimes expressed in the success of nationalistic parties in certain European countries. The arrival of large groups of immigrants will pose major challenges to European societies, among other things in terms of political representation, integration and social cohesion. Moreover, the scarcity of skilled young people also makes it necessary to increase the overall employment rate to optimise the use of the existing labour force. It is essential in particular to create new types of jobs or take measures in order to keep in employment persons reaching the end of their career, or to reintegrate them into the labour market, particularly the most highly skilled. This requires drastic adjustments in the labour market in order to even out as far as possible the potential imbalances between the supply of and demand for human capital.

… and / or increased productivity?

Even if there is a substantial improvement of the participation rate and massive immigration of young human capital, the ageing process means that it is essential in the coming years that there be drastic increases in productivity. This is necessary if economic growth, high standards of living and social cohesion of the population are to be improved or even merely maintained them at current levels. In mature economies, as is the case in the European Union, the main engine of productivity is technological progress. This necessity of an increase in productivity in the working population requires greater attention and a massive allocation of resources to two crucial and closely interlinked areas:

- the generation and assimilation of new knowledge, the source of future competitiveness;
- education and training of human capital.

In the area of scientific and technological research, even if investment in public and private research were to be increased significantly, it is also crucial that there be improved co-operation and co-ordination between the private and public sectors. The training of human capital generating, assimilating and disseminating new knowledge and enabling it to be turned into innovations requires not only the allocation of sufficient resources but also a structural reorganisation of education and training systems. This implies not only improved training of young people, but also the extension of such training to cover an individual's entire career through life-long training. It will become more and more important to reduce the rate at which human capital becomes obsolete. From a political point of view, such an allocation of resources is likely to be subject to pressure from an electorate more inclined to support healthcare and pension programmes than the training of young people or scientific research (Holtz-Eakin, 2000). A very relevant question is how far the political leaders will be able to reconcile the wishes of an increasingly elderly electorate with the crucial need for resources to stimulate productivity.

[4] *By way of comparison, 5% of GDP is roughly the proportion of resources that Europe spends on education, at all levels and including all sources of funding, private as well as public.*

Modernising the social model

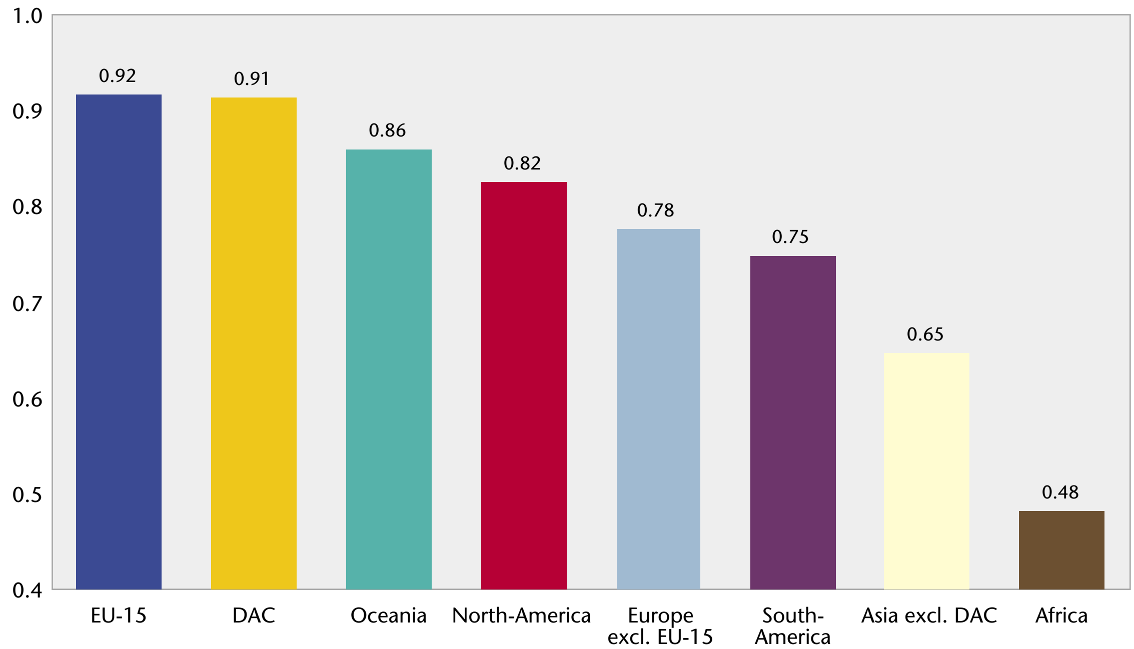
Wealth, health and education as public goods

Europeans are an ageing minority in global terms, but compared with other continents they are wealthy and highly educated. Europe, *"the driving force for economic development and modernity"* (Landes, 1998) has acquired considerable assets and benefits during its long history of economic prosperity and the development of social well-being. Even if one takes into account substantial differences between its different social welfare systems, Europe, compared with other continents and regions in the world, benefits from a high level of wealth and education, and, via social transfers, from a high degree of social cohesion.

The European Union is the region with the highest 'human development' levels in the world (figure 1.3). Because individual well-being requires much more than economic wealth alone, the 'Human Development Index' combines the three basic dimensions of human development: leading a long life in good health, being well-educated and having access to the resources necessary to enjoy a decent standard of living. In Western Europe, the average income per person (in purchasing power standard) is five times higher than that of a citizen of Asia (excluding Japan) or South America, and nearly twelve times higher than that of a person in Africa. Moreover, within the EU-15, per capita GDP is converging between the Member States, indicating convergence in the standards of living of the European countries (European Commission (2001/1b)). Finally, European citizens appear to constitute one of the best-educated populations on earth, and benefit from the highest standards of living.

Beyond individual well-being, a sufficiently high level of per capita wealth also enables collective services to be provided in the public interest. In a democratic society with a prosperous and stable economy, the State can act as arbiter in the (re)distribution of the wealth produced. Through public spending on the social security system, it has mechanisms at its disposal to guarantee a minimum level of social protection for the population as a whole and, in particular, the groups most vulnerable in socio-economic terms. Within the EU-15, 18% of the population in 1996 had an income below the poverty line[5]. This figure would rise to 26%, increasing

Figure 1.3 Human development index worldwide (1999)



Source: DG Research
Data: World Bank, World Development Indicators 2001 and 2002.
Note: The Human Development Index (HDI) is a composite indicator summarising three basic indicators of human well-being: life expectancy at birth, gross schooling rate and per capita GDP (at purchasing power standard). These three indicators get equal weight within the HDI. Figures by region/continent are population-weighted averages. (See glossary of country groupings in Annex).

Third European Report on S&T Indicators, 2003

[5] *According to the Eurostat definition, this is the proportion of the population with an income, after tax and social transfers, equal to or less than 60% of the average of the country concerned (European Commission (2001/1b)).*

poverty by almost half as much without social transfers (European Commission (2001/b)).

However, the provision of social protection is not self-evident. On the one hand it requires solidarity between all population groups; on the other hand it implies a long-term commitment, since any reduction in poverty and social cohesion calls for considerable effort by the whole of a society during several generations. This is especially true when economic growth slows down and governments are exposed to budgetary constraints, because of which they are likely to reduce public spending, or rely more on long-term external borrowing to finance social security. The resulting increase in consolidated debt may then endanger macro-economic stability and growth in entire regions. It creates a need for inter-generational solidarity, since future generations are obliged to pay back present spending, sometimes even decades later.

Compared with other parts of the world, Europe stands out because of its extensive social model, with major efforts to ensure a high standard of social protection and cohesion (table 1.1). Through its public spending, Europe devotes a relatively large share of its wealth to social transfers for healthcare, pensions and the provision of a high standard of basic education.

Table 1.1 Total public spending on pensions, healthcare and education worldwide (percentage of GDP at current prices last year available between 1994 and 2000)

	Total	Pensions	Health	Education
America		**4.7**	**4.3**	**4.9**
US	30.1	5.4	5.1	5.4
Rest of America		3.9	3.4	4.4
Europe		**8.5**	**5.3**	**4.9**
EU-15	46.2	10.2	6.5	5.0
Rest of Europe		7.0	4.2	4.5
Asia		**2.4**	**1.7**	**2.9**
Japan	38.1	5.1	4.8	3.6
Rest of Asia		2.2	1.5	2.8
Oceania		**4.9**	**5.4**	**5.8**
Africa		**0.8**	**1.8**	**3.6**

Source: DG Research
Data: World Bank, Eurostat, OECD.
Notes: The figures for the EU-15 date from 2000 (total public spending, spending on pensions), 2000 or 2001 (education) and 2000 (health). The figures for the other industrialised countries and OECD members refer to 1999 (total public spending), the last available year between 1994 and 1997 (health and pensions) and 1998 (education). The figures for the other countries refer to the last year available between 1994 and 1997 (education), between 1996 and 1998 (health) and between 1991 and 1997 (pensions). For definitions, see World Bank Development Indicators 2002.
Third European Report on S&T Indicators, 2003

Although the above figures reflect the extent of public commitment to social protection, they reveal nothing about the effectiveness of spending or concrete social return. One of the reasons for social inequality within a society is the uneven distribution of wealth. Figure 1.4 gives an overview of this type of economic inequality for the various regions of the world. It shows, for the last year available between 1990 and 2001, the Gini coefficient for the country or continent concerned[6]. The higher the Gini coefficient, the more uneven the income distribution is.

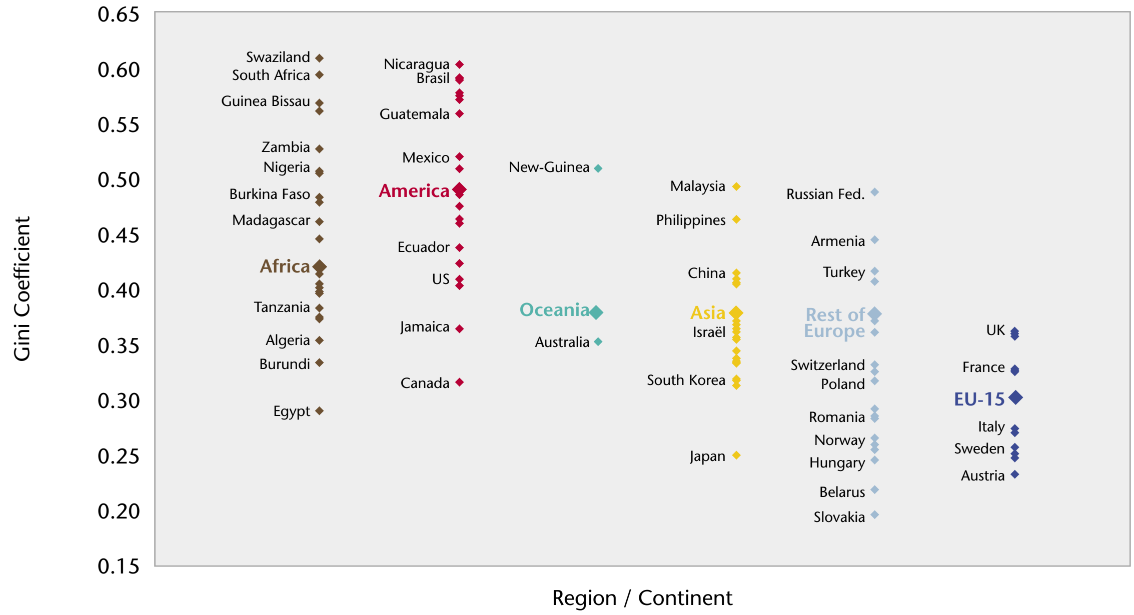
Obviously, there is not necessarily a direct relationship between the overall level of per capita wealth and the distribution of this wealth between population groups. Thus the US is a country with less equality than Burundi, Egypt or Romania. Furthermore, there appears to be no close positive correlation between rapid economic growth and inequality of income distribution. The Asian countries, for example, experienced the highest growth rates during most of the last decade, but did not have the greatest disparities. Finally, extreme disparities can be a barrier to economic growth, like in a lot of South American or African countries.

Europe appears to be the continent with the smallest income disparities in the world, but an important distinction has to be made between two different groups. The EU-15 is the genuine model of economic cohesion: it is the world region with by far the most equal income distribution. In addition, differences across Member States are considerably less than those between countries in other continents (cf. the variation around the average for each continent). The situation in the rest of the continent is much worse, even if income inequalities in these countries are less than those in the US, China or Africa.

From a trend angle, it is worth mentioning that nearly all countries, including most of the industrialised countries, seem to have experienced a U-shaped change in inequality, with a decline of income inequality in the 1970s and 1980s and increases in the 1990s. One should pay very special attention to this development, even if the increase in disparities was much smaller in Europe than in other industrialised regions, in particular North America (UNDP 2001; Higgins and Williamson, 1999).

[6] *The Gini coefficient is one of the indicators most often used to measure income disparities. It is always between 0 and 1, with a coefficient of 0 representing a perfectly even distribution, i.e. a situation in which each population group has the same share of available income. In a perfectly unequal society, i.e. one in which the richest group holds all of the available income, the Gini coefficient is equal to 1.*

Figure 1.4 Income inequality: Gini coefficients by country and weighted average by continent (last year available between 1990 and 2000)



Source: DG Research
Data: World Bank, Eurostat, OECD.
Note: The figures for the EU-15, the US, Japan and other OECD countries are for 2000. The estimates for other countries refer to the last year available between 1990 and 1998. The figures by region/continent are population-weighted averages. 'Rest of Europe' consists of the Candidate countries, the EFTA countries and 'other Europe' (see glossary of country groupings in Annex).
Third European Report on S&T Indicators, 2003

Competitiveness with high social cohesion?

However, this European social welfare system is undergoing increasing pressure, due to both external and internal factors. On the one hand, intensified globalisation and competition, and increased technological change are breeding new inequalities while at the same time demanding higher levels of competitiveness. On the other hand, the pressure on the social model will grow due to the phenomenon of ageing and the enlargement of Europe to include new Member States with less social cohesion and a lower standard of living. Taking into account this new, changing environment, can such a model, which provides the highest 'human development' and social cohesion in the world, be preserved?

We have here a crucial dilemma between competitiveness on the one hand and social cohesion on the other. A realistic assessment might be to conclude that it is not possible to maintain the European social model. Therefore, a defensive answer to this threat would consist of downgrading it in order to increase competitiveness. Another, more affirmative answer but also much more complex, is two-fold: to build new competitive factors on the one hand and to modernise the European social model on the other hand (Rodrigues, 2002; Esping-Andersen, 2002).

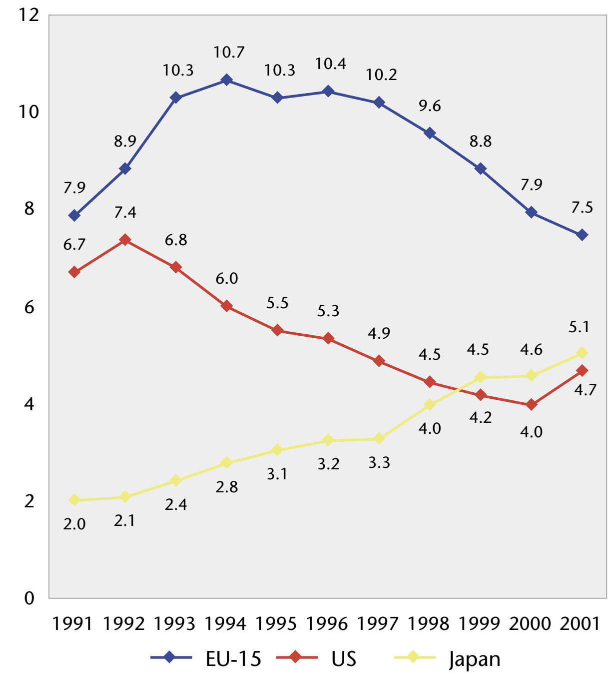
Building up new competitive factors might be possible thanks to the new opportunities created by the knowledge-based economy, including the modernisation of companies, public services, schools, transport, cities and all the surrounding environment. This calls for a broad commitment to active policies in the fields of education, research, and economics. The cornerstone of this modernisation process is investment in human capital and new knowledge. Only through the development of new competitive factors will Europe be able to meet the increasing social demands and to maintain – or even improve – social cohesion.

Modernising the social model implies the creation of conditions to help people moving from a job without a future to a job with a future. Analysis of EU employment growth during the last years reveals substantial improvement in this regard (see figure 1.5). Besides favourable macro-economic conditions, the job creation witnessed since 1997 also reflects labour market reforms undertaken by Member States. This includes measures to lower the cost of labour and/or to improve the adaptability of the workforce, sustained wage moderation, improved real wage flexibility and cuts in social security contributions and taxes. Labour markets have also tended to become more flexible, as witnessed by the large contribution of the development of part-time and temporary employment to overall job creation.

Despite this impressive performance in the second half of the 1990s, human resources are still under-utilised in the European Union and structural problems continue. Unemployment – in particular long-term unemployment – is still high in a number of Member States and regions. Action is needed to ensure that the cyclical increase in unemployment expected in 2002 and 2003 does not become structural. In some Member States a high rate of unemployment co-exists alongside a large number of unfilled job offers, especially for highly-skilled human capital. Finally, labour force participation rates, especially for older workers and women, are unsatisfactory. Determined continuation of policy action to reduce unemployment and put in place a full strategy for increasing participation rates is essential. Promoting the training of human resources in order to improve qualifications and make them adaptable throughout their working life could act as a catalyser in this context.

However, thinking that the population, via education and training, can be adapted to new market conditions and that education and training will, thus, resolve the social problem, is a fallacy. Investment in education, training and life-long learning might be inefficient if it is not backed up by social investment: children's ability to learn and success in school depend directly and powerfully on the social situation within their families. Lingering social inequalities unavoidably produce educational and cognitive inequalities. Active social investment is also an answer to new needs created by changes in the family structure: new household forms and life-style patterns, much less linear, homogeneous and predictable, are emerging. Therefore, it appears to be important to redefine social policy in order to nurture strong and viable families adapted to the new and rapidly changing working conditions.

Figure 1.5 Unemployment rate (%) in the EU-15, the US and Japan (1991-2001)



Source: DG Research
Data: Eurostat, New Cronos
Note: The unemployment rate considered here is the total number of unemployed divided by total labour force.
Third European Report on S&T Indicators, 2003

Economic challenges: combining prosperity, stability and dynamism

The issues

Modernising the economic and social environment to support the transition to the knowledge-based economy, providing more and better jobs and promoting active social policies cannot happen without sound and sustainable economic growth. The increasing pressure on the working population due to the ageing process unavoidably calls for drastic increases of productivity. Even if there is 'efficient' immigration of young talent and higher participation rates that can compensate for the reduced workforce, a substantial increase of labour productivity will be more than necessary if we are to keep a high standard of living for everyone. Therefore, it is generally recognised that over a long period productivity, competitiveness and economic growth are above all determined by technological progress and the accumulation of human capital[7]. These factors are in turn largely dependent on investment in education, research and innovation and its outcomes. In a knowledge-*driven* economy, education, research and innovation policies are thus key elements for fostering productivity and economic growth in the long term.

On the other hand, increasing and stimulating public and private investment in the fields of education, research and innovation may jeopardise budgetary positions and endanger macro-economic stability in the short-term. Inversely, focusing on stability should not happen at the expense of those investments that can enhance long-term economic growth. The real economic challenge for Europe consists thus of finding the right balance between restrictive policies focusing on short-term budgetary and monetary stability on the one hand, and active policies achieving higher economic growth paths on the other hand. One might consider, indeed, that these two options are not necessarily incompatible. In this section we will first review the recent progress made by European Member States in terms of macro-economic stability. The following section will analyse to what extent this was translated into higher economic growth. Finally we will see to what extent a suitable matching can be found between macro-economic stability policies on the one hand and long-term growth policies on the other hand.

[7] *Estimations made by the European Commission point to a contribution of technical progress to the potential economic growth of 50% to 56% (European Commission (2001d)).*

Prosperity and macro-economic stability: real progress made during the 1990s

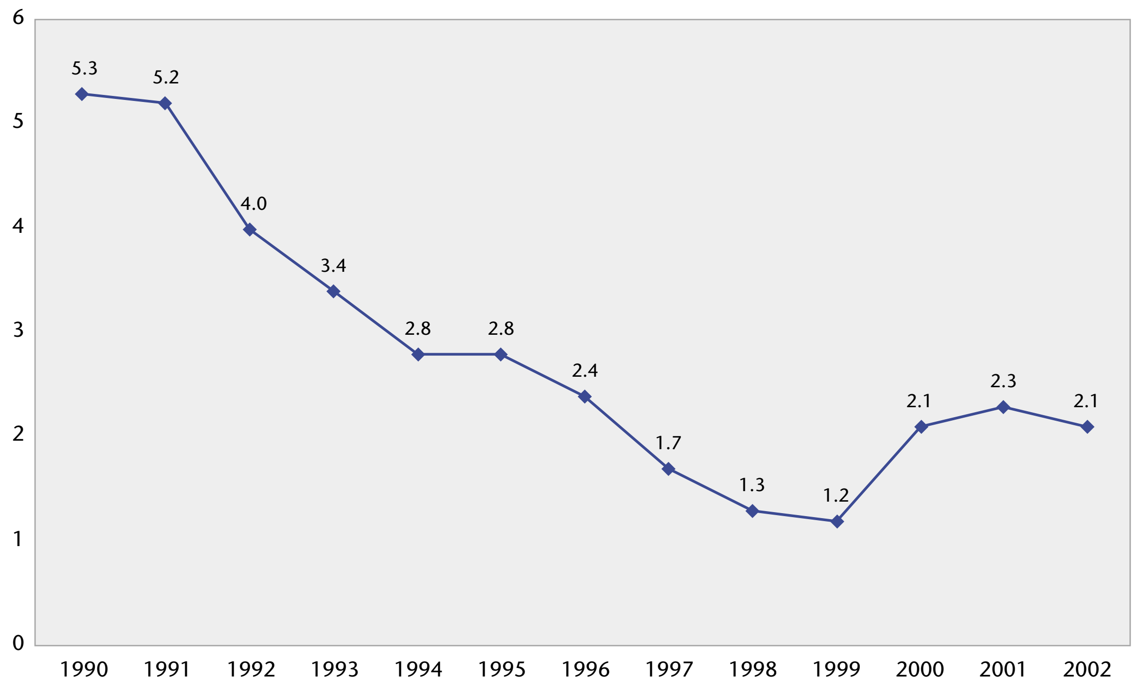
The policy of macro-economic stability has delivered substantial results in recent years. Following the Maastricht Treaty (1991), the European Member States have made large efforts to respect the convergence criteria in order to support the introduction of a common currency in January 1999. The European policy of macro-economic stability is focused on three main areas: reducing inflation, creating healthy public finances and reducing public indebtedness.

The commitment to price stability has in recent years fostered a culture of stability and confidence in Europe. It reduces uncertainty and promotes wage moderation, providing the necessary basis for an investment-friendly environment. The very stable inflation expectations of below 2% bear witness to this. As figure 1.6 shows, the EU made considerable progress in this area during the 1990s. Consumer product prices were on a very clear downward trend during the last decade, which also encouraged wage restraint (the rise in inflation in 2000 being due mainly to energy price rises). It is thanks to these concerted efforts that Europe, and in particular the EU-15, stand out in terms of price stability and low inflation compared with other parts of the world. Despite the aggravation of the situation in 2001 and 2002, actual forecasts expect that inflationary pressures remain subdued over the medium term and that, in the course of 2003, inflation will stabilise at levels below 2% (European Commission (2002/3)).

A sound budgetary policy is the second pillar of the macro-economic framework, and a third important element of the Stability Pact is public debt reduction. Medium-term budgetary positions in balance or surplus allow for a steady decline in government debt and interest payments. This enhances the capacity to deal with budgetary challenges, in particular those stemming from ageing populations. Substantial progress has been made in recent years (figure 1.7) even if the situation slightly deteriorated from 2000 on. During the second half of the 1990s, all Member States improved their budgetary position: most of them were able to reduce public spending and to bring deficits under the 3% of GDP threshold. A lot of Members States had a positive budgetary balance in 2001 and the overall European budget deficit (0.8% in 2001) is due to the substantial increase of public expenditure in some of the large Member states.

Simultaneously with these achievements, Europe has made substantial progress too in terms of market integration. In the financial services and capital markets, the European Monetary Union (EMU) and the introduction of the Euro have already created new opportunities for efficiency gains and reduced distortions in competition nurtured by fluctuating exchange rates ('competing' exchange rates). The Union also achieved a substantial convergence and overall decrease of real interest rates, in particular long-term interest rates. Nev-

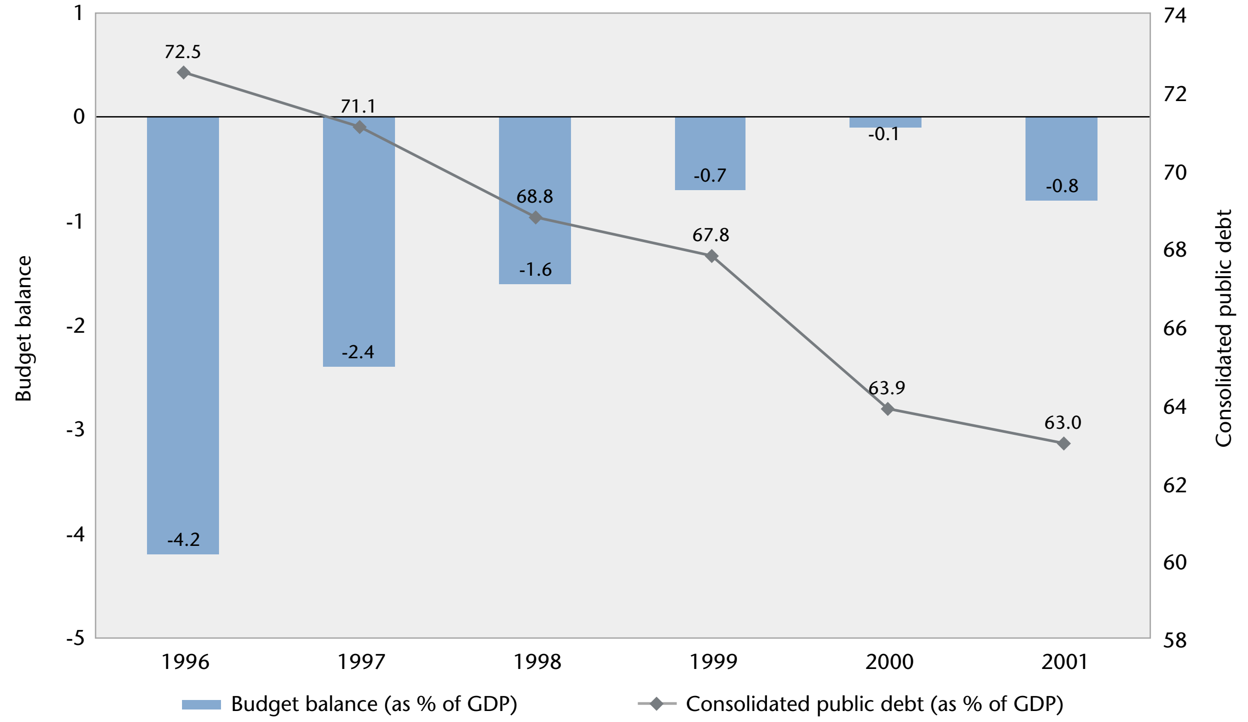
Figure 1.6 Annual inflation rate in EU-15 in % (1990-2001)



Source: DG Research
Data: Eurostat, New Cronos
Note: The annual inflation rate here refers to the HICP (Harmonised Indices of Consumer Prices).

Third European Report on S&T Indicators, 2003

Figure 1.7 Budget balance and consolidated public debt in EU-15, 1996-2001, as percentage of GDP



Source: DG Economic and Financial Affairs, DG Research
Data: Eurostat (NewCronos); European Commission (2002/3)
Note: Budgetary balance and public debt are expressed as percentage of GDP, excluded UMTS licences.

Third European Report on S&T Indicators, 2003

ertheless, despite encouraging progress, there is still a long and unfinished agenda to be completed. Large segments of European product markets are still insufficiently integrated to make the Union an attractive location for investments; improvement is needed too with regard to the cross-border provision of services, and the mobility of both skilled and unskilled workers (Baciocchi, 1999).

Growth and productivity: lack of dynamism

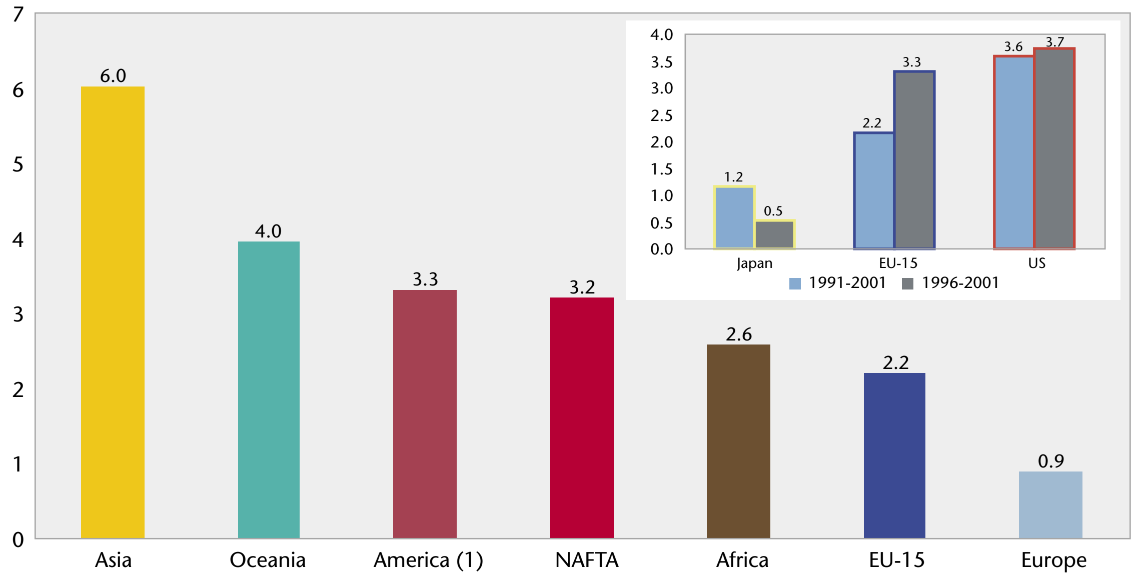
Despite this progress towards more macro-economic stability, Europe still suffers from a growth handicap. The world growth rate of GDP gradually picked up during the 1990s, rising from below 3% to nearly 4% in 2000. This increase resulted from the performance in a number of regions such as the emerging markets of Asia, the Central European countries, the United Kingdom, and above all North America and the US, which represents more than a quarter of world GDP. The reasons for this acceleration in economic growth are varied:

- ability to attract foreign direct investment (Central Europe, China);
- specialisation in rapidly growing industries such as electronics (New Asian Economies, Scandinavian countries, Ireland);
- very fast growth in the production and use of the new technologies (US) (Artus, 2002).

With few exceptions, Europe has not fully benefited from this improvement in the growth rate. More specifically, the Euro area continued to grow slowly until 1998-1999, which explains Europe's rather lacklustre performance compared with other parts of the world (figure 1.8). US GDP rose by an average of 3.6% a year between 1991-2001. In the shorter term, during the second half of the period (1996-2001), it showed an even more sustained trend at 3.7%. By comparison, the EU figure is more modest, with a growth trend of 2.2% a year over the decade. Although growth accelerated during the second half of the 1990s (with an annual growth rate rising to 3.3%), the difference with the US remains striking. In terms of GDP per capita, the gap between Europe and the US has been widening during the 1990s, after over four decades in which Europe had consistently caught up with the Americans (Soete, 2002).

The increased economic growth in Europe during the second half of the 1990s came more from the increase in the number of hours worked rather than from an increase in labour productivity (figure 1.9). In the long run, improvement in economic growth, and thus in the overall standard of living, is broadly determined by the rate of productivity growth. Maintaining high standards of living as the working age population starts to decline due to ageing, will increasingly depend upon productivity increases. Labour productivity growth in the EU is relatively low and has actually slowed by half a percentage point on average between the first and second half of the 1990s. This is essentially due to the increase of the employ-

Figure 1.8 Average annual growth rate of GDP by continent, 1990-2001. Inserted: Average annual growth rate (%) of GDP in Japan, the US and EU-15 in 1991-2001 and 1996-2001 (€PPS1999)



Source: DG Research
Data: World Bank, World development indicators 2001 and 2002, OECD, Eurostat
Note: (1) NAFTA included.
The growth rates are for most of the countries in the world referring to the period 1990-1999; for the industrialised countries, they refer to the period 1990-2001. For EU-15, they cover the years 1991-2001. The average annual growth rate by continent is a GDP-weighted average. "Europe" represents the EU-15, EFTA, the Candidate countries and 'other Europe' (see glossary of country groupings in Annex). The low figures for Europe can be explained by the weak growth performance of some ex-USSR republics.
Third European Report on S&T Indicators, 2003

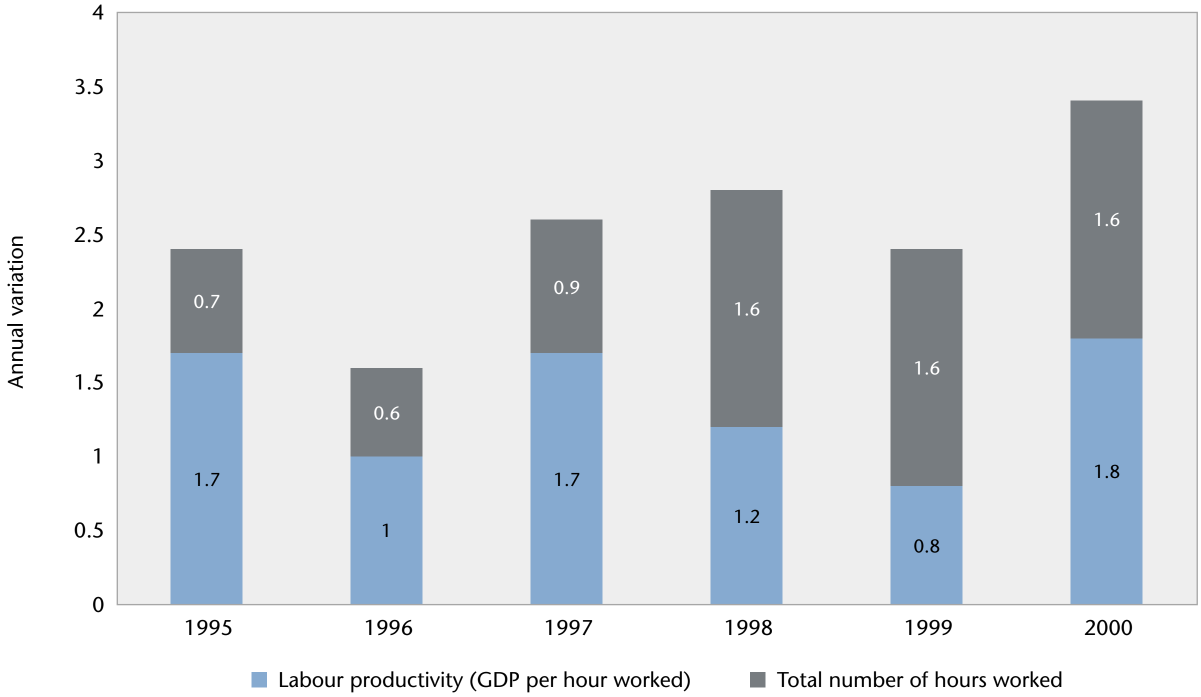
ment component in growth following structural reforms. At the cycle's peak in 2000, the productivity growth rate was back at the average of the early 1990s, reaching nearly 2%.

Productivity is affected by many factors, but depends largely on investments and their performance, which determine the structure and size of the capital stock and enable the penetration of new technologies in the economy. A higher rate of investment growth raises the capital available per worker and, *ceteris paribus*, labour productivity. Given that the acquired macro-economic stability provides a solid basis, there is both a need for and scope to improve the investment environment, via structural reforms on product, capital and labour markets, the development of an adequate and homogeneous regulatory environment, efficient public services, and a satisfactory supply of network infrastructure. However, improving the environment might not be enough. It remains crucial to increase the rate of investment, particularly investment in research and innovation, and education and training to enhance technological innovations, skills and the adaptability of the workforce.

The Union has a lower overall rate of investment (in 2002 gross fixed capital formation as percentage of GDP was 20.3% for EU-15) than its main competitors Japan (25.3%) and the US (20.5%). Moreover, the growth of the investment rate during the 1990s was lower in Europe. Whereas it slowed down in Europe over the last decade, it increased significantly in the US, at a rate of 2.7% per year between 1991 and 2001. The difference between countries making an effort to increase investment on the one hand, and others is striking in terms of the capital intensity trend. Per capita productive capital rose by 4% a year between 1994 and 2001 in the US, but by less than 2% a year in the EU-15. The same gap appears when capital related to GDP is considered (Artus, 2002). In terms of investment in research and new technologies as well, the contrast is striking: the share of resources going into research and development in Europe was 1.9% in 2000, against 2.7% in the US and 3.0% in Japan (European Commission (2002h)). The proportion of high-tech manufacturing and user sectors in the economy is also higher in the US and Japan than in Europe, where, in addition, it fell during the 1990s. High-tech and medium high-tech industries in Europe contribute significantly to overall employment, but their share in total value added is lower than in Japan and the US. Thus labour in the high-tech sector is less productive than in the US or Japan, which leads to the conclusion that the high-tech sector in the EU is not yet the excellent knowledge producer and transformer that it should be.

So, did the focus on macro-economic stability limit a higher investment rate and the potential for economic and productivity growth? Theoretically, the two options (stability versus enhancing long-term economic growth) are not incompatible. The following section tries to explain to what extent they can co-exist.

Figure 1.9 Components of economic growth in the euro area (1996-2000)



Source: DG Economic and Financial Affairs
Data: European Commission (2002a)

Third European Report on S&T Indicators, 2003

Investments in education, research and innovation, essential complements to macro-economic stability

Relationships between macro-economic stability and economic growth are interactive and very complex. The economic experience of the last few decades shows that one cannot build sustainable economic growth when there is monetary and budgetary imbalance. Of course, by printing money, running a budget deficit or keeping interest rates artificially low, one can sometimes bolster economic growth in the short-term. However, the dysfunctions and imbalances that such a policy causes, damage the sustainability of economic growth sooner or later. On the other hand, having policies which are too restrictive often lead to a slowing down of investment and a fall-off in domestic demand, causing declining productivity, economic redundancies and higher unemployment. The rising tensions and social demands that result from this undermine the confidence of financial markets in public policies, and a vicious circle is set up between economic growth, interest rates and employment. Thus, monetary stability depends both on productivity increase and economic growth, and on improvement of employment and living standards. Therefore, the complexity of the relation between growth and macro-economic stability necessarily entails appropriate matching of monetary and budgetary policies to policies of growth and income.

Macro-economic stability is thus necessary for sustainable and lasting economic growth but is not sufficient on its own. In other words, economic growth is not a bonus, or a by-product of a general policy of fine-tuning financial and macro-economic balances. In the long-term, economic growth is above all defined by technological progress and the accumulation of human capital, which determine the way and speed at which technological progress penetrates economic texture. Moreover, economists now agree that technological progress is not an exogenous factor, a kind of ‘manna from heaven’ permanently available to the economy, but an endogenous factor and main driver of productivity and growth. If it is not exogenous or automatically available, it has to be funded or stimulated. This recognition thus changes the traditional views on the interaction between technological progress, growth and macro-economic stability: economic growth is seen as depending on the relative balance between savings and spending, since it influences the development of the factors supporting the pace of technical progress. In other words, macro-economic policies that also seek to favour economic growth must improve the conditions for funding so that more scientific and technical know-how and technological innovations can be accumulated and disseminated.

Given this, macro-economic stability becomes clearly valuable too for the development of technological progress: it does not adversely affect the funding of the main sources of growth such as research, innovation and education. Since technological progress is an intangible and long-term activity, it is even more difficult to finance it in an environment of monetary instability. The effect of monetary uncertainty is that companies become unsure about the future and re-define their strategy towards shorter-term prospects, because they cannot predict the profitability of long-term investments. Together with inflation, fluctuating exchange rates hamper the pursuit of growth and the creation of jobs in the long term. A greater co-ordination on monetary matters allows for the reduction of distortions in competition resulting from country-specific strategies ('competing' exchange rates), preventing European firms from being competitive in technology and industry on world markets. Stable prices and exchange rates are two crucial macro-economic factors essential to better long-term planning of industrial and technological investment by European companies.

The converging downward trend in real interest rates, particularly long-term rates, and public spending cuts are also factors that favour growth and technological progress. Indeed, it is primarily intangible investment that is affected when real interest rates are high. It has then to rely solely on public resources and those of the private sector, which are reduced because the globalisation and the liberalisation of capital markets expose this kind of long-term investment to increased competition with lower-risk investments that have a higher rate of return in the short term. In other words, long-term lowering of real interest rates will ease the constraints, which hamper the funding of intangible investment. Stable exchange rates, together with lower real long-term interest rates can contribute to limiting the short-term view of economic agents. Secondly, public spending cuts are also a crucial objective because they reduce government deficits and ease the upward pressure on real interest rates that is exerted by government indebtedness. Together with stability in prices, exchange rates and public finances, increasing long-term savings is necessary for -at least- two reasons. On the one hand, it increases capacity for cheaper financing of (intangible) investments. On the other hand it allows meeting the growing demand for capital that is needed to safeguard the social model, and to combat social exclusion.

So macro-economic stability policy and its components do not in themselves hamper long-term economic growth or technological and social progress. However, the danger lies in over-restrictive and exclusive implementation of those policies, not linked to and well balanced with other policies promoting long-term (intangible) investments and economic growth. Indeed, past experience shows that unless stability policies are applied on the appropriate scale, these same objectives may generate counter-effects damaging to growth, jobs and technological progress. In other words, just as macro-economic stability was an unavoidable step towards the EMU and is still necessary to lasting long-term growth, European policies of growth and intangible investment are essential if the positive effects on growth and employment expected by the creation of the EMU are to take concrete shape. These three categories of European policies need to be implemented in a co-ordinated way; there cannot be any form of trade-off between these different policies any more than between short- and long-term objectives (Von Tunzelman, 1995; Caracostas and Muldur, 1998).

These considerations have important implications for the appreciation of the extent to which 'stability' can be combined with growth-stimulating policies. It is very important to make a clear distinction in the nature of public expenditures. Some of these, by increasing and stimulating intangible investment, are engines of future competitiveness and economic growth, and are therefore crucial to ensure long-term viability of the European Growth and Stability Pact. Thus, one could suggest to take into account this distinction and, for instance, to reduce the scope of the 3% of GDP threshold for budgetary deficits and to exclude from this criterion the expenditure in research, education and innovation. The European Council already acknowledged the importance of those expenditures for economic growth and stability. In 1996, at the Summit of Florence, it therefore called on the Member States "*to step up their efforts at budgetary consolidation […], making a selective restructuring of expenditure that encourages intangible investment in human capital and research and development, innovation and the infrastructure essential to competitiveness […]*" (Council document SN300/96). This clear position was emphasised again at the Lisbon summit in 2000, by suggesting to "*redirect public expenditure towards increasing the relative importance of capital accumulation -both physical and human- and support research and development, innovation and information technologies*" (Council document 100/1/00, par. 23).

As previous sections of this chapter clearly demonstrated, a European policy of growth, based on the intensive development of intangible investment, is more than necessary not only to ensure sustainable macro-economic stability in Europe and improve competitiveness, but also to meet the needs of the emerging knowledge-based economy and to respond to the challenges of the ageing phenomenon. The following chapters of this report will analyse in detail the evolution, structure and performance of investment in science and technology in Europe, and will enable a comparison of Europe with its main competitors in these matters.

Economic growth and environmental sustainability?

Ensuring long-term economic growth is necessary, but it should not be at the expense of environmental preservation. Economic growth has by definition negative externalities:

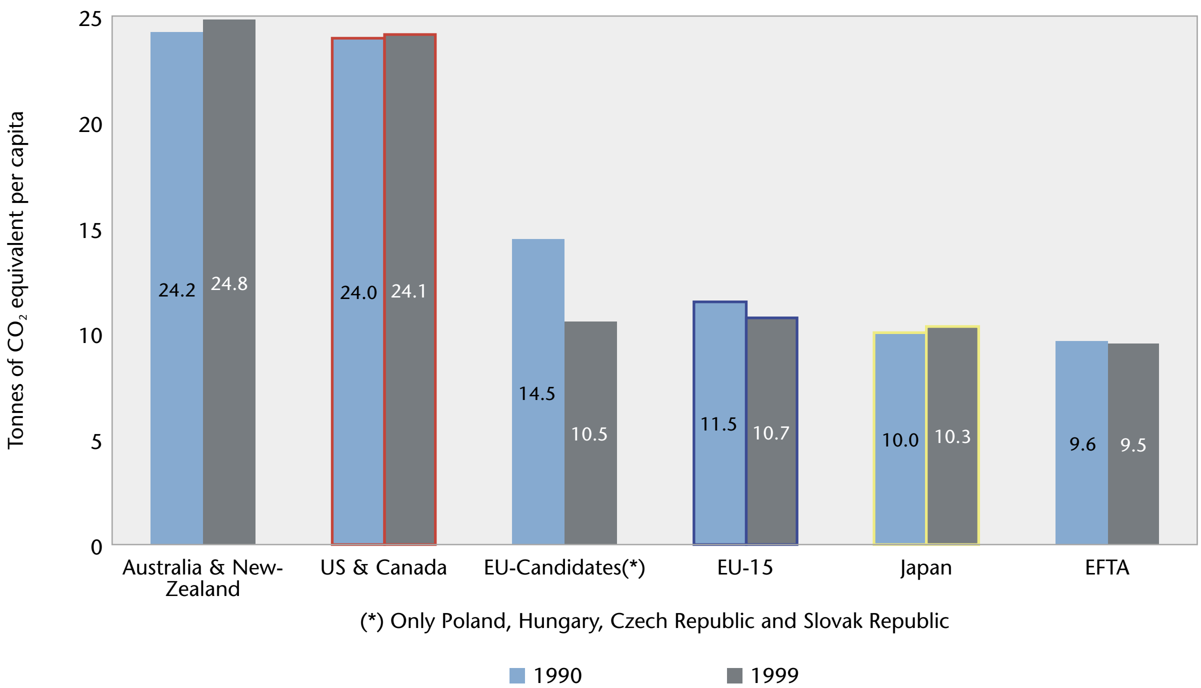
one of them is pollution, or in a broader sense, environmental damage. Pressure on the environment from demographic and industrial growth and the concentration of human activities is increasing year by year, with inevitable negative effects such as pollution, emissions of greenhouse gases, waste production, or deterioration in natural resources. A globally polluted environment, shrinking natural resources and ever growing health and social problems call for radically new concepts for the future of industrial society. A new production and consumption system is required that is able to reduce the use of natural resources and to avoid pollution to the maximum extent possible, moving away from the simple growth-oriented type of industrial technologies (Meyer-Krahmer, 2001).

Indeed, the relationship between industrial production, economic growth and material well-being (per capita GDP) on the one hand, and pollution levels on the other, is not linear. A responsible region concerned about its environment will try to *optimise* the effects of its economic activity, i.e. to minimise harmful by-products without sacrificing part of its material well-being or endangering economic growth. It is necessary to sever the link between economic growth and environmental impact, since a healthy and protected environment is essential for the quality of life of present and future generations. Research and technology policies can substantially contribute to this goal, first because of the need for innovations to solve problems of currently unsustainable production methods and consumption patterns and, second, because of the need to develop and diffuse a wide range of environmentally ‘clean’ technologies.

Europe has made a great deal of progress in this regard during the last 30 years. Since the 1970s, the European Union and its Member States have put in place a system of laws and environmental controls, which have enabled the quality of air and water to be constantly improved. This means that, as far as atmospheric pollution is concerned, Europe has lower pollution levels than most other industrialised parts of the world. Greenhouse gas emissions, expressed as tonnes of CO_2 equivalent per capita, in Europe (and Japan) during the 1990s were less than a half of those recorded in North America and the industrialised regions of the Pacific (figure 1.8). According to the most recent data from the United Nations Environmental Programme, the trend of these emissions during the last decade has also been downward in Europe, unlike in other industrialised regions.

Environmental protection requires an effort from all the economic operators involved in the production system. Companies are becoming increasingly aware of their environmental management responsibility to society and are introducing procedures to observe, detect, monitor and even reduce the impact of their activities on the environment. The environmental standard ISO 14001 award scheme provides a measure of the scale of these efforts. ISO 14001 was established in 1995 by the *International Standards Organisation* and defines the administrative model, responsibilities, proce-

Figure 1.10 Greenhouse gas emissions (in tonnes of CO_2 equivalent per capita) in the industrialised world, 1990 and 1999



(*) Only Poland, Hungary, Czech Republic and Slovak Republic

Source: DG Research
Data: UN, United Nations Environment Programme, document FCCC/SBI/2001/13, World Bank, Eurostat
Note: The graph includes six pollutant gases: CO_2, CH_4, NO_2, HFC, PCF and SF_6.

Third European Report on S&T Indicators, 2003

dures, processes and resources required to implement an environmental management system. More recently, additional and more specific standards – ISO 14004 and ISO 14031 – concerning the measurement of environmental performance have been launched. These standards relate to all types of organisation, in all sectors of the economy. Analysis of the breakdown of sites certified under the ISO 14001 standard reveals that nearly half the certified sites are located in Europe, compared with less than 10% in the US and just over a third in Asia (Férone, 2001, p. 50-51).

Although these initiatives are laudable, it is clear that there is still a great deal to be done. Environmental constraints are increasing from year to year. Even if some progress has been made in many fields, the global balance still remains negative. Moreover, the ecological challenges reach far beyond national and continental frontiers, and therefore require internationalisation of efforts to protect the environment. An international system of governance is more than necessary in this area. It is a challenge for Europe to take leadership in these matters, by promoting new, environmentally friendly technologies, products and processes. However, even if research and innovation policies might contribute substantially to a better preservation of the environment, solving the 'environmental challenge' requires a larger, systemic approach, which integrates behaviourial and structural change, better regulations, and both penalties and incentives. Technology and innovation policy has to develop a comprehensive approach to a broad range of different policies (technology, price systems, attitudes and behaviour, etc.), different sub-systems and actors (public, semi-public bodies, companies, banks, research institutes, etc.) at different levels (European, national, regional and local).

Europe and the rest of the world: globalisation, enlargement and governance

Globalisation and its challenges

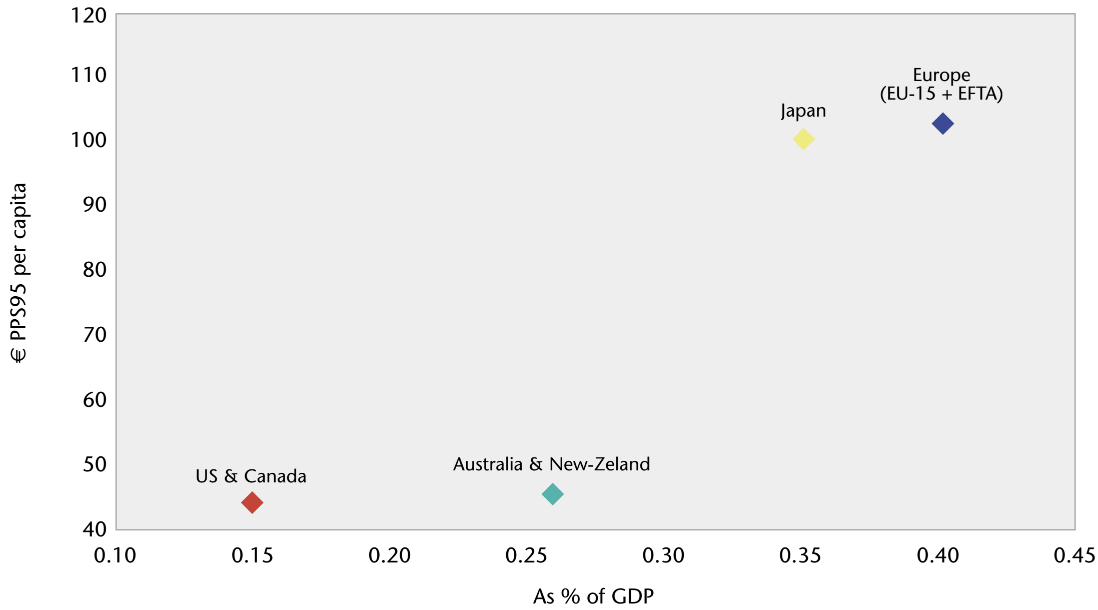
Globalisation is a process that has been ongoing, albeit not in a linear fashion, over a long period of time. In economic and financial terms, it has been characterised by a strong expansion of trade in goods and services and, more recently, by a strong expansion of international capital flows. The underlying factors for this growth are to be found in the rapid technological progress of the past decades, leading to radical reductions of transport and communication costs and an unprecedented increase in information-processing capabilities. Public-policy measures, like the dismantling of quotas and tariff restrictions on trade and the liberalisation of capital movements, were other factors of crucial importance. The further integration of markets and the emergence of a knowledge-based economy with its faster rate of spread of innovations are boosting this globalisation process and exacerbating its effects, both positive and negative.

The process of globalisation over the past 50 years has been accompanied by a six-fold rise in world output, while the global population increased about two and half times (Maddison, 2001). This translates into major improvements in the income per capita, human welfare and quality of life of a substantial part of the world's citizens. Although correlation does not imply causality, there is little doubt that these achievements would not have been possible without continued progress towards economic integration. Recent studies by the World Bank have shown that developing countries that have opened up their economies over the last 20 years have demonstrated a stronger growth performance than those that have not pursued economic integration (World Bank, 2002).

However, this progress was certainly not equally distributed across all regions of the world. The gap between richer and poorer countries has widened during the last 40 years. According to estimates by the United Nations, real per capita income disparities at purchasing power parity between the industrialised regions (OECD countries) and the developing regions have more than doubled between 1960 and the present day (UNDP, 2001). Some countries with fast economic growth, such as the Newly Industrialising Economies of Asia, have managed to join the group of developed countries. However, 75% of the developing countries have had a much lower per capita GDP growth rate than the industrialised countries during the past 30 years (IMF, May 2000). There still remains a large group of -very poor- countries that are less integrated into the global economy, and do not benefit from the advantages of the globalisation process. Their share in world trade has fallen and they continue to be unable to attract foreign direct investment. Improving living conditions and the economic situation in these countries is one of the major challenges for the global economy and European policies. Moreover, economic and financial globalisation is associated with other challenges such as communicable diseases, climate change, loss of biodiversity and lack of international security. Addressing these issues –that is, providing the world with public goods- can be seen as part of a strategy of minimising the negative effects of globalisation and maximising its positive effects.

The widening gap between rich and poor countries calls for a more active policy regarding promoting and financing development in the less favoured regions of the world. A number of poor countries are trapped in a situation of low income and poverty, low levels of education and investments, and in a lot of cases high indebtedness. Therefore, international assistance is crucial. However, trends in official development assistance have been disappointing in the last years. Official development assistance by major donors in terms of their GDP declined from 0.33% in 1990 to 0.22% in 2000 (0.40% for EU-15 and EFTA) (World Bank, 2002). Although Europe is

Figure 1.11 Flows of funds from the OECD countries for development aid (2000, as percentage of GDP and in € PPS95 per capita)



Source: DG Research
Data: OECD, World Bank 2001 and 2002, Commission services (DG External Relations, DG Humanitarian Aid Office, DG Europe-Aid - Cooperation Office)
Note: The flows of funds in question concern 'Public aid for net development', which includes international transfers by a donor of financial resources, goods or services paid for by the donor, less the refunds made to the donor and loans contracted from the donor during the same period. The figures by region/continent are averages weighted for GDP and population.

Third European Report on S&T Indicators, 2003

clearly the most generous donor (figure 1.11), the contributions remain far from the 0.7% of GDP target put forward by the 1969 Pearson Report. Recent estimates point to the fact that current levels of official development assistance should be doubled in order to help low-income countries reach their millennium development goals of halving poverty between 1990 and 2015 (European Commission (2002e)).

However, international assistance goes far beyond financial aid only. Better integration of developing countries into the world economy requires also commitments and efforts in other fields like indebtedness (i.e. alleviating the debt burden: developing countries' consolidated debt relative to GDP doubled between 1981 and 1998) or trade (facilitating market access for agricultural and labour-intensive manufactured goods, where developing countries' comparative advantage often lies). Moreover, it must be accompanied by political and institutional progress, leading to the construction of stable states, with integer, competent administrations and institutions to support political democracy. All of this implies stronger efforts and commitments by European Union Member States (European Commission (2001f)).

On the other hand, the increased internationalisation of economic activity has raised issues about the appropriate level of (economic) policy-making, and the capacity of national governments to set rules and standards. The regulation of globalisation, and more especially the international monetary, financial and trading system, is necessary to reduce any resulting abuses. It depends on the on-going reform of the United Nations and the Bretton Woods institutions, namely the role of the International Monetary Fund (IMF) in financial markets, and of the World Trade Organisation, in order to foster multilateral trade. A better co-ordination of Europe's foreign policies can play a substantial role in this framework. To put it in other words: the real challenge for Europe in these matters is how to translate the new competitive factors generated by the emerging knowledge-based economy into more equally distributed economic and social development outside of the Union.

Towards an enlarged Europe

A very up-to-date example of integration processes is of Europe's enlargement to include new Member States. All the demographic, economic, social and political challenges, which are dealt with in this chapter, will be heightened as a result of the new structure and composition of the European Union. In 2004, Europe will undergo the widest enlargement ever, with the accession to the EU of 10 new Member States[8]. This enlargement represents a great opportunity for future growth and welfare, but will also bring with it huge challenges.

[8] *Cyprus, Czech Republic, Estonia, Hungary, Latvia, Lithuania, Malta, Poland, Slovak Republic, Slovenia.*

The EU has gone through a number of enlargements in the past, with the integration into the Common Market of the UK, Denmark and Ireland in the 1970s, Greece, Spain and Portugal in the 1980s, and Austria, Sweden and Finland in 1995. However, the enlargement now taking shape, is of an unprecedented scale because of the number of candidate countries, their geographical size, population, diversity and cultural and historical wealth. It is the result of the gradual but intensive drawing together of the EU with Central and Eastern Europe, following the fall of the Berlin Wall in 1989. Soon after this major event in European history, the EU established diplomatic relations and trade agreements with the Central and Eastern European countries. Being their biggest source of trade, aid and investment, the EU soon became their main economic partner. Since 1994, it is the biggest market for exports from the region, absorbing more than half the total. Today, the EU accounts for about 60% of exports from the Central and Eastern European countries.

Enlargement of the EU to take in new applicant countries, "*an irreversible process the benefits of which are already visible*"[9], is primarily aimed at continuing the process of integrating the European continent through peaceful means, by extending this area of stability and prosperity towards new members. As recent conflicts in Europe in the Balkans have shown, it remains essential to guarantee peace, democracy and human rights throughout Europe through economic and political progress. Through enlargement, the EU will contribute to this process by creating a common internal market of more than 500 million consumers, ending the long period of division in Europe.

The expected benefits of such an enlargement for the new countries and the EU-15 are numerous, extensive and occur at various levels. The extension of an area of peace, stability and prosperity in Europe will strengthen security for all of its people. The increase in the size of the European Union market, with its current 370 million consumers, by more than 100 million consumers in fast growing economies will boost growth and create employment in both the existing and the new Member States. It will also allow increased mobility of people, capital and ideas within the European continent. From a wider perspective, the adoption by the new Member States of the Community Rules on environmental protection and the fight against crime, drugs and illegal immigration will help to improve the quality of life for citizens throughout Europe. Lastly, enlargement will strengthen the EU's international role in fields such as foreign affairs, security, trade, governance and development aid. Some of the positive effects of enlargement are already visible, notably in Central and Eastern Europe. The economic reforms in these countries have produced high levels of growth at twice the EU average and better employment prospects. It is a process that has been supported and encouraged by the prospect of EU membership and by financial aid from the EU. This has also led to an increase in the EU's trade surplus with these countries (17 billion euro in 2000) and to growth and job creation in the Member States. A further benefit is that other countries will gain considerable benefits from an enlarged European Union. A single set of commercial rules, customs tariffs and administrative procedures will apply in the future within an enlarged, uniform market, providing substantial positive spill-overs in terms of international trade and capital movements. This will simplify transactions for third-country operators in Europe and improve the conditions for investment and trade, benefiting not only the EU but also its commercial partners around the world.

On the other hand, enlargement on such a scale will bring with it huge challenges. In terms of economic and income disparities between people, regions and countries, for instance, Europe will face a significantly new landscape. An analysis of the situation as it stands today points to a doubling of the income gaps between countries and regions; a doubling in the sense that if Europe consists of 25 countries:

- At the national level, over *one third* of the population will live in countries with an income per head less than 90% of the EU-25 average – compared to *one sixth* in the present EU-15;
- At the regional level, the average income per head for the bottom 10% of population, living in the least prosperous regions of EU-25, will be only 31% of the EU-25 average. In the EU-15 today, the income per head of the bottom 10% of population equates to 61% of the average.
- At the national level, in a Union of 25 the countries separate into three main groups. The most prosperous group comprises 12 of the current Member States of the Union – all except Greece, Spain and Portugal – where income is above average. This is followed by an intermediate group of Greece, Spain and Portugal, together with Cyprus, Malta, Slovenia and the Czech Republic, where income per head is about 80% of the EU-25 average with 13% of the total EU-25 population. The real change compared with the EU-15 of today, however, would be the existence of a third group comprising the 6 remaining new Member States Estonia, Hungary, Latvia, Lithuania, Poland, and the Slovak Republic where income per head is around 40% of the EU-25 average. This is a significant group, accounting for around 16% of the population of the EU-25.

Thus, enlargement will widen the economic and social disparities between regions and nations markedly. Given existing levels of income per head in the new Member States and the experience with the progress made within the present EU-15, convergence between regions in the enlarged Union will take at least two generations assuming it occurs at the same pace (European Commission (2001/1b)).

The globalisation process and the enlargement of the European Union, and the opportunities and challenges thereof, unavoidably call for structural reform in political and institutional matters, leading to a new EU governance model. Such

[9] *Günter Verheugen, Member of the European Commission responsible for enlargement, in European Commission (2002d).*

a new governance model must be more coherent, so that Europe can grow stronger at home and become a better leader in the world. In that way, it will be able to seize the opportunities which globalisation present for economic and human development and respond properly to environmental challenges, unemployment, food safety, crime and regional conflicts. Better governance must give Europe the means to provide its citizens and the rest of the world with more security and human development – which is, providing the world with public goods.

In this context Europe faces a double challenge: there is not only the need for urgent action to improve governance under the existing treaties, but also for a broader debate on the future of Europe given the coming enlargement and sustained American leadership on the international political scene. Moreover, the overall goal of better governance must be based on the simple principle that has guided European integration since the European Community was founded: integrating the people of Europe, while fully respecting national identities. The European Union cannot build and develop institutions in the same way as national governments; it must build partnerships and rely on a wide variety of actors, so that expectations can be met in different ways (European Commission (2001e)).

Europe's response to the challenges: the Lisbon strategy

The Lisbon European Council in 2000 set as a ten-year goal for the EU to become the most competitive and dynamic knowledge-based economy in the world. Subsequent Council meetings at Stockholm and Barcelona have served to review and add further impetus to these objectives. This section gives a first overview of the progress made in the transition to a knowledge-based economy. However, in order to fully understand the implications of the Lisbon target, this section starts by discussing the significance of this extraordinary European Council meeting.

The Lisbon Council Meeting (March 2000)

The European Council Meeting took place under the Portuguese presidency on 23rd and 24th of March 2000 in Lisbon. The strategic goal adopted by this European Council consisted of transforming the Union by 2010 – over a ten year period – into "*the most competitive and dynamic knowledge-based economy in the world, capable of sustainable economic growth with more and better jobs and greater social cohesion*" (Council doc. 100/1/00 Rev.1 paragraph 5).

This strategic goal was defined bearing in mind both external challenges – globalisation – and internal constraints – Europe's response. Comparing the EU with the US in economic terms, it was observed that after four decades in which continental Europe had consistently caught up with the US, the process appeared to be going into reverse. The main reason for this was considered to be the US speedier transition to a 'knowledge-based economy'. The Lisbon meeting was of great importance for Europe's future. It not only managed to get an agreement of all Member States on a strategic goal to achieve in ten years time. Beside this achievement, it also indicated how the transformation towards a knowledge-based economy should come about, taking into account the specificity of the 'old continent' and the challenges it is facing.

As we have seen in the previous sections of this chapter, Europe faces a number of internal constraints or, put more positively, challenges. The quintessence of the knowledge-based economy revolves around the supply of highly skilled workers. Yet, Europe is faced with an ageing population, a decreasing interest among young people in studying science and engineering, an increasing 'digital divide' and new inequalities, rigid labour markets, sub-optimal levels of mobility among researchers, macro-economic pressures on government budgets, etc. At the same time, Europe would like to maintain its own distinct 'social model'. Higher growth paths must be combined with achieving social inclusion and cohesion, providing more people with better jobs, allowing families to better reconcile professional careers with private lives, keeping pension systems financeable, establishing economic growth that is environmentally sustainable for future generations, etc. So the conclusions of the Lisbon meeting go much further than catching-up with the US.

The Lisbon meeting deserves credit for the fact that it tackled Europe's challenges on a wide and integrated front, within the framework of Europe's social model, while fully respecting the economic and societal diversities among Member States. To start with the policy actions required to achieve the transition towards a knowledge-based economy and society, Lisbon launched actions which can be summarised under the following three headings:

1. Further consolidation and unification of the economic environment

- **A Complete and Fully Operational Internal Market**. This includes the development of a strategy to remove barriers to services, liberalisation in areas such as gas, electricity, postal services and transport, updating of public procurement rules, measures to promote competition and shifting the focus of State aids from the support of individual companies or sectors to help with 'horizontal objectives' of Community interest such as regional development, employment, environment, research and training.

- **Efficient and Integrated Financial Markets.** This includes the implementation of the Financial Services Action Plan, of the Risk Capital Action Plan and tax provisions for savings.

- **Macro-economic Policy Co-ordination: Fiscal Consolidation, Quality and Sustainability of Public Finances.** The Lisbon Conclusions stressed the opportunity provided by growth for fiscal consolidation and improving the quality and sustainability of public finances. Therefore, it called for a report by spring 2001 'on the contribution of public finances to growth and employment', and more particularly 'for comparable data and indicators' as the basis for an evaluation of a number of 'concrete measures' that might be contemplated. What is at stake here is: the redirection of public expenditures towards increasing the relative importance of both physical and human capital accumulation, support for research and development, innovation and information technologies, combined with the restructuring of public finances to make them more sustainable in the context of the ageing process (Lisbon Conclusions op.cit. §22-23).

2. Stimulating the creation, absorption, diffusion and exploitation of knowledge

- **A European Area of Research and Innovation** which includes the removal of remaining obstacles to researchers' mobility, benchmarking of R&D policies of Member States (e.g. through Innovation Scoreboards) and establishment of a Community patent.
- **Education and Training for Living and Working in the Knowledge Society** – As Europe's path to the future is through the creation of the knowledge-based society, the aim should be to guarantee learning and training opportunities to three target groups: i) young people, ii) unemployed adults, iii) and those in employment who face redundancy. This domain is, however, primarily the responsibility of Member States – the EU urged Member States to increase per capita investment in human resources annually.
- **Encouraging the Start-up and Development of Innovative Businesses** – This includes benchmarking costs of setting up new business in Member States, introduction of a European Charter for Small Companies, continuing review of EIB and EIF financial instruments 'to redirect funding towards support for business start-ups, high-tech firms, micro-enterprises and other risk capital initiatives' (Lisbon Conclusions op.cit. §14-15).

3. Better working conditions, better social protection and cohesion

- **More and Better Jobs: an Active Employment Policy** – The idea goes back to the Amsterdam Treaty and the Luxembourg Extraordinary Council of 20-21 November 1997. Four key areas of concern are identified: i) improvement of employability and reduction of skill gaps, ii) introduction of benchmarking on lifelong learning, iii) increase in employment in services, iv) promotion of equal opportunities in order to reconcile working and family life. Two targets were set in Lisbon:
  - to raise the employment rate from an average of 61% in 2000 to as close as possible to 70% by 2010
  - to increase the number of women in employment from an average of 51% in 2000 to more than 60% in 2010.
- **An Information Society for All** which means that 'every citizen must be equipped with the skills needed to live and work in this new information society' (Lisbon Conclusions op.cit. §8-11). This includes liberalisation of telecommunications markets, internet access at schools, provision of low cost, high speed interconnected networks for internet access.
- **Modernising Social Protection** – The 'European social model' and its 'developed systems of social protection' are still non-negotiable. However, modernisation in favour of 'an active welfare state' is required if Europe is to meet the new priorities of 'long-term sustainability of social protection systems in the face of an ageing population, social inclusion, gender equality and quality health services' (Lisbon Conclusions op.cit. §31).
- **Promoting Social Inclusion** – The most effective way of combating social exclusion is seen to be in the creation of jobs and more particularly efforts to 'open up new ways of participating' in the knowledge-based society (Lisbon Conclusions op.cit. §32-34).

A successful response to the challenge of globalisation needs to be implemented on a wide front, which is exactly what happened in Lisbon. Of course, agreeing on a wide spectrum of policies is one thing; maintaining the momentum of this meeting among Member States is another. Policy-making processes in Europe take place in multi-actor, multi-level settings; the principle of subsidiarity is enshrined in the Treaty creating a highly decentralised system of decision-making. The institutional innovation that was launched in Lisbon is called the 'new open method of co-ordination' and was seen as a tool to achieve momentum by monitoring progress on a continuous basis and at specified time intervals. The 'new open method of co-ordination' also appears to be of crucial importance in the context of the enlargement. What does this method entail?

Introducing the 'new open method of co-ordination' at all levels was coupled with a stronger guiding and co-ordinating role for the European Council to ensure more strategic direction and effective monitoring of progress. It was agreed that a meeting of the European Council was to be held every spring to monitor progress. The new open method of co-ordination involves:

- Fixing guidelines for the Union combined with specific timetables for achieving the goals which they set;
- Establishing, where appropriate, quantitative and qualitative indicators and benchmarks against the best in the world and tailored to the needs of the different Member States and sectors as a means of comparing best practices;

- Translating these European guidelines into national and regional policies by setting specific targets and adopting measures, taking into account national and regional differences;
- Periodic monitoring, evaluation and peer review organised as mutual learning processes.

The Barcelona Council Meeting (March 2002)

Ever since this decision was taken at Lisbon, the Spring meetings of the European Council receive a lot of media attention and coverage. In this respect, the Barcelona Council deserves special mention. Held under the Spanish presidency on 15 and 16 March 2002, the Barcelona Council managed to institutionalise the 'Lisbon process' and took a large number of practical decisions to implement the Lisbon strategy. The European Commission's Synthesis Report for the Barcelona Spring Meeting features three prominent messages:

- Strong emphasis on the continuing validity of the Stability and Growth Pact;
- An insistence on the need for progress towards all Lisbon targets;
- A call for focus in three priority areas (Employment; Connecting Europe and Connecting Markets; and Knowledge).

The strong emphasis put on the continuing validity of the Stability and Growth Pact confirms the European Commission's approach and line of thinking that a stable macro-economic environment still represents the best hope for stronger growth. At the same time the macro-economic framework should allow for investments considered crucial to bring about the knowledge-based economy and society, such as investments in education and training, research and development, innovation and entrepreneurship. Therefore, the ten policy areas agreed upon in Lisbon (presented here under three headings) are still valid and Member States should continue to work on their implementation. It was reconfirmed that the European social model will remain valid, also after the EU's enlargement, as an overall framework to achieve economic and social cohesion. However, three priority areas – already touched upon at the previous European Council Spring meeting in 2001 in Stockholm[10] – deserve special attention and more focus. Of these three priority areas – dealing with employment, liberalisation of markets and knowledge – the last one will be given more attention further here, given the focus of this report on Science, Technology and Innovation.

At the Barcelona Council meeting, the failure of the European higher education and research system to attract enough people and investment, both from within Europe and world wide was seen as the central problem for the creation of a European 'knowledge area'. Therefore, it represents also one of the core obstacles to achieve the transition towards the knowledge-based economy. In order to create a true European 'knowledge area', more focus and action was needed on encouraging:

- genuine mobility for all those involved in education, research and innovation;
- the establishment of European networks and Centres of Excellence in research and education (becoming reality in the 6th Framework Programme);
- enhancement of the dimension of lifelong learning as this is still not a reality for most EU citizens;
- more private sector investments in research, from current 56% of GERD to 66% (two thirds) in 2010 (with a particular emphasis on life sciences & biotechnology and clean technologies).

Together with education and innovation, research plays a vital role in the knowledge-based economy as already emphasised by the incoming Commissioner for Research, Philippe Busquin at the start of his mandate in 2000. However, research activities at regional, national and European Union level must be better integrated and co-ordinated to make them as efficient and innovative as possible, and to ensure that Europe offers attractive prospects to its best brains. Commissioner Busquin's view on Europe's research policy entitled the 'European Research Area' was endorsed at the Lisbon Council Meeting. The European Research Area should be considered a new landmark for Research and Technological Development policy at EU level as it advocates a fundamental reshaping of relationships between 'layers and players' in the RTD landscape (Corvers, forthcoming 2003).

The idea of the ERA centres around an institutional reshaping to turn the EU into one 'European Knowledge System', which functions as a true Single Market for research. It is based on a new rationale for Community action in the area of science and technology and on a new form of Commission involvement in the management of European RTD policy. The ERA thus intends to promote a more coherent overall policy framework. It has *"the ambition of* re-inventing *the European research landscape, in* re-defining *the roles of each of the players (including public authorities and private operators) and* re-configuring *the processes and policies that underpin the research effort in Europe"* (Mitsos, 2001).

To move so many actors in such a complex and decentralised policy setting in a common direction requires clear targets, which will allow monitoring. It was agreed at the Barcelona Council meeting that Member States should strive to achieve 3% of GDP to be spent on research by 2010. According to the latest available data, the level of spending is at 1.93% (EU

[10] *The Spring meeting of the European Council in 2001 took place in Stockholm under the Swedish presidency on 23 and 24 March. 'Environment', 'Employment' and 'Enlargement' were set as the three core topics of the Göteborg Council meeting that followed in July 2001 in order to focus the agenda of the Member States.*

average in 2000). Two Member States, namely Sweden (3.78%) and Finland (3.37%), already surpass the 3% target level as well as some twenty regions, amongst which are Braunschweig (6.34%) and Stuttgart (4.84%) in Germany, and Midi-Pyrénées (3.73%) and Île-de-France in France (3.53%).[11] Germany, with 2.48% of GDP spent on research, is already close to the 3%. Another target set at Barcelona was that two thirds of this investment should come from business – one of Europe's weaknesses compared to the US. The current EU level of business financed R&D is at 56.3% of total R&D spending, compared to the US with 68.2% and Japan with 72.4%.[12]

The Lisbon process – via the new open method of co-ordination – will be applied to monitor the progress made towards these Barcelona objectives. In this process, indicators are paramount to inform policy-makers whether they are on track and to what extent they are (not). Developing a more sophisticated system of RTD and innovation indicators, with more up-to-date data, is paramount to design appropriate policies at every level. This report is intended to contribute to this development. The next section will present some indicators intended to assess the progress made in the transition to a knowledge-based economy.

The knowledge-based economy: how far are we?

The Spring 2003 Report of the European Commission (European Commission, 2003d) assesses to what extent Europe is on the right track as far as the transition to the knowledge-based economy is concerned. According to its analysis, both the level of overall investment in the transition to being a knowledge-based economy and its growth rate are still significantly lower in Europe than in the US and Japan. The report particularly emphasises the weak contribution of the private sector to the funding of research and the limited quantity of human resources in science and technology (particularly the low number of researchers). While the other chapters of this report analyse in detail the specific characteristics, strengths and weaknesses of the European research systems with regard to their investment and performance, the data and figures presented in this last section of chapter 1 give a general aggregated overview of the investment and performance of the European Union and its Member States in their transition to the knowledge-based economy.

Figure 1.12 shows the latest available composite indicator of investment in the knowledge-based economy, which confirms the observations to be included in the Spring 2003 Report. In order to advance effectively towards the knowledge-based economy, countries need to invest in both the creation and the diffusion of new knowledge. The composite indicator of investment in the knowledge-based economy addresses these two crucial dimensions of investment. It includes key indicators relating to R&D effort (GERD per capita), highly skilled human capital (total number of researchers per capita and number of new S&T PhDs per capita), investment and participation in education (educational spending per capita and share of adult population participating in life-long learning), modernisation of public services (e-government or part of public services available on-line) and purchase of new capital equipment that may contain new technology (gross fixed capital formation – excluding construction – per capita) (table 1.2). By aggregating these various types of investment into one single measure, the composite indicator allows us to provide a quick overview of the overall rate of investment in the knowledge-based economy[13].

Table 1.2 Component indicators for the composite indicator of investment in the knowledge-based economy

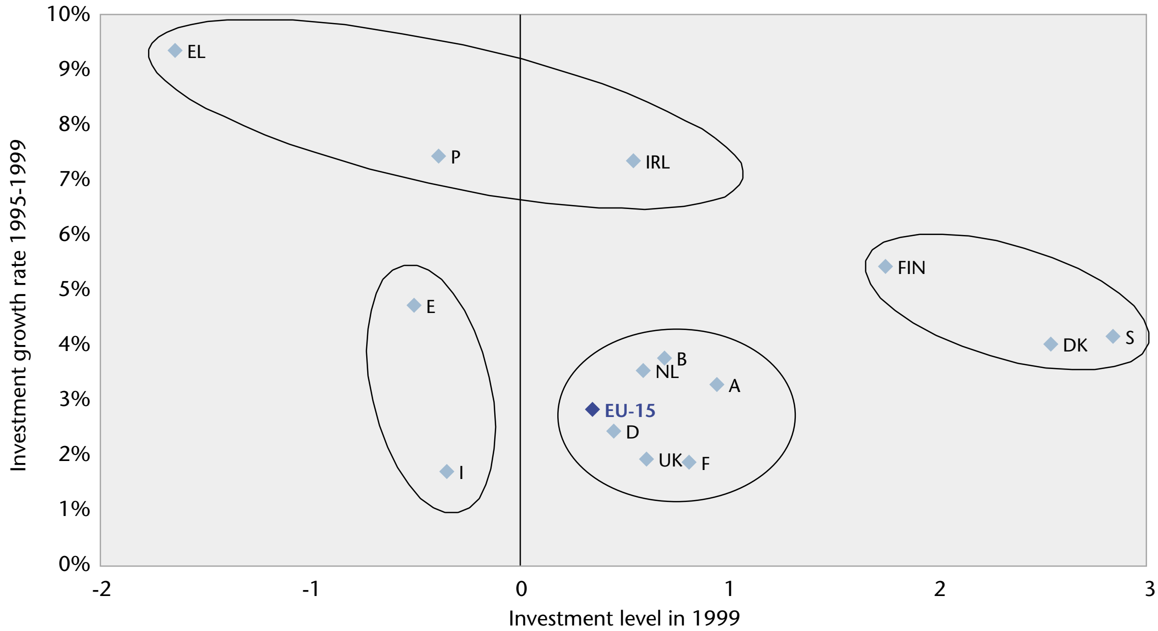
Sub-indicators	Type of knowledge indicator
Total R&D expenditure per capita	Knowledge *creation*
Number of researchers per capita	Knowledge *creation*
New S&T PhDs per capita	Knowledge *creation*
Total Education Spending per capita	Knowledge *creation* and *diffusion*
Life-long learning	Knowledge *diffusion* : human capital
E-government	Knowledge *diffusion* : information infrastructure
Gross fixed capital formation (excluding construction)	Knowledge *diffusion* : new embedded technology

Source: DG Research
Data: Key Figures, 2002

Third European Report on S&T Indicators, 2003

[11] *Member State and EU average: 2000; regional data: 1999; data source: EUROSTAT.*
[12] *Data: 2002; EU average does not include Luxembourg; data source: EUROSTAT*
[13] *Even though some components of this indicator represent stocks, since most of these sub-indicators represent investment, overall it can still be interpreted as reflecting 'overall investment rate' in the knowledge-based economy. For more details about the calculation of the composite indicator and the weights used, please refer to methodological annex to chapter 1.*

Figure 1.12 Composite indicator of investment in the knowledge-based economy. Relative country positions in 1999 and annual growth rate 1995-1999 (EU-15 and Member States)



Source: DG Research
Data: Eurostat, DG Information Society
Note: All 7 sub-indicators were included for the investment level in 1999 (horizontal axis), but the indicator on e-government could not be included in the comparison of the growth rates (no data available on e-government for 1995). L is not included (no data for most of indicators). For more details about the calculations and methodology, see the methodological annex to Chapter 1.

Third European Report on S&T Indicators, 2003

Figure 1.12 shows on the horizontal axis the position of each country as far as its investment level in 1999 is concerned, compared to the European average and the other Member States. On the vertical axis, it measures the extent to which each country progressed between 1995 and 1999. The figure is complemented by table 1.3, which allows a more detailed analysis of the relative position and growth score of each country for each component of the composite indicator. The table indicates for each sub-indicator to what extent the country deviates from the EU average, both in terms of investment level in 1999 and in terms of growth rate. In the text that follows, we first give a general description of the position and growth of groups of countries and then continue with a more thorough country-specific analysis of strengths and weaknesses for each sub-indicator.

Obviously there are different strategies to facilitate the transition towards a knowledge-based economy. Some countries or regions focus on the creation of new knowledge, whereas others put more emphasis on the diffusion and acquisition of competitive, new knowledge from abroad. Within the European Union, a distinction can be made between four groups of countries, based on the efforts made during the period 1995-1999 to make a successful transition to a knowledge-based economy.

- The Nordic countries Finland, Sweden and Denmark are best prepared and are rapidly turning their economies into knowledge-based economies. These countries not only demonstrate high levels of investment at the end of the 1990s, they also show an overall rate of investment growth clearly above the European average. In 1999 all three countries had high levels of investment for nearly all types of investment. Only capital formation in Finland and the number of new S&T PhDs in Denmark are not above EU average (table 1.3). During the second half of the 1990s Sweden shows a high rate of growth for all components of the investment, except for life-long learning (much lower than average). Finland's investment growth is clearly higher for a majority of domains, but not with regard to capital formation, educational spending and participation in life-long learning, which are around the European average. Denmark shows a strong growth rate in research expenditure and educational spending and an average growth in domains where the country already benefits from a high investment level. One should pay some attention, however, to the low rate of growth of the number of new S&T PhDs (below EU average), a domain where Denmark does not excel.

- The second group consists of six countries: Austria, Belgium, France, Germany, the Netherlands and the United Kingdom. This group is characterised by an overall level and growth of investment much closer to the European average, although still slightly above it as regards the investment level. However, investment patterns vary significantly between the six countries, reflecting differences in policy priorities and/or the nature of the innovation

Table 1.3 Composite indicator on investment: comparison of EU Member States with the European average for each sub-indicator, for both the level in 1999 and the growth rate between 1995 and 1999

	Total expenditure in R&D		Human Capital				Overall Investment		Information infrastructure		Education		Training	
	GERD per capita		*New S&T PhDs per capita*		*Researchers per capita*		*Capital formation per capita*		*e-government*		*Educational spending/cap.*		*Lifelong learning*	
	Level 1999	Growth 1995-1999	Level 1999	Growth 1995-1999	Level 1999	Growth 1995-1999	Level 1999	Growth 1995-1999	Level 1999	Growth 1995-1999	Level 1999	Growth 1995-1999	Level 1999	Growth 1995-1999
DK	+	+	0	-	++	0	++	0	++	:	++	+	++	0
FIN	++	++	++	++	++	++	--	0	++	:	++	0	++	0
S	++	+	++	++	++	+	+	+	++	:	++	+	++	--
A	0	++	0	+	0	++	0	0	-	:	++	0	0	0
B	0	+	0	-	+	++	++	0	--	:	++	+	0	++
D	++	0	+	0	+	0	-	0	-	:	0	0	0	--
F	0	-	+	-	0	-	0	0	+	:	+	0	-	--
NL	+	0	-	--	0	+	++	+	--	:	+	0	+	-
UK	0	-	0	+	0	0	0	-	+	:	0	-	++	+
EL	--	++	--	++	--	++	--	++	-	:	--	++	--	++
IRL	-	+	0	++	0	++	0	++	++	:	0	+	0	++
P	--	++	--	++	--	++	0	++	+	:	-	++	-	--
E	--	+	-	-	--	++	-	+	+	:	--	+	-	+
I	--	0	--	--	--	--	+	0	-	:	0	-	-	+

++: well above EU average; +: above EU average; 0: close to EU average; -: below EU average; --: well below EU average

Source: DG Research
Data: Eurostat, DG Information Society
Notes: Investment level is based on standardised scores; deviation is expressed as number of standard deviations σ from European average: - -: more than 1σ below EU average; -: between 1σ and ½ σ below EU average; 0: between ½ σ below and ½ σ above EU average; +: between ½ σ and 1σ above EU average; ++: more than 1σ above EU average; : means data non available
Investment growth rate is based on average annual real growth rate (in %), deviation is expressed as the absolute difference between country-specific growth rate and European average growth rate: - -: more than 3% below EU average; -: between 3% and 1% below EU average; 0: between 1% below and 1% above EU average; +: between 1% and 3% above EU average; ++: more than 3% above EU average; : means data non available
Since the indicator on e-government is not available for 1995, it could not be included in the comparison of the growth rates. L is not included (no data for most of indicators).
For more details about the calculations and methodology, see the methodological annex to Chapter 1.

Third European Report on S&T Indicators, 2003

system. For instance, the somewhat higher investment levels of France and the UK are due to good scores in educational spending, e-government and new PhDs for France, and to participation in life-long learning and to e-government for UK, whereas Germany shows a high investment level in research expenditure per capita and in human capital, but has much lower scores in all other fields. The Netherlands and Belgium both have a relatively high level of capital formation, educational spending (particularly Belgium) and research expenditure (the Netherlands). The higher investment level of Austria seems to be essentially due to high educational spending.

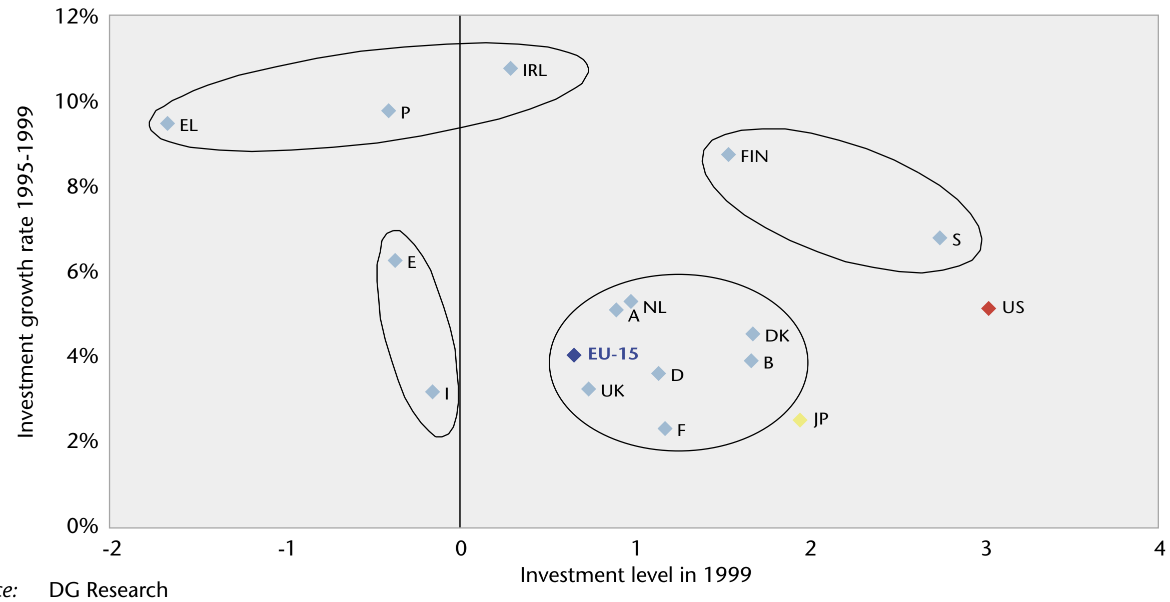
During the second half of the 1990s Germany had an average rate of investment growth in all categories, negatively affected, however, by very weak growth for participation in life-long learning. France's investment growth is below average for all types of investment (particularly life-long learning) except educational spending per capita (around average). The growth pattern for the UK is not drastically different, except when one considers the growing participation in life-long learning and the increase in the number of new PhDs per capita. The somewhat higher pace of growth for Austria was due to increased efforts in research expenditure and human capital, whereas growth for the Netherlands can be attributed for the major part to the growing number of researchers and capital formation. Belgium had a relatively high pace of growth for all types of investment (particularly life-long learning and number of researchers), except for capital formation (around average) and number of new PhDs (below average).

- A third group of three countries – Greece, Portugal and Ireland – demonstrates very high growth rates of investment, even higher than those of the Nordic countries. Greece and Portugal are in 1999 still below average in terms of investment level. For Greece, this is due to a low investment level for all categories of investment; which is the case for Portugal too, except for capital formation and e-government (close to or slightly above average). However, these countries are catching up with the rest of Europe at a very rapid pace. Moreover, their catch-up is due to strong growth for all types of investment (with the exception of life-long learning in Portugal, where growth scores between 1995 and 1999 remain clearly below average). Ireland, on the other hand, is already slightly above the European average level in 1999, thanks to the excellent position of this country with regard to e-government. The reason for the Irish catching up lies in rapid growth in all types of investment in the second half of the 1990s, especially in human capital, capital formation and life-long learning.

- A fourth group consists of two big southern European countries, Spain and Italy. They are both situated significantly below the EU average as far as investment levels are concerned. Italy demonstrates weak scores in all types of investment, with the exception of capital formation (slightly above average) and educational spending (around average), whereas Spain has in 1999 a low investment level in all categories but e-government. However, Spain shows an investment growth clearly above the European average, which was possible through increased efforts in nearly all components of the knowledge-based economy (the only exception was the weak growth in the number of new PhDs). If maintained, Spain's investment behaviour might allow the country to reach the same level as the rest of Europe in the coming years. For Italy, on the other hand, the situation should be taken seriously: the country indeed combines a low level of investment with weak or average growth scores for all types of investment (the only exception being the participation in life-long learning). For this country it is becoming urgent to mobilise more resources for its transition to the knowledge-based economy.

Beyond this intra-European comparison, it is also very interesting to compare the European Union, taken as a whole, with its main competitors the US and Japan. Unfortunately, since some data are not yet available for the US and Japan (concerning e-government, educational spending and life-long learning), such a comparison is so far only possible for four out of seven components of the composite indicator. The graph below thus shows a provisional version of the composite indicator on investment, which is intended merely to better assess the position of the European Union vis-à-vis the US and Japan[14].

Figure 1.13 Provisional composite indicator of investment in the knowledge-based economy for comparison between the EU-15, Japan and US. Relative country positions in 1999 and annual growth rate 1995-1999



Source: DG Research
Data: Eurostat
Note: Only 4 sub-indicators were included for both the investment level in 1999 (horizontal axis) and the growth rates: R&D expenditure (GERD per capita), PhDs (number of new S&T PhDs per capita), Researchers (number of researchers per capita) and gross fixed capital formation (GFCF (excluding building) per capita). The three other sub-indicators (e-government, educational spending and life-long-learning) are not available for the US and JP. L is not included (no data for most of indicators). For more details about the calculations and methodology, see the methodological annex to Chapter 1.

Third European Report on S&T Indicators, 2003

[14] *The graph also shows the scores of the various Member States in order to illustrate the existence of wide disparities within the European Union, even to the extent of individual Member countries approaching the scores of the US and Japan. It is worth noting that, despite substantial changes in the composition of the composite indicator, the groups remain unchanged in most cases (except for Denmark, which 'leaves' the group of the Nordic countries and joins the 'average' group) in comparison with the previous graph. This is an indication for the relative robustness of the composite indicator.*

Table 1.4 Composite indicator on investment: comparison of the US and Japan with European average for each sub-indicator, for both the level in 1999 and the growth rate between 1995 and 1999

	Total expenditure in R&D		Human Capital				Overall Investment	
	GERD per capita		*New S&T PhDs/cap.*		*Researchers/cap.*		*Capital Formation/cap.*	
	Level 1999	Growth 1995-1999	Level 1999	Growth 1995-1999	Level 1999	Growth 1995-1999	Level 1999	Growth 1995-1999
US	++	+	-	-	++	+	++	+
JP	++	0	--	++	++	+	++	--

++: well above EU average; +: above EU average; 0: close to EU average; -: below EU average; --: well below EU average

Source: DG Research
Data: Eurostat
Notes: cf. table 1.3.
Only 4 sub-indicators were included; the three other sub-indicators (e-government, educational spending and life-long-learning) are not available for the US and JP. For more details about the calculations and methodology, see the methodological annex to Chapter 1.

Third European Report on S&T Indicators, 2003

The figures confirm that the EU, as a whole, is lagging behind the US in terms of both investment level and growth. The US has both a higher level and growth rate for all types of investment. The only exception is the number of new S&T PhDs per capita, which at the end of the 1990s was clearly higher in Europe than in the US and grew at a much faster pace in the EU between 1995 and 1999. However, it will be demonstrated – and further analysed – in chapter 4 of this report that this higher production of human capital in Europe does not translate into a higher number of researchers per capita, since a significant number of European PhDs are not employed in research functions or leave the European research system to work abroad (‘brain drain’, generally towards the US). Japan also has a higher investment level than the EU-15 (except for PhDs, but here it is catching up at a very rapid pace). It is interesting to see that some Member States such as Sweden have overall levels of investment and growth patterns comparable to or even better than those of the US and Japan.

Beyond the low scores of – the majority of – European countries in terms of investment in the knowledge-based economy, the Spring 2003 Report will also emphasise some weaknesses in terms of research outcomes and performance, particularly with regard to technological performance. Indeed, investing in the knowledge-based economy is only half the story. The various components of investment in knowledge, as described above, need to produce successful outcomes if a good transition is to be realised. Productivity needs to be maintained and improved but for this to happen, and for it to be sustainable, there needs to be good performance in science and technology, effective use of the information infrastructure and a well-performing education system (low dropout rate). The second composite indicator, presented in the figure 1.14, regroups these four most important elements of the ‘performance in the transition to the knowledge-based economy’. By including overall productivity, scientific and technological performance, usage of the information infrastructure (e-commerce, or percentage of companies setting their products/services through electronic market places) and effectiveness of the education system (table 1.5), it provides an overview of the overall performance of the Union and its Member States in their transition to the knowledge-based economy[15].

Table 1.5 Component indicators for the composite indicator of performance in the knowledge-based economy

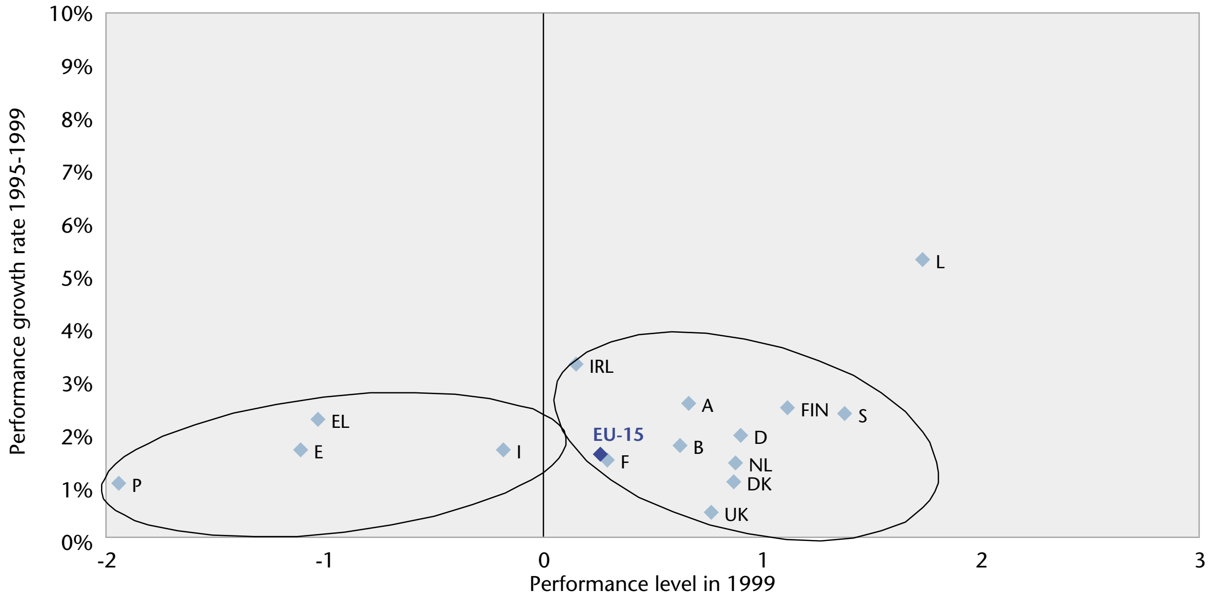
Sub-indicators	Type of knowledge indicator
GDP per hour worked	Productivity
European and US patents per capita	S&T performance
Scientific publications per capita	S&T performance
E-commerce	Output of the information infrastructure
Scholling success rate	Effectiveness of the education system

Source: DG Research
Data: Key Figures 2002

Third European Report on S&T Indicators, 2003

[15] *For more details about the calculation of the composite indicator and the weights used, see the methodological annex to chapter 1.*

Figure 1.14 Composite indicator of performance in the transition to a knowledge-based economy. Relative country positions in 1999 and annual growth rate 1995-1999 (EU-15 and Member States)



Source: DG Research
Data: Eurostat, EPO, USPTO, ISI/CWTS, DG Information Society
Note: All 5 sub-indicators were included for the performance level in 1999 (horizontal axis), but the indicator on e-commerce could not be included in the comparison of the growth rates (no data available on e-commerce for 1995). The data for the UK's schooling success rate are partial and not completely harmonised. To allow calculations, UK growth from 1995 to 1999 has therefore been taken as 0, which may lead to a marginal underestimation overall of the performance growth for UK and EU-15. For more details about the calculations and methodology, see methodological annex to Chapter 1.

Third European Report on S&T Indicators, 2003

Table 1.6 Composite indicator on performance: comparison of EU Member States with the European average for each sub-indicator, for both the level in 1999 and the growth rate between 1995 and 1999

	Overall Productivity *GDP per hour worked*		Technological Performance *Patents*		Scientific Performance *Publications/cap.*		Information Infrastructure *e-commerce*		Effectiveness Education *Schooling success rate*	
	Level 1999	Growth 1995-1999	Level 1999	Growth 1995-1999	Level 1999	Growth 1995-1999	Level 1999	Growth 1995-1999	Level 1999	Growth 1995-1999
B	++	0	0	0	+	0	-	:	0	0
DK	0	0	+	-	++	0	0	:	+	-
D	0	0	++	0	0	+	+	:	0	0
F	+	0	0	--	0	0	-	:	0	0
IRL	0	++	--	++	-	+	+	:	0	0
L	++	++	0	++	--	-	+	:	0	++
NL	++	0	+	++	++	-	0	:	0	0
A	0	+	0	-	0	+	+	:	+	0
FIN	0	0	++	+	++	0	+	:	+	0
S	0	0	++	++	++	0	+	:	++	0
UK	-	-	0	-	++	-	++	:	++	:
EL	--	+	--	++	--	++	-	:	0	+
E	--	0	--	++	-	++	--	:	--	+
I	+	0	--	0	-	0	-	:	-	+
P	--	+	--	0	--	++	--	:	--	-

++: well above EU average; +: above EU average; 0: close to EU average; -: below EU average; --: well below EU average

Source: DG Research
Data: Eurostat, DG Information Society
Notes: cf. table 1.3.
Since the indicator on e-commerce is not available for 1995, it could not be included in the comparison of the growth rates. For more details about the calculations and methodology, see the methodological annex to Chapter 1.

Third European Report on S&T Indicators, 2003

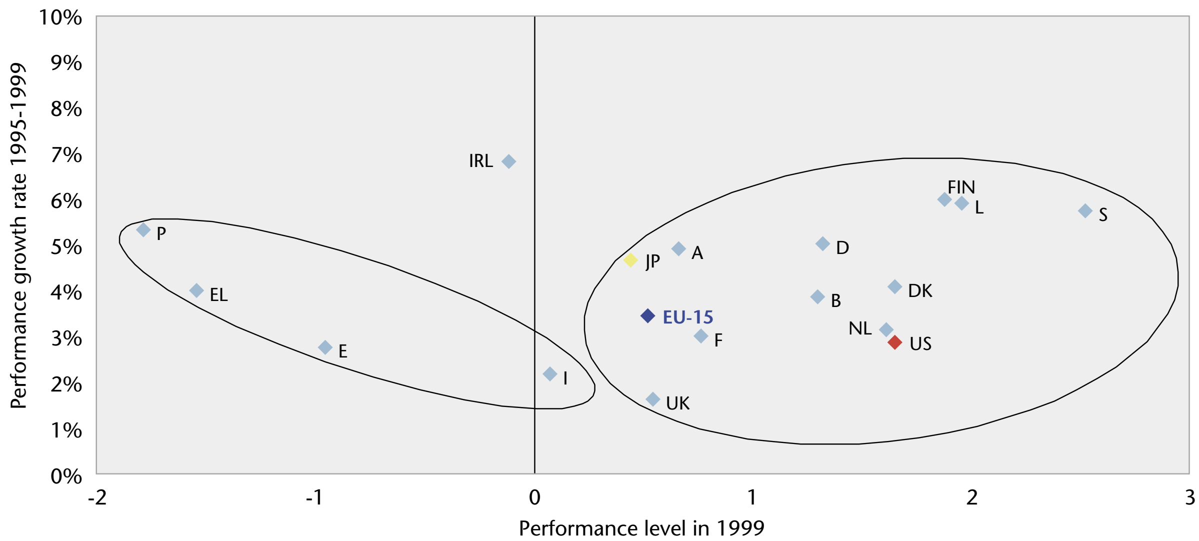
Figure 1.14 shows on the horizontal axis the relative position of each country as far as its performance level in 1999 is concerned, compared to the European average and the other Member States. On the vertical axis, it gives the progress made in this area between 1995 and 1999. Table 1.6 shows for each component of the overall performance indicator to what extent a Member State deviates from the EU average, both in terms of performance level in 1999 and growth rate. This allows a detailed analysis of country-specific strengths and weaknesses for each sub-indicator to be undertaken.

Within the European Union, the indicator again shows that it is possible to follow different strategies. Luxembourg, for instance, has the highest performance level and growth rate, although it invests much less than other countries in knowledge creation. Thanks to successful specialisation in some sectors of the economy (especially banking and general business services), it apparently succeeds in attracting highly skilled manpower and generating activities with high value added. Therefore, the high score of this country is essentially due to the very high level and growth of its GDP. Apart from the case of Luxembourg, a distinction can be made between two large groups of countries in terms of their performance in moving towards the knowledge-based economy. However, the differences here are much less marked than they were for investment.

- A broad group of 10 countries consisting of Austria, Belgium, Denmark, Finland, France, Germany, Ireland, the Netherlands, the UK and Sweden is quite close to the European average in terms of performance level and growth rate. The good position of Finland and Sweden is principally due to the strong scientific and technological performance of these countries during the 1990s, and, to a lesser extent, to their high schooling success rate and e-commerce development. Ireland has a relatively higher rate of growth during the second half of the nineties, thanks to a rapid increase in overall productivity and technological performance, and to a lesser extent, in scientific performance, which allows it to approach the EU average by the end of the decade. The UK, on the other hand, is characterised by low growth rates, which can be explained by the weak scores in productivity growth, scientific and technological performance, whereas France has particularly low growth rates in technological performance.

- The second group consists of four countries: Greece, Italy, Portugal and Spain. This group is lagging behind the EU average in terms of performance level at the end of the 1990s with a rate of growth around the EU average. These countries demonstrate weak performance level in nearly all components of the indicator (the only exceptions are average schooling success rates for Greece and above average productivity for Italy). Greece and Spain show rapid progress in scientific and technological performance, which is also the case, although to a lesser extent, for Portugal. Italy had average growth rates in all components of

Figure 1.15 Provisional composite indicator of performance in the transition to a knowledge-based economy for comparison between the EU-15, Japan and US. Relative country positions in 1999 and annual growth rate 1995-1999



Source: DG Research
Data: Eurostat, EPO, USPTO, ISI/CWTS
Note: Only 3 sub-indicators were included for both the performance level in 1999 (horizontal axis) and the growth rates: overall productivity (GDP per hour worked), patents (share of EPO and USPTO patents) and scientific publications per capita. No data available on e-commerce and schooling success rate for the US and Japan. The data for the UK's schooling success rate are partial and not completely harmonised. To allow calculations, UK growth from 1995 to 1999 has therefore been taken as 0, which may lead to a marginal underestimation overall of the performance growth for UK and EU-15. For more details about the calculations and methodology, see the methodological annex to Chapter 1.

Third European Report on S&T Indicators, 2003

the performance indicator (except for the above average schooling success rate). Greece's somewhat higher growth rate in overall performance might be a positive consequence of the increased efforts of this country during the 1990s. On the other hand, Portugal's significant increase in investment, as already mentioned, has not yet been converted into clear effects on the aggregated level, although the country shows impressive growth scores in terms of scientific performance and productivity growth slightly above average. It is important to recognise, however, that there is always a time-lag between making an investment and observing its effects.

Similarly to the indicator on investment, a comparison between the European Union, Japan and the US is so far only possible for some of the components of the composite indicator. The comparative results presented in figure 1.15 regroup three out of five indicator components, since it was impossible to integrate data on e-commerce and schooling success rates for the US and Japan[16].

Table 1.7 Composite indicator on performance: comparison of the US and Japan with European average for each sub-indicator for both the level in 1999 and the growth rate between 1995 and 1999

	Overall Productivity *GDP per hour worked*		Technological Performance *Patents*		Scientific Performance *Publications/cap.*	
	Level 1999	Growth 1995-1999	Level 1999	Growth 1995-1999	Level 1999	Growth 1995-1999
US	+	0	0	-	0	--
JP	--	0	0	-	-	0

++: well above EU average; +: above EU average; 0: close to EU average; -: below EU average; --: well below EU average

Source: DG Research
Data: Eurostat, DG Information Society
Notes: cf. table 1.3.
Only 3 sub-indicators were included; the two other sub-indicators (e-commerce and schooling success rate) are not available for the US and JP. For more details about the calculations and methodology, see the methodological annex to Chapter 1.

Third European Report on S&T Indicators, 2003

In the aggregate, the EU is lagging behind the US in terms of performance level, even if seven European countries demonstrate in 1999 comparable or even better positions than the US. However, in the second half of the nineties the majority of European countries managed to improve their performance level at a more rapid pace than the US, since the performance growth rates of all European countries except the UK, Italy and Spain were higher than the US ones. Nevertheless, this higher growth is still not sufficient to eliminate the existing gap between the EU and the US in the short-term, and certainly not by 2010. To avoid this, it is necessary not only to increase the size of investment made in the knowledge-based economy, but also to improve the way it is allocated and implemented.

The Spring 2003 Report will recognise and emphasise these findings. Therefore, it will pay special attention to research, knowledge and innovation, and will encourage Member States, despite current national budgetary constraints, '*to create or improve the conditions for more public and private investment in education, research and the knowledge economy*' (Spring Report 2003). One of its main priorities for the coming months links investment to performance in the transition to the knowledge-based economy, by recommending that '*a boost* [should be] *given to knowledge and innovation*'. This means '*supporting entrepreneurship, promoting knowledge industries and the diffusion of new ideas, technologies and services*', which must be underpinned by '*effective and increased investment in education, life-long learning and research*' (Spring Report 2003).

[16] *The non availability of those data gives components as scientific and technological performance a higher weights within the composite indicator, which explains some changes compared to the previous figure.*

Conclusions

This introductory chapter has outlined the main challenges that Europe will face in the coming years. A policy of growth, based on the intensive development of intangible investment, is necessary not only to ensure sustainable macro-economic stability and improve competitiveness, but also to meet the needs of the emerging knowledge-based economy and to respond to the challenges of the ageing population. Moreover, these demographic, economic and social challenges are not isolated problems but are interrelated in their nature, and need therefore to be tackled through co-ordinated and well-balanced policies. The Lisbon strategy outlined an integrated set of policies, measures and actions that can raise Europe's performance by accelerating the transition to the knowledge-based economy, while preserving – and modernising – Europe's unique social welfare model and decoupling economic growth from environmental damage.

At the core of this strategy is the stimulation of the transition to a knowledge-based economy. In this matter, however, the latest available data presented in this chapter should be taken seriously, since they show in various aspects of the transition an increasing gap between Europe and its main competitors. At the beginning of this century, the European Union is lagging behind the US and Japan. Moreover, the observed growth rates will not allow Europe to catch up rapidly, certainly not by 2010. While this general observation hides significant disparities between Member States with some countries needing to make much larger efforts than others, it is crucial for all of them not only to increase the volume of investment made in the knowledge-based economy, but also to improve the way it is allocated and implemented.

Investing more and better in the transition to a knowledge-based economy requires more efforts from everyone. As far as policy-makers are concerned, it calls for a clearer, stronger commitment towards a better and more efficient co-ordination of policies at three different levels. Firstly, there is the requirement of a good co-ordination between macro-economic policies on the one hand and structural policies (particularly education, research, innovation and employment) on the other hand. As this chapter has demonstrated, monetary and budgetary stability is necessary to ensure sustainable economic growth, but is on its own not sufficient to generate long-term economic growth. Therefore, it has to be complemented and well balanced with active education, research, innovation and employment policies, which promote the accumulation of human capital, technological progress and innovation, sources of future competitiveness, economic growth and jobs creation.

Secondly, it means also a better co-ordination between structural policies themselves. For instance, it does not make sense to treat the research system as separate from the education system or from employment policies. Recently, at the Barcelona Council of March 2002, an increase in R&D investment approaching 3% of GDP by 2010 was agreed upon as one of the strategic objectives (in 2000 current spending was at 1.93% for the EU-15 against 2.69% in the US and 2.98% in Japan). Two thirds of this increased investment should be made by the private sector through increased research efforts (in 2000 current industry-financed R&D was at 56.3% of total R&D spending in Europe, against 68.2% in the US and 72.4% in Japan). However, increasing the level of R&D investment makes little sense if the research system does not have enough highly qualified research scientists at its disposal, or if it cannot attract enough good researchers and guarantee them greater mobility. In other words, a correct matching of these policies (research, education and employment) is necessary in order to deliver converging impacts. Moreover, public policies must take concrete steps to provide business with an environment that encourages and facilitates R&D activities and the transfer of knowledge into marketable products and services. For instance, alleviating the administrative burden and the cost of patenting in Europe (through the creation of a unique 'Community Patent') might certainly contribute to this goal. In a broader context, this requires a new, better look at the economic, social and fiscal factors that influence company decisions with regard to investment in research and innovation. Unavoidably, it also calls for an improvement in the way in which research and innovation policies are matched and co-ordinated with other government policies, in particular industrial and competition policy.

Thirdly, it also requires better co-ordination of policies at the regional, national and international levels with regard to scientific and technological research. Better co-ordination here means finding the right balance between regional and national specific characteristics on the one hand, and the common interest on the other hand (scale effects). Strongly linked to this is the initiative to create a true "European Research Area"(ERA) launched by Commissioner Philippe Busquin in 2000. The ERA aims at a coherent restructuring of the Europe research systems through greater co-ordination and co-operation in order to turn them into one true 'Single Market for Research'. In the context of a better 'vertical' integration of research policies, one should mention the emergence of "benchmarking" of research policies – of which indicators are an important component – as one of the tools for implementing the new "open method of co-ordination" of policies which was established at the Lisbon summit in March 2000. From a theoretical point of view, the need for better co-ordination of policies is strongly linked to the concept of system of innovation, which is used extensively in this report and defined in the introduction of Part I. According to this model, policies need to both take into account the specific characteristics of the local context and to detect systemic imperfections. A first step towards identifying systemic failures is benchmarking.

In this context, monitoring the progress made in the various fields of Europe's research systems and detecting their strengths and weaknesses through reliable indicators is obviously of crucial importance. This is one of the key aims of this report. The following chapters present the latest and most reliable data on investment in and performance of European research, and compare the position of Europe in these matters with its main competitors, Japan and the US. It consists of two main parts:

- Part I deals with 'input indicators' of research in three different chapters. Chapter 2 analyses overall investment in R&D and the level and characteristics of the public contribution herein. Chapter 3 goes on to present investment in R&D, undertaken by business enterprises. Finally, in chapter 4 human resources in Science and Technology (graduates and PhDs in science and technology, researchers) are analysed.
- Part II presents the 'output-indicators', providing a broad overview of Europe's scientific and technological performance compared with the rest of the world. Chapter 5 deals with the latest data on scientific performance (publications, citations, Nobel prizes), while chapter 6 analyses patents and high-tech trade. The importance and evolution of so-called 'key technologies' (biotechnology, nanotechnology) and the structure of linkages between science and technology are also explored in a dedicated dossier.

Selected Bibliography

Abramovitz, M. and David, P. (1996), 'Technological change and the Rise of Intangible Investments: the US Economy's Growth-path in the Twentieth Century', in: OECD, *Employment and Growth in the Knowledge-based economy*, OECD Documents, Paris.

Andersson, Fr. And Konrad, K. A. (2001), 'Globalization and Human Capital Formation' (Social Science Research Center Berlin, Discussion Paper FS IV 01-01), Berlin.

Archibugi, D. and Lundvall, B.-Å. (eds.) (2001), 'The Globalizing Learning Economy', Oxford University Press, Oxford New-York.

Artus, P. (2002), 'Croissance: d'où viennent les handicaps de la zone euro et du Japon?', in: Chevalier, J.-M. et Pastre, O. (eds.) (2002), *Où va l'économie mondiale? Scénarios et mesures d'urgence*, pp. 29-39.

Baciocchi, V. (1999), 'La Convergence européenne des critères de Maastricht', *Economie Appliquée*, t. LII, 1999, nr. 4, pp. 69-101.

Barro, R. J. (1999), 'Inequality, Growth and Investment', (NBER Working Paper 7038), Cambridge [MA], March 1999.

Baudchon, H. (2002), 'Le contre-choc de la "nouvelle économie". Une étude de cas sur cinq pays de l'OCDE', *Revue de l'OCDE*, No. 83, Oct. 2002, pp. 243-289.

Boekholt, P. (ed.) (2002), 'Innovation Policy and Sustainable Development: Can Innovation Incentives make a Difference?', (Contribution to a Six Countries Programme Conference, Brussels, Feb.-March 2002).

Caracostas, P. and Muldur, U. (1998), 'Society, the endless frontier. A European vision of research and innovation policies for the 21st century', OPOCE, Luxembourg.

Castells, M. (1996), 'The Rise of the Network Society', *The Information Age*, nr. 1, Oxford.

Chevalier, J.-M. (2002), 'L'énergie: la sécurité des approvisionnements en question', in: Chevalier, J.-M. et Pastre, O. (eds.) (2002), *Où va l'économie mondiale? Scénarios et mesures d'urgence*, Paris, pp. 107-115.

Corvers, F. and Nijkamp, P. (forthcoming), 'Regional Development and EU Research Policy', Springer Series.

Crafts, N. (2000), 'Globalization and Growth in The Twentieth Century' (IMF Working Paper, WP/00/44).

David, P and Foray, D. (1995), 'Accessing and Expanding the Science and Technology Knowledge Base', *STI Review*, 16, pp. 16-38.

De Boissieu, Chr. (2002), 'Gouvernance mondiale et construction européenne', in: Chevalier, J.-M. et Pastre, O. (eds.) (2002), *Où va l'économie mondiale? Scénarios et mesures d'urgence*, Paris, pp. 41-50.

Della Gaspera, S. (2001), 'Richesse et population mondiale, l'inégale répartition', *Cahiers français*, nr. 305, nov-dec. 2001, pp. 18-22.

Drucker, P. (2001), 'The Next Society', *The Economist*, Nov. 3rd, 2001.

Esping-Andersen, G. (2002), 'A new European social model for the twenty-first century?', in: Rodrigues, M. J.(ed.) (2002), *The New Knowledge Economy in Europe. A Strategy for International Competitiveness and Social Cohesion*, Cheltenham-Northampton, pp. 54-94.

European Commission (1997), *Second European Report on S&T Indicators 1997*, Report EUR 17639, OPOCE, Brussels.

European Commission (1999/6), *European Economy. Generational accounting in Europe*, (European Economy, report and studies), OPOCE, Luxembourg.

European Commission (2000), *Bringing our needs and responsibilities together - Integrating environmental issues with economic policy*, Communication from the Commission to the Council and the European Parliament, Brussels (COM(2000) 576 Final).

European Commission (2000/2), *European Economy. Public Debt and Fiscal Policy in EMU*, (European Economy, report and studies), OPOCE, Luxembourg.

European Commission (2001a), *A mobility strategy for the European Research Area*, Communication from the Commission to the Council and the European Parliament, Commission document COM(2001) 331 Final.

European Commission (2001b), *Budgetary challenges posed by ageing populations: the impact on public spending on pensions, health and long-term care for the elderly and possible indicators of the long-term sustainability of public finances*, (Report of the Economic Policy Committee) EPC/ECFIN/655/01 Final.

European Commission (2001c), *EU Sustainable Development Strategy. A test case for good governance*, Position paper of the European Consultative Forum on the Environment and Sustainable Development, OPOCE, Luxembourg.

European Commission (2001d), *European Economy. The broad guidelines of economic policies in 2001*, OPOCE, Brussels, 2001.

European Commission (2001e), *European Governance. A White Paper*, OPOCE, Brussels (COM(2001) 428 Final).

European Commission (2001f), *L'Union Européenne dans le monde*, OPOCE, Luxembourg.

European Commission (2001g), *Rapport annuel sur la mise en oeuvre de l'aide extérieure de la Commission Européenne*, OPOCE, Luxembourg.

European Commission (2001/1a), *European Economy. Current issues in economic growth*, (European Economy, report and studies), OPOCE, Brussels, 2001.

European Commission (2001/1b), *Unity, solidarity, diversity for Europe, its people and its territory. Second report on economic and social cohesion*, OPOCE, Luxembourg.

European Commission (2001/3), *The EU Economy. Public Finances in EMU – 2001*, Directorate-General for Economic and Financial Affairs, OPOCE, Luxembourg.

European Commission (2002a), *Annual report on structural reforms 2001. Report addressed to the Council and the Commission*, Directorate-General for Economic and Financial Affairs – Economic Policy Committee, Brussels (DGECFIN/EPC/171//01-EN).

European Commission (2002b), *Commission presents roadmap to increase investment in research*, Press Release of the Commission, Brussels (IP/02/1291).

European Commission (2002c), *Competitiveness Report 2002*, OPOCE, Luxembourg.

European Commission (2002d), *L'élargissement de l'Union Européenne, une chance historique* (http://europa.eu.int/comm/enlargement/report2002/index.htm), Sept. 2002.

European Commission (2002e), *Responses to the challenges of globalisation. A study on the international monetary and financial systems and on financing for development* (Working document of the Commission Services, Directorate-General Economic and Financial Affairs), Brussels.

European Commission (2002f), *Still a long way from fulfilling the Lisbon Objective: Europe is not investing enough in knowledge*, Press Release of the Commission, Brussels (IP/02/1639).

European Commission (2002g), *The European Research Area: Providing new momentum. Strengthening – Reorienting – Opening up new* perspectives, Communication from the Commission, Commission document COM(2002) 565 Final.

European Commission (2002h), *Towards a European Research Area. Science, Technology and Innovation. Key-Figures 2002*, OPOCE, Luxembourg.

European Commission (2002/3), *The EU Economy. Public Finances in EMU – 2002*, Directorate-General for Economic and Financial Affairs, OPOCE, Luxembourg.

European Commission (2003a), 'Investment in Knowledge – the way forward', Speech of the President of the European Commission at the European Parliament on 14 January 2003, Commission document SPEECH/03/4.

European Commission (2003b), *Commission assesses implementation of 2002 Broad Economic Policy Guidelines*, Press Release of the Commission, Brussels (IP/03/38).

European Commission (2003c), *Report on the implementation of the 2002 Broad Economic Policy Guidelines* [manuscript], Brussels (COM(2003) 4/3).

European Commission (2003d), *Choosing to grow: knowledge, innovation and jobs in a cohesive societty,* Report to the Spring European Council, 21 March 2003 on the Lisbon strategy of economic, social and environmental renewal, Communication from the Commission, Commission document COM (2003) YYY final.

European Council (1996), 'Conclusions of the Presidency of the Florence European Council of 21 and 22 June 1996', Council document SN300/96.

European Council (2000), 'Conclusions of the Presidency of the Lisbon European Council of 23 and 24 March 2000', Council document 100/1/00.

European Council (2002), 'Conclusions of the Presidency of the Barcelona European Council of 15 and 16 March 2002', Council document SN 100/1/02 Rev1.

European Round Table of Industrialists (ERT), Improved investment conditions. Third survey on improvements in conditions for investment in the developing world, Report to the ERT, 2002.

Fagerberg, J., (2001), 'Europe at the Crossroads: The Challenge from Innovation-based Growth', in: Archibugi, D. and

Lundvall, B.-Å. (eds.) (2001), *The Globalizing Learning Economy*, Oxford University Press, Oxford, New-York, pp. 45-60.

Férone, G., d'Arcimoles, Ch.-H., Bello, P., Sassenou, N. (2001), 'Le développement durable. Des enjeux stratégiques pour l'entreprise', Paris.

Ferrandon, B. (2001), 'Inégalités, pauvreté: comment les mesurer ?', *Cahiers français*, nr. 305, nov-dec. 2001, pp. 8-17.

Giraud, P.-N. (2002), 'Le défi des inégalités', in: Chevalier, J.-M. et Pastre, O. (eds.) (2002), *Où va l'économie mondiale? Scénarios et mesures d'urgence*, Paris, pp. 69-79.

Higgins, M. and Williamson, J. G. (1999), *Explaining Inequality the World Round: Cohort Size, Kuznets Curves and Openness*, (NBER Working Paper 7224), Cambridge [MA], July 1999.

Holtz-Eakin, D., Lovely, M.E., Tosun, M.S. (2000), *Generational conflict, human capital accumulation, and economic growth*, (NBER Working Paper Series, 7762), Cambridge [MA], June 2000.

International Monetary Fund, 'World Economic Outlook', May 2000.

Kousnetzoff, N. (2002), 'Démographie et croissance mondiale à l'horizon 2030', *La lettre du Centre d'Etudes Prospectives et d'Informations Internationales (CEPII)*, nr. 208 (Jan. 2002), Paris.

Landes, D. S. (1998), 'The Wealth and Poverty of Nations: why some are so rich and some so poor?', London.

Landes, D. S. (1999), 'The Unbound Prometheus. Technological Change and Industrial Development in Western Europe from 1750 to the Present', Cambridge University Press, Cambridge.

Leadbeater, Ch. (1999), 'Living on Thin Air. The New Economy with a Blueprint for the 21st Century', Penguin Books, London.

Ludlow, P. (2002), *The Barcelona Council. European Council Commentary*, vol. 1, nr. 2, Eurocomment, Brussels.

Lundvall, B.-Å. and Jonhson, B. (1994), 'The Learning Economy', *Journal of Industry Studies*, vol. 1(2), pp. 23-42.

Maddison, A. (2001), 'The World Economy. A Millennial Perspective', OECD (Development Centre Studies), Paris.

Metcalfe, J. S. (1995), 'The Economic Foundations of Technology Policy: Equilibrium and Evolutionary Perspectives', in: Stoneman, P. (1995), *Handbook of Economics and Innovation*, Oxford-Cambridge, pp. 409-512.

Meyer-Krahmer, Fr. (2001), 'Industrial Innovation and Sustainability – Conflicts and Coherence', in: Archibugi, D. and Lundvall, B.-Å. (eds.) (2001), *The Globalizing Learning Economy*, Oxford University Press, Oxford, New-York, pp. 177-194.

Mitsos, A. (2001), The Territorial Dimension of Research and Development Policy: Regions in the European Research Area, (presentation held at the Valencia Conference 'The Regions and Research and Development and Innovation Policy: The Challenges and Prospects of Territorialisation' on 23.02.2001 (text can be downloaded from http://europa.eu.int/comm/research/area/regions.html)).

Nelson, R. R. and Romer, P. (1996), 'Science, Economic Growth and Public Policy', in: Smith, B. L. R., Barfield, C. E., *Technology, R&D and the Economy*, Brookings, Washington D.C.

Nicolas, Fr. (2001), 'Mondialisation et inégalités Nord-Sud', *Cahiers français*, nr. 305, nov-dec. 2001, pp. 34-39.

OECD (1998), 'Human Capital Investment. An International Comparison' (Centre for Education Research and Innovation), Paris, 1998.

OECD (2001), 'Trends in International Migrations', Paris.

Rodrigues, M. J. (2002), 'For a European Strategy at the turn of the century', in: Rodrigues, M. J.(ed.) (2002), *The New Knowledge Economy in Europe. A Strategy for International Competitiveness and Social Cohesion*, Cheltenham-Northampton, pp. 1-27.

Sachwald, Fr. (2001), 'Dynamique des inégalités mondiales: rattrapages internationaux et ajustements internes', *Cahiers français*, nr. 305, nov-dec. 2001, pp. 26-33.

Schienstocks, G. (2001), 'Social Exclusion in the Learning Economy', in: Archibugi, D. and Lundvall, B.-Å. (eds.), *The Globalizing Learning Economy*, Oxford University Press, New-York, pp. 163-176.

Smith, K. (2002), 'What is the 'knowledge economy'? Knowledge intensity and distributed knowledge bases', (Working Paper United Nations University / INTECH).

Soete, L. (2002), 'The challenges and the potential of the knowledge-based economy in a globalised world', in: Rodrigues, M. J.(ed.) (2002), *The New Knowledge Economy in Europe. A Strategy for International Competitiveness and Social Cohesion*, Cheltenham-Northampton, pp. 28-53.

Soete, L., (2001), 'The New Economy: A European Perspective', in: Archibugi, D. and Lundvall, B.-Å. (eds.) (2001), *The Globalizing Learning Economy*, Oxford University Press', Oxford, New-York, pp. 21-44.

Teece, D (2000), *Managing Intellectual Capital. Organizational, Strategic, and Policy Dimensions*, Oxford University Press, Oxford, 2000.

UNICE (2002), *Ensuring EU Enlargement is a Success. The UNICE Position*, Brussels, 2002.

United Nations Development Programme (UNDP) (2001), *Human Development Report 2001. Making New Technologies Work for Human Development*, New-York, (UNDP) (2001).

Viginier, P. e.a. (2002), *La France dans l'économie du savoir: pour une dynamique collective*, Commissariat Général du Plan, Paris.

Von Tunzelman, G.N. (1995), *Technology and Industrial Progress. The Foundations of Economic Growth*, Aldershot-Brookfield.

World Bank (2001), *World Development Indicators 2001*, New York.

World Bank (2002), *World Development Indicators 2002*, New York.

PART I

Investment in knowledge production, dissemination and absorption

In the first chapter of this Report, it has been argued that the European Union is evolving into a post-industrial and knowledge-based society, just as two centuries ago Europe evolved from an agrarian into an industrial society. Production is shifting steadily from material and labour intensive products and processes to knowledge intensive ones. In this context, the key strategic resource for future prosperity has become knowledge itself. Knowledge-based societies and economies are based on the production, distribution and use of knowledge. Therefore, economic growth depends directly on investment in knowledge that increases the productive capacity of traditional factors of production, i. e. knowledge and resulting innovations raise the returns on and the accumulation of other types of investment

But what precisely is knowledge? It is necessary to more fully define this and related complex concepts – such as that of systems of innovation – as repeated references will be made to them further on in this report.

Knowledge is inexhaustible. As such it differs from natural resources such as coal, iron and oil, the driving forces behind earlier economic transformations. The more knowledge is used, the more it multiplies and expands.

But knowledge is not accessible to all. It can be absorbed, applied and transmitted only by educated minds. Therefore, as societies and economies become more knowledge-intensive, it also becomes more important than ever to invest in structures that help absorb existing and develop new knowledge.

There exist different kinds of knowledge. Knowledge is created by multiple actors through multiple activities and therefore comes in multiple forms. Essentially, knowledge is more than information, which is merely one specific kind of knowledge, namely codified knowledge that exists independently from individuals. Knowledge in a broader sense, however, also includes the capability to treat and understand data and information.

The kinds of knowledge that are required in the knowledge-based economy and the innovation process vary and comprise for instance technological and scientific knowledge, education, information processing and organisational knowledge. These types of knowledge can take various forms such as embodied knowledge (in human beings or equipment) or disembodied knowledge (in articles, blueprints, patents, software and databases).

A further important and interesting distinction is between tacit knowledge (skills, competencies, routines) and codified knowledge. This distinction has far-reaching consequences for the production and dissemination of knowledge. Tacit knowledge is acquired through experience (learning, producing, researching) and consists of the accumulation of human skills and techniques. Tacit knowledge cannot be transferred easily and is therefore a valuable asset for both the provider and the recipient. Tacit knowledge can be codified but this depends on the pecuniary and non-pecuniary reward systems and the costs of codification. Codified scientific and technological information, on the other hand, is a so-called "non-rival public good" (and is partly non-excludable), which raises the problem of its optimal use (David & Foray, 1995; Dasgupta & David, 1994)[1].

The whole of knowledge relevant for innovation constitutes the so-called knowledge base, i.e. the knowledge needed for innovations residing in and generated by formal R&D systems, education and training systems, and economic routines. The knowledge base comprises three relevant production areas:

- the general scientific knowledge base;
- public industrial knowledge;
- knowledge of a particular firm.

As far as the knowledge base is concerned what is first of all important are existing stocks of knowledge, and their utilisation and distribution (accessibility/transferability, Edquist 1997[2]). In this sense, the concept of the knowledge base needs to be further developed to include the distribution power of a knowledge system and its openness (international spillovers). In addition to internal interaction effects, succesful innovation also depends on complementary inputs from other markets – such as financial and labour markets, institutional/regulatory conditions (IPR, competition rules, entrepreneurial culture, etc.) and – considered as crucial – education and training of human resources.

Then of course the challenge is to increase the stock of knowledge further through knowledge creation. The current view of innovation in a knowledge-based economy is that knowledge creation depends very much on interaction effects between different kinds of knowledge. This interactive model of innovation process or so-called 'chain-link model' stresses the interactions and diffusion of knowledge flows (continuous interactions and feedback, linkages between upstream and downstream research, external feedback between science, technology and process phases of development, see Kline & Rosenberg, 1986)[3]. Consequently, as firms do not innovate in isolation but in co-operation and interaction with other organisations the final innovation output is an outcome of knowledge investment and of interdependencies and interactions between the various (market and non-market) institutions of the innovation system (for example Edquist, 1997[2]; Metcalfe, 1995[4]).

[1] *David, P and Foray, D. (1995), 'Accessing and Expanding the Science and Technology Knowledge Base', STI Review, 16, pp. 16-38. Dasgupta, P. & David, P. (1994) 'Toward a new economics of science' in Research Policy, 23, pp. 487-521.*

[2] *Edquist, Ch. (1997) Systems of innovation. Technologies institutions and organisations, Pinter, London.*

[3] *Kline, S.J. and Rosenberg, N. (1986). The Positive Sum Strategy, Harnessing Technology for Economic Growth "An Overview of Innovation", National Academy Press, Washington D.C., US*

[4] *Metcalfe, J. S. (1995), 'The Economic Foundations of Technology Policy: Equilibrium and Evolutionary Perspectives', in: Stoneman, P. (1995), Handbook of Economics and Innovation, Oxford-Cambridge, pp. 409-512.*

Investment in efficient educational and training systems is important in order to make use of existing stocks of knowledge and for knowledge creation. Firstly, well-developed and effective education systems produce the researchers needed to create new knowledge as a basis for future competitiveness. Secondly, having a large base of well-educated and well-trained people is important for the availability of "absorptive capacity". This is crucial for the diffusion of new knowledge and its transformation into innovations that may create economic growth and welfare. Moreover, in an era of greatly increasing globalisation and even more intensive competition, well-educated people and thus a high level of absorptive capacity are key to facing the challenges of rapidly evolving economies. In other words, and following the formulation of the Lisbon European Council in March 2000, the advance towards a knowledge-based economy must be supported by a process of accumulation of scientific and technical skills, as well as by a general upgrading of the human resources in the EU.

Thus the transition towards a knowledge-based society and economy depends essentially on investment in knowledge, its quality, and its dissemination. The following table serves as a guiding map of the various types of knowledge investment (in broad sense) and their measurement that are analysed in the underlying chapter. Evidently, the coverage of the knowledge investment is limited by the availability of data and our present conceptual understanding about the knowledge-based economy.

Types of knowledge, generation and investment

Type of knowledge	Institution/actor	Generation	Investment
Scientific knowledge	Universities	Public sector research activities	R&D expenditure in universities
	Public Research institutes		R&D expenditure in public research institutes
	Business sector R&D	Business sector research activities	R&D expenditure in business sector
Technological knowledge	Business sector R&D in firms	Business sector research activities	R&D expenditure in business sector
	Business sector research In research institutes	Business sector research activities in industrial research institutes	R&D expenditure in business sector research institutes
	Public sector Research institutes	Public sector research activities	R&D expenditure in public research institutes
	Universities	University research activities	R&D expenditure in universities
	R&D in emerging business sector (spin-offs, business creation)	Research and development in emerging firms	Venture capital in seed stage
			Financial support for emerging firms (HT and KIS)
Innovations	Business sector	Business sector research and development activities	R&D expenditure in business sector
	Business sector, Emerging business sector	Business sector's complementary intangible assets	CIS: market introduction of innovation, training linked to innovation, industrial design, extra-mural R&D
			Venture capital in seed, start-up and expansion phase
		R&D activities related to the commercialisation of innovations	Venture capital in seed phase
Human capital	Universities	Higher education	Investment in higher education
	Universities	Scientific education	Investment in university, education and research
	Research activities (public – business sector)	Research activities	Investment in public sector research
	High School	Education	Investment in education
Skills/ competences	High School	Education	Investment in education
	Business sector	Training	Investment intra-firm education
	Professional courses	Life-long learning	Investment professional training
	Industrial and scientific production	Learning-by-doing	Employment
ICT/ Information	ICT-industry in Business sector	Use/Access to ICT/information distribution	Investment in ICT hardware
		Networks	Investment in ICT software

The insight that the productive use of knowledge, as well as knowledge creation, depend on interaction effects between multiple actors - the inherent assumption being that innovation requires an institutional innovation infrastructure – brings us to the concept of systems of innovation.

Systems of innovation were originally conceived of as national. The concept originated in the 19^{th} century Germany, and subsequently became underrated, but it has recently come to the fore once more. It generally approaches innovation as a system-event and specifically analyses the interrelations and interactions between all institutions and organisations which at the national level occupy themselves with innovation or influence it (government, universities, public research organisations, industrial laboratories, financing mechanisms, foreign partners). (Edquist, 1997)

The idea of a national innovation system goes back at least to the conception of Friedrich List of the national system of political economy in 1841. List was at that time concerned with the fact that Germany was underdeveloped in relation to Great Britain and he wondered how Germany would be able to overtake Great Britain. To that end he advocated the protection of infant industries as well as a broad range of policies designed to enable and accelerate industrialisation and economic growth. He was very much aware of, among other things, the importance of knowledge accumulation compared to physical capital investment (or so-called intangible versus tangible investment), of forging links between science and education, of importing and diffusing foreign knowledge compared to stimulating domestic knowledge development and of the role of government.

The success of R&D lab driven technological development during the First and Second World Wars undermined the use of the concept of IS. Innovation was now seen as pushed by technology (‘technology-push model’). A so-called linear model of innovation was conceived: R&D leads to innovation leads to diffusion leads to economic growth. But in the post-WWII period, evidence accumulated that innovation is due not only to technology developed in R&D labs but also to overall education and training levels, production processes, engineering, design, and quality control, and that innovation does not by itself lead to economic growth but that diffusion and social innovation are also required for that, all of which assumes that a well performing national innovation system is in place.

The concept of system of innovation is used extensively in this report because it offers a number of valuable insights with real and tangible policy implications. We mention just two of those insights here. A first one is that the use of knowledge and knowledge creation are context-related and interactive. This means that policy, to be effective, should focus on the specifics of every system. Policies have to be tailored to specific sectors and develop competencies that are specific to the local or regional context. Another insight is that policy should focus on removing systemic imperfections. A first step towards identifying and resolving these systemic failures is benchmarking.

Even though systems of innovation were originally conceived of as national, recently more and more attention is being paid to on the one hand their regional and sub-regional dimensions (e.g. clusters) as well as their international dimension.

In Europe, the European Commission has played an important role in strengthening the international character of the systems of innovation through the promotion of cross-border research projects, mobility of researchers, and international benchmarking. It will continue to do so through the concept and tool of the European Research Area. Some of the results that have been accomplished thus far and some of the challenges that still have to be overcome are spelled out in this report.

Outline of Chapter 2, 3 and 4

The different elements of investment in knowledge will be analysed in the following three chapters. The first two chapters concentrate on public and private investment in R&D, the third on the human resources in S&T.

Chapter 2 starts with the overall investment in R&D by analysing the gross expenditure on R&D (GERD) in detail. It will provide a comparison of world regions, investment gaps, R&D intensities and trends of overall R&D investment. The section gives also a good overview of the public and the private share in the investment figures. In the following sections the public financial contribution to R&D will be analysed in detail. In addition, the government expenditure on R&D (GOVERD) and the higher education expenditure on R&D (HERD) are examined. In Dossier I, figures on Government Budget Appropriations for R&D (GBAORD) will be analysed in order to complete the picture of public investment in R&D.

Chapter 3 deals with the private investment in R&D, undertaken by business enterprises. The analyses on the business expenditure on R&D (BERD) will be supplemented by two important options of private investment in R&D: company mergers & acquisitions and venture capital. A dossier on ‘spin-offs’ follows at the end of Chapter 3.

In Chapter 4, human resources in S&T as an important input in the knowledge production are analysed. The first section presents researchers, R&D personnel and university graduates in science and engineering (S&E) as the key indicators of human resources in S&T. The second section presents potential shortfalls in the future. In the following three sections investment in education, the attraction of researchers from abroad and the encouragement of women into S&T are discussed in order to show possible starting points to meet the shortage problems. A dossier on ‘Women in Science’ follows at the end of Chapter 4, which presents some indicators and concepts of measurement of differences in S&T due to gender.

CHAPTER 2
Investment in Science, Technology and New Knowledge

This chapter examines and compares the development of research financing and expenditure on research and development (R&D) in the EU, the US and Japan. It focuses on trends in R&D related activities especially since the mid-1990s.

Section 1 offers a general overview and examines trends in the overall levels of financing of and expenditure on R&D in the EU, the US and Japan, as well as across the EU over the past decade. Possible scenarios for growth of R&D expenditures until 2010 are also presented and discussed.

Section 2 takes a closer look at the role of the government sector as a financier of R&D and as an important player within a national innovation system. The changing role of government in R&D is discussed, and the volume and trends of government-financed R&D are examined.

Section 3 investigates the role of government research laboratories as R&D performers and analyses recent developments in R&D expenditure by government. In addition, R&D performance by government is reviewed by providing a closer analysis of European public research institutes.

Section 4 describes the changes, and also certain challenges of the higher education sector, before providing data for this sector. Finally, a summary and conclusions of the entire chapter are presented.

Section I Trends in R&D investment

Investment in knowledge creation and its production is one of the prime concerns of policy-makers. Investments can be analysed from different angles. First, there is the question concerning amounts spent, in terms of gross domestic product (GDP), in real terms, growth rates and so on. The second question is who invests? In general, a distinction is made between public and private investment, but even here, a more detailed analysis is feasible. The final question relates to production and performance: where does the R&D work take place? Each of these rather complex issues will be addressed in this chapter.

1. Development of total financial resources devoted to R&D

Average levels of R&D expenditure are lower in the EU than in the US and Japan

Trends in the volume of R&D expenditures have varied considerably in the EU area during the past couple of decades. In the 1980s, the volume of research funding and R&D intensity both showed an upward trend in the EU countries. In real terms, R&D expenditure increased on average by 4% a year between 1981 and 1991. The corresponding figures for the US and Japan were 4.3% and 6.9%, respectively.

In 1991, the real growth of R&D expenditure funding slowed in the EU area. This phase of stagnation lasted for four years, followed by slow growth in 1996 and 1997. In the period from 1991 to 1997, expenditure on R&D in the EU increased by a mere 0.7%. In the US and Japan, the stagnation of R&D resources lasted only from 1992 to 1994. Belgium, Ireland, Denmark and Sweden were the only EU countries where real R&D expenditures continued their more or less upward trend throughout the 1990s.

Figure 2.1.1 shows the volume of gross domestic expenditure on R&D (GERD) in the EU, the US and Japan in 1991, 1995 and 2000. The most notable change in the first half of the decade took place in the US, where expenditure on R&D was increased by Purchasing Power Standards (PPS[1]) 7 billion. At the same time, R&D expenditure was relatively stable in the EU and Japan.

In 2000, the EU countries allocated an estimated PPS 141 billion to R&D (164 billion euro, in current terms). The figure was 10% higher than in 1998, and almost 4% higher than the previous year. Thus, the latest development in R&D expenditure in the EU has been more favourable, following several years of rather level investment. In 2000, the volumes of R&D expenditure for the US and Japan were PPS 226 billion (288 billion euro) and PPS 84 billion (154 billion euro), respectively.

In spite of the favourable growth rates of R&D investment in the EU over the past few years, the relative position of the EU compared to the US weakened throughout the 1990s. The negative trend for the EU becomes clear when the absolute volume of total R&D financing of the EU is compared to that of the US.

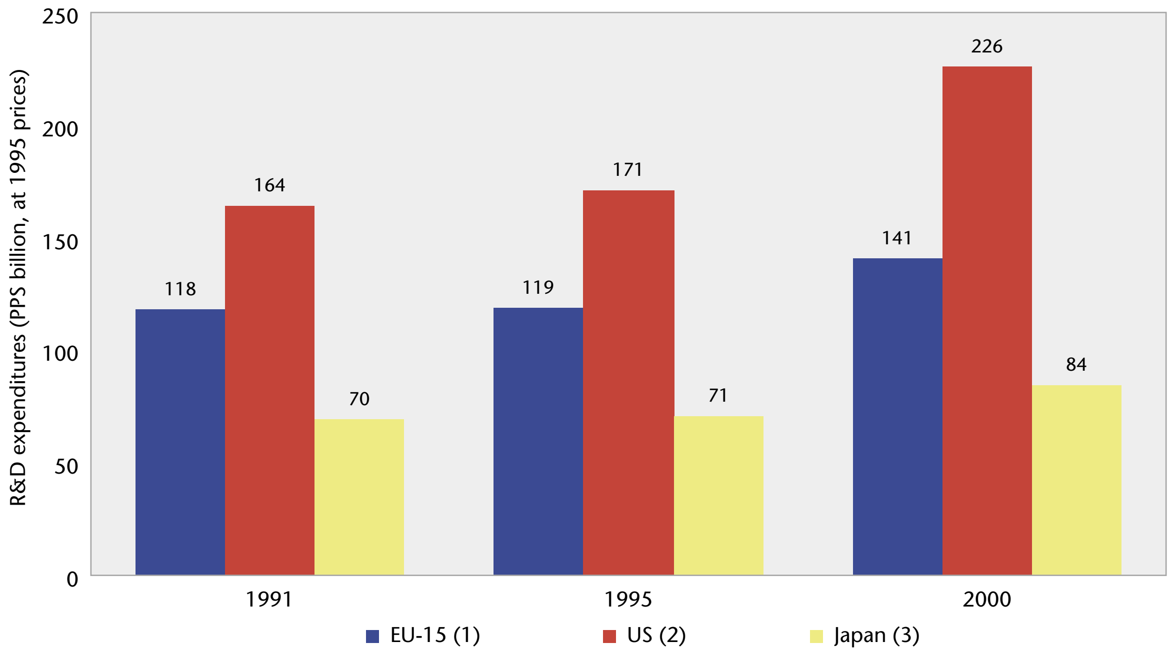
Figure 2.1.2 shows the evolution of the absolute gap between the EU and the US over the past decade. This gap has widened continuously, especially since 1994. The difference in absolute terms is an important issue because of the cumulative nature of knowledge production. Since R&D is at the heart of knowledge production, the increasing difference in R&D investment between the EU and the US translates into a widening gap in the accumulation of economically useful knowledge and innovation potential. This has obvious implications for competitiveness.

In the earlier part of the 1990s, the EU managed to an extent to stabilise the R&D investment gap with the US. In 1994, however, the narrowest gap still accounted for PPS 44 billion (figure 2.1.2). This has nearly doubled since the mid-1990s. While in 1991 the EU had invested 28% less in R&D than the US, by 2000 the difference already amounted to 38%. The investment gap between the EU and the US was some PPS 86 billion in 2000. The picture is less bleak when the EU is compared to Japan. Since 1997, the gap has increased significantly in favour of the EU. In 2000, the difference was a record PPS 59 billion.

Figure 2.1.3 shows real growth rates of R&D expenditure, i.e. R&D performance, over the two consecutive periods – in 1991–1995 and 1995–1999 – in the EU, the US and Japan. It also compares growth rates for the following four distinct EU country groups:

(1) A group comprising the four largest economies and R&D financiers in the EU (EU-4 – Germany, France, Italy, the United Kingdom);

Figure 2.1.1 Gross domestic expenditure on R&D in real terms, 1991, 1995 and 2000 (PPS billion, at 1995 prices)

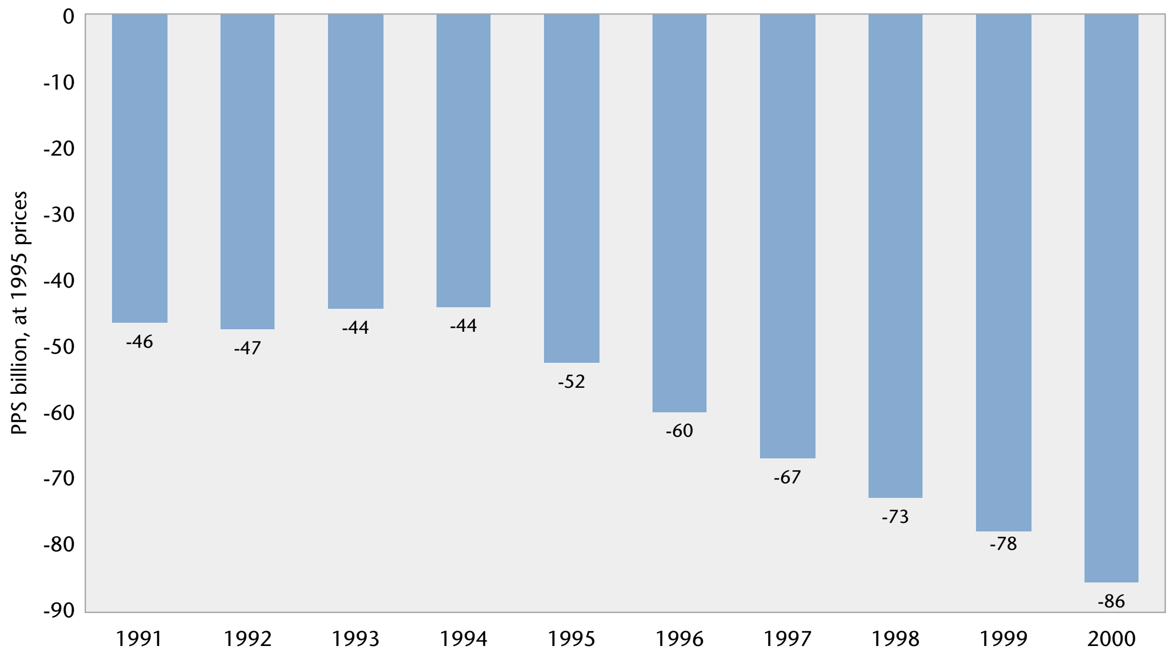


Source: DG Research
Data: OECD – MSTI database (STI, EAS Division) with DG Research provisional estimates
Notes: (1) L data are not included in EU-15 average. Data for 2000 are estimated. See endnote 1. (2) US: See endnote 2. Endnotes are at the end of section 1. (3) Data for Japan for 1991 and 1995 adjusted by OECD.

Third European Report on S&T Indicators, 2003

[1] *In this chapter, development of R&D expenditure in real terms was calculated from data in Purchasing Power Standards (PPS) at 1995 prices and exchange rates, rather than in ECU/Euro based on exchange rates. PPS are based on comparisons of the prices of representative and comparable goods or services in different countries in different currencies on a specific date (Eurostat 2001).*

Figure 2.1.2 Absolute gap in R&D investments between the EU-15 (1) and the US is growing (PPS billion, at 1995 prices)



Source: DG Research
Data: OECD – MSTI database (STI, EAS Division) with DG Research provisional estimates
Note: (1) L data are not included in EU-15 average.

Third European Report on S&T Indicators, 2003

(2) EU countries other than the four biggest economies listed above and Luxembourg (EU-10);

(3) The Nordic EU countries (Denmark, Finland, Sweden);

(4) A group of EU countries that allocate the least to R&D in volume terms (Greece, Ireland, Portugal).

In the 1991–1995 period, the rates of growth for the EU, the US and Japan were at a markedly low level, and also fairly similar (figure 2.1.3). For the four main EU economies, the growth rate was negative. However, the situation changed in the 1995–1999 period. The latter part of the decade saw more positive growth rates for R&D expenditure than the earlier part with the figures for the three major economic blocs being substantially higher.

However, compared to the US growth (25%) over the period 1995–1999, the real increase in R&D expenditure in the EU and Japan was clearly smaller, i.e. below 15%. This trend implies that the gaps in R&D expenditure between the US, the EU and Japan not only started to widen, but also – somewhat alarmingly – did so with increasing speed during the latter part of the 1990s.

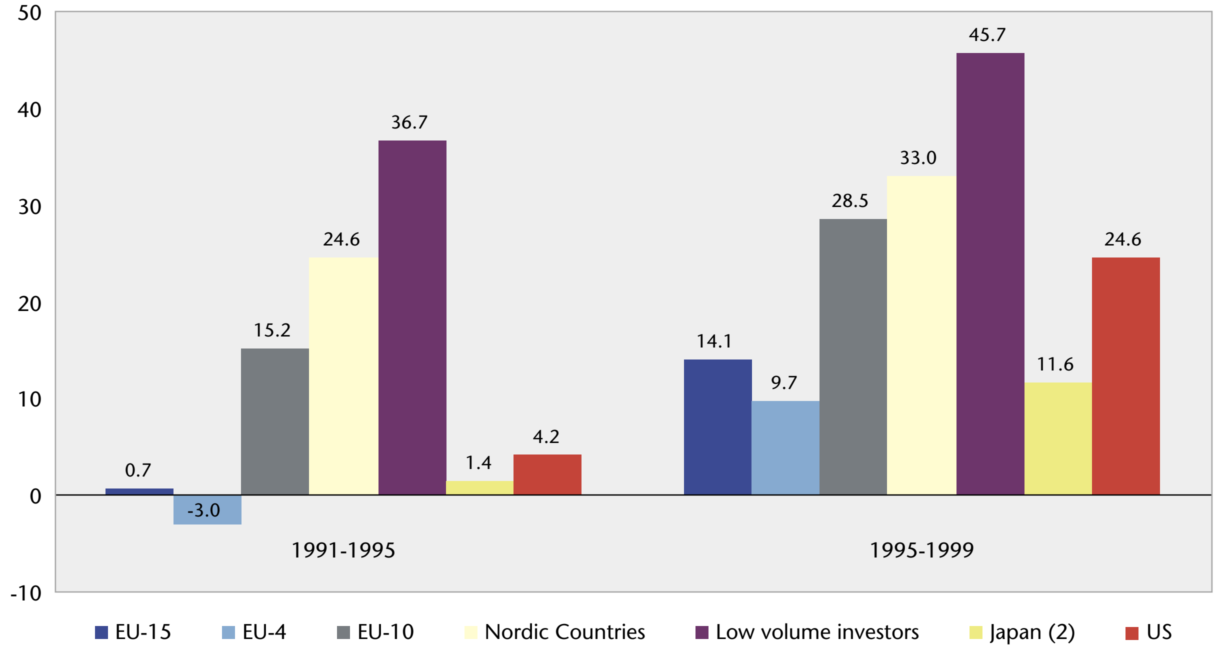
The comparatively weak development in R&D expenditure in the EU was mainly due to slow growth in the largest EU economies (negative growth in 1991–1995, and 10% in 1995–1999 for EU-4). Throughout the 1990s, the growth rates for both the Nordic countries and countries with a relatively low volume of R&D were higher than those of the others.

The annual real growth rate of R&D expenditure for individual countries in 1995–1999 is shown in figure 2.1.4. The highest growth rates were recorded for Finland (on average 14% per year), Greece (12%) and Portugal (11%). The growth rates for these three countries are somewhat different from those of the others. Compared to the figure for the US (6%), the relative rate of growth in R&D expenditure was slower in all the major EU economies.

In the UK, France and Italy, the annual real growth in R&D expenditure was low, at 1.2–2.0% (figure 2.1.4). Of the main EU economies, only Germany managed a growth rate above the EU average. However, since 1999, both France and the UK have shown signs of recovery and made efforts to compensate – at least partially – for lower investments earlier in the decade. This is in contrast with Italy, where the real expenditure on R&D in the late 1990s was some 5% lower than at the beginning of the decade.

In the second half of the 1990s, most countries experienced average annual growth rates that were higher than those for the first half of the decade. The only exceptions were Ireland, Sweden and the UK, which showed declining growth rates in the latter part of the decade. In spite of this, the growth rates for Ireland and Sweden were high, and considerably above the average for the EU.

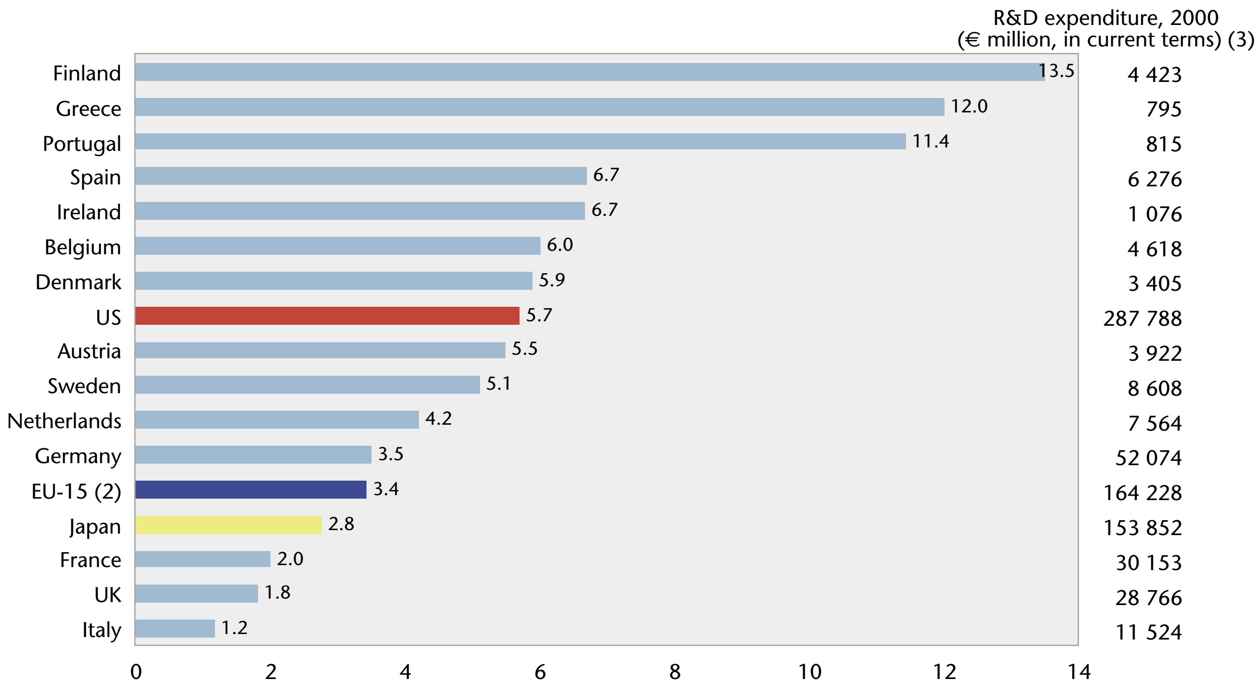
Figure 2.1.3 Real growth (%) of R&D expenditure, from 1991 to 1995 and from 1995 to 1999 (1)



Source: DG Research
Data: OECD – MSTI database (STI, EAS Division) with DG Research provisional estimates
Notes: (1) L data are not included in EU-15 average. EU-15: See endnote 1. EU-4: comprises the largest EU economies, i.e. D, F, I and UK. EU-10: comprises EU countries excluding EU-4 and L. Nordic countries: DK, FIN and S. Low volume investors: EL, IRL and P. (2) The value for Japan refers to 1996–2000 instead of 1995-1999.

Third European Report on S&T Indicators, 2003

Figure 2.1.4 R&D expenditure – average annual real growth (%), 1995 to latest available year (1)



Source: DG Research
Data: OECD – MSTI database (STI, EAS Division) with DG Research provisional estimates
Notes: (1) FIN, UK, US, EU-15: 1995–2000; JP: 1996–2000; D, E, A: 1995–2001; I: 1997–1999; F: 1997–2000; all other countries: 1995–1999. (2) L data are not included in EU-15 average. (3) B, DK, EL, IRL, I, NL, P, S: 1999; D, E, A: 2001.

Third European Report on S&T Indicators, 2003

On the basis of the average annual real growth of R&D expenditure in the latter part of the 1990s (figure 2.1.4), it is clear that a process of convergence within the EU, and also across individual EU countries, has taken place. Countries that were catching up recorded favourable rates of growth of R&D financing and performance.

While this may be the case in relative terms, the reality is that divergence within the EU increased in absolute terms. For instance, the very high average annual rate of growth of R&D expenditure in 1995–1999 in Greece (12%), Portugal (11%) and Ireland (7%) means, in absolute terms, a real growth of PPS 235–381 million. At the same time, the lower rate of real growth for Germany (3.5%) means an increase of PPS 5.3 billion over the same period.

Since 1999, the real growth of R&D expenditure in Germany has been relatively high. This is especially the case if the figure for Germany is compared to those of the other major EU economies. As a result, Germany alone accounted for almost one-third of the EU-level real increase of R&D expenditure in 1995–1999. Over this period, Germany together with Spain, Sweden and Finland, accounted for some 57% of the total growth of R&D activity in the EU.

R&D investment and R&D intensity: what do they reveal?

R&D comprises creative work undertaken on a systematic basis in order to increase the stock of knowledge, including knowledge of man, culture and society, and the use of this stock of knowledge to devise new applications (OECD 1993). R&D is a major form of knowledge investment, the others being spending on education and on information and communication technologies. The volume of R&D investment reflects the economy's efforts in creating and accumulating new knowledge, which is essential to modern knowledge-based economies. It may also be considered an indirect measure of a society's innovation capacity. The ability to create, disseminate and exploit knowledge and information is increasingly crucial to the competitiveness of the economy and to higher standards of living and public health.

R&D intensity, that is R&D expenditure (or investment) as a proportion of GDP, provides a useful measure of how much countries invest in R&D in relation to the value of their total production. As far as research is concerned, it also reflects the knowledge intensity of the economies in question. R&D intensity facilitates the comparison of R&D expenditure between countries of different sizes.

However, the question concerning the level and the growth of R&D intensity is not a simple one. In addition to direct R&D funding, there are many other factors that indirectly affect the level of R&D intensity. These include industrial structure (for example, the share of R&D-intensive fields of industry in the enterprise sector), the rate of growth of GDP, and the development of a government budget. For instance, the structure of industry in the US is far more specialised in R&D-intensive sectors, such as those in the fields of high-tech production, than in the EU. This structural factor partly explains the R&D investment gap between the US and the EU. In general terms, the relatively low volume of business sector R&D investment in the EU (compared to the volume in the US) is responsible for more than three quarters of the gap (in real terms) in 2000.

The question on the absolute volume of R&D investment and the level of R&D intensity is not purely one of money. Both investment and intensity reflect indirectly, and are dependent on, the availability of a sufficient stock of human resources, a regulatory environment for R&D, and the capacity of national innovation systems to digest and exploit investment in R&D effectively. In the end, the question is one that concerns the effectiveness of the entire innovation system, the capacity to make resources available for R&D, and the ability to transform investment into new knowledge, advancement and innovation.

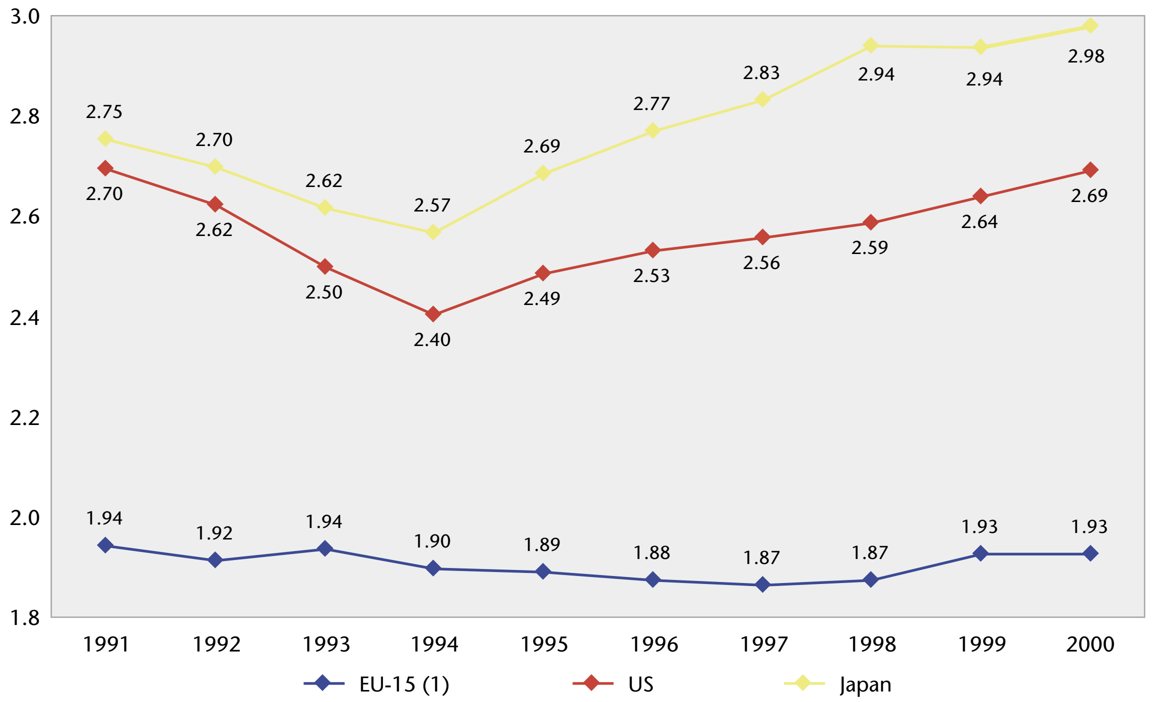
R&D intensity compared by world region: EU is losing the ground

The average R&D intensity for the EU was 1.93% in 2000 (figure 2.1.5). The figure was practically at the same level as in 1991. Thus, the link between volume of R&D and gross national income remained largely unchanged in the EU throughout the past decade. In the 1990s, the fluctuation in R&D intensity was far greater in the US and Japan than in the EU. In the US, for instance, R&D intensity started to decline after 1991, and dropped to 2.4% by 1994.

Since 1994, the growth of R&D financing has outpaced the growth of the overall economy in the US. As a result, by 2000 R&D intensity had increased steadily to almost 2.7%. The substantial growth of R&D intensity since 1994 was possible partially because in 1994–2000 the US experienced the greatest real increase of R&D expenditure for any 6-year period in its history (NSF 2002).

Throughout the 1990s, EU-level R&D intensity was at a substantially lower level than the corresponding figures for the US and Japan. In 1994, the EU average of 1.9% was 0.5 percentage points below the US figure, and 0.7 percentage points below Japan. In 2000, the EU level dropped to some 0.8 percentage points below the level of the US and to more than one percentage point below the Japanese level. In a nutshell, the EU has fallen continuously further behind the US and Japan since the mid-1990s.

Figure 2.1.5 R&D intensity (%) in the EU-15, the US and Japan, 1991–2000



Source: DG Research
Data: OECD – MSTI database (STI, EAS Division) with DG Research provisional estimates
Note: (1) L data are not included in EU-15 average.

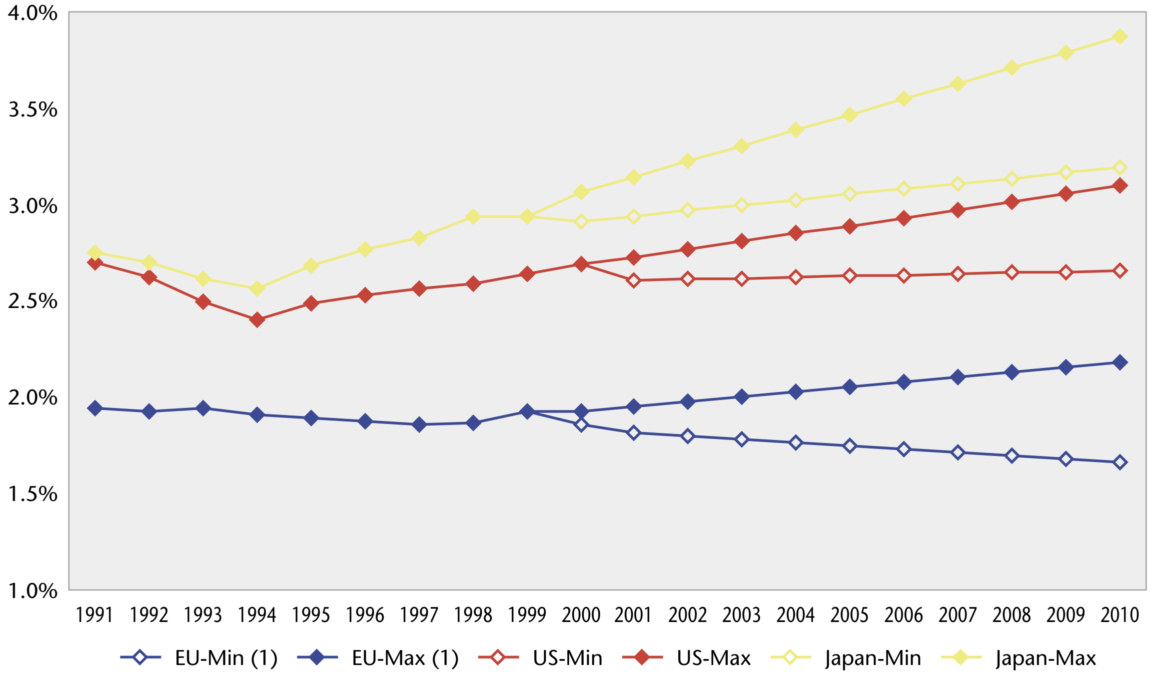
Third European Report on S&T Indicators, 2003

Estimates of the possible evolution of research expenditure in the 2000–2010 period are examined next. Figure 2.1.6 shows potential scenarios for the evolution of R&D intensity during this period. Growth rates were calculated for the EU, the US and Japan for three time periods within the last decade: one for the entire decade; the second for the period 1994–1999; and the third for 1996–1999. For each economic block, a "best-case scenario" and a "worst-case scenario" growth rate were taken from the highest and lowest rates in the three time periods mentioned above. These are represented in the figure as "min" or "max".

Research expenditure in the EU over the last decade has been relatively stable at around 1.9% of GDP. If the current trend continues, the best the EU could hope for, is a rate of around 2.2–2.3% by 2010. It should be remembered, however, that this is only a "best-case scenario" based on the performance in the 1990s. Calculating a "worst-case scenario" using downward trends would find EU research expenditure at below 1.8% of GDP. It is clear, then, that if the EU is to increase its overall level of research expenditure to a figure approaching 3% by 2010 – as was agreed by the European Council in 2002 in Barcelona – substantial efforts are needed to create the conditions in which this might be achieved.

Nevertheless, even by employing the most optimistic of estimates, if there is no major reorientation of public and private policy towards research expenditure, the EU will still be spending well below 2.5% of its GDP on research. Even a "best-case scenario" would be substantially below the current relative level of US spending. The gap between the US and the EU is widening, and will continue to widen over the current decade, unless efforts are increased significantly.

Figure 2.1.6 R&D intensity (%) – forecast to 2010 with minimum and maximum projections, and with the presumption that no major changes in policy or in the R&D environment as a whole will occur



Source: DG Research
Data: Basic data: OECD – MSTI database (STI, EAS Division) with DG Research provisional estimates. Projections: DG Research
Note: (1) L data are not included in EU-15 average.

Third European Report on S&T Indicators, 2003

R&D intensity within the EU: Nordic countries and countries catching up lead the pack

Recent levels of R&D intensity differ considerably across the EU countries and the US and Japan (figure 2.1.7). The highest R&D intensity was recorded for Sweden (3.8% in 1999) and Finland (3.4% in 2000), followed at some distance by the US and Japan. The figure for Germany was also very high at more than 2.5%. Sweden and Finland stand out clearly in the EU group, and these two economies form a distinct group. In addition to high R&D intensity, they are characterised by features that include high per capita volume of R&D, high private sector share of total R&D, high share of high-tech industries of total value added and of exports, and real growth of GDP above the EU average since the mid-1990s.

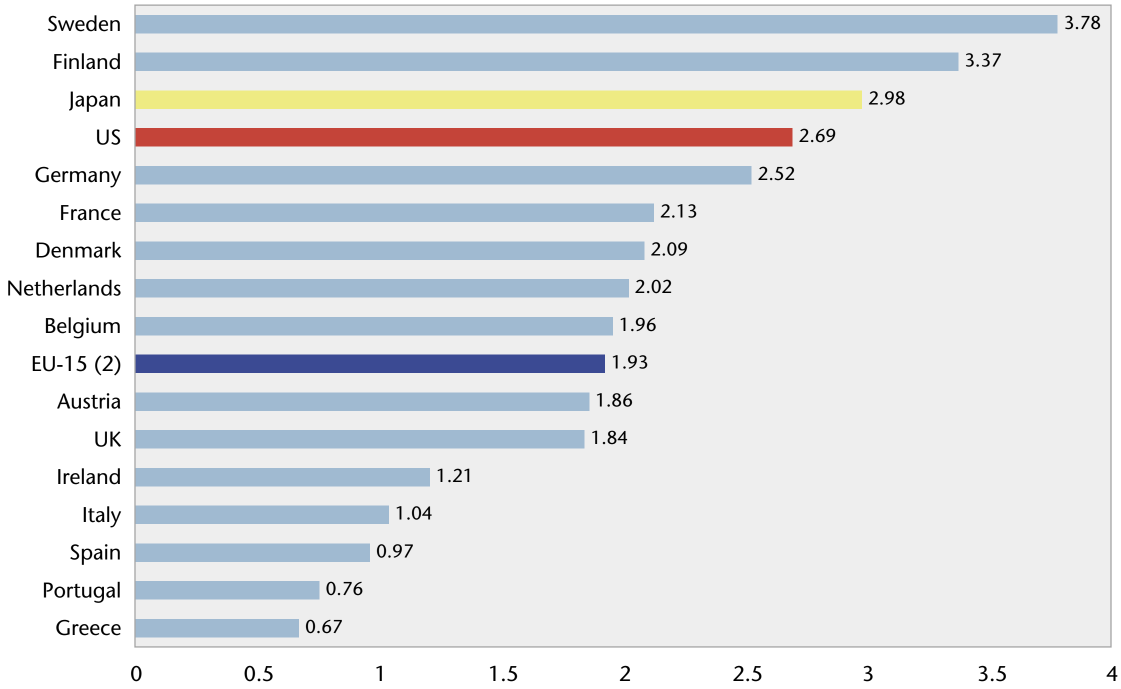
The poor development of EU-level R&D intensity throughout the 1990s was mainly due to extremely limited growth of the R&D/GDP ratio in the major EU economies (Germany, France, Italy and the UK). Indeed, most of these EU economies, which currently account for some three-quarters of total EU R&D expenditure, recorded lower levels of R&D intensity in 1999 than in the early 1990s. During the latter part of the decade, the real volume of R&D and R&D intensity increased substantially in Germany only.

In terms of relative growth of R&D intensity, Greece, Finland and Portugal recorded the highest figures in the latter part of the 1990s (figure 2.1.8). Those countries that are catching up from a lower level of R&D intensity, i.e. Greece, Portugal, Spain, Italy, and Ireland, experienced rather different trends compared to each other. For the first three, growth rates were favourable, but the growth recorded for Italy and Ireland was negative.

In Ireland, for instance, the strong upward trend of R&D intensity in the earlier part of the 1990s levelled off in 1996. From that year onwards, the figure took on a downward trend. This is partly because of the high average annual real growth of GDP of almost 10% since 1995. As a result of substantial growth of the economy, a marked increase in R&D volume (figure 2.1.4) has not resulted in positive growth of R&D intensity.

In Italy, on the other hand, even with a more moderate rate of growth of the economy, it was difficult for R&D expenditure to follow the pace of growth of GDP during the latter part of the 1990s. The same holds good for France and the UK: the overall economy outpaced the growth of R&D investments. However, this fact should not be taken as the sole key to the negative growth of R&D intensity. It suggests that the status of R&D in the economic sphere has weakened in relative terms. In any case, the average annual real growth of R&D was very low in all these EU economies in the late 1990s.

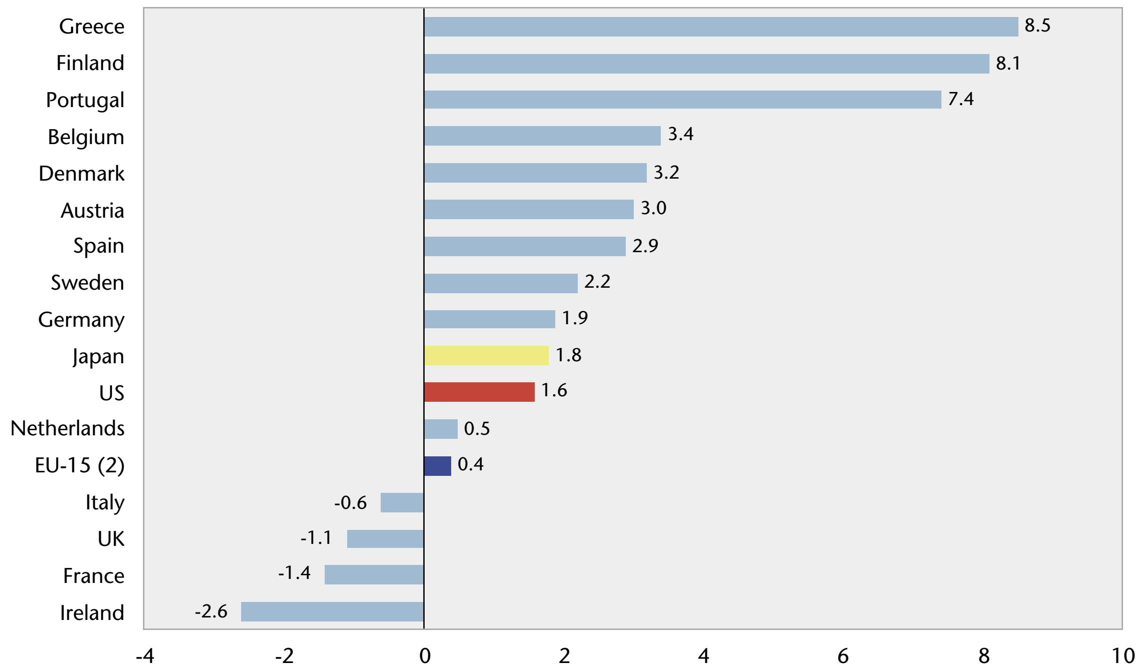
Figure 2.1.7 R&D intensity (%), latest available year (1)



Source: DG Research
Data: OECD – MSTI database (STI, EAS Division) with DG Research provisional estimates
Notes: (1) D, E, A: 2001; F, FIN, UK, US, JP, and EU-15: 2000; all other countries: 1999. (2) L data are not included in EU-15 average.

Third European Report on S&T Indicators, 2003

Figure 2.1.8 R&D intensity (%) – average annual growth, 1995 to latest available year (1)



Source: DG Research
Data: OECD – MSTI database (STI, EAS Division) with DG Research provisional estimates
Notes: (1) JP: 1996–2000; FIN, UK, US, EU-15: 1995–2000; D, E, A: 1995–2001; I: 1997–1999; F: 1997–2000; all other countries: 1995–1999. (2) L data are not included in EU-15 average.

Third European Report on S&T Indicators, 2003

Policy measures to increase R&D intensity and R&D investment in Member States

Since 1997, some countries have set targets for raising the level of R&D intensity and have launched ambitious policy measures with the aim of increasing R&D funding. For instance, in Austria one policy objective is to increase the R&D/GDP ratio to 2.5% by 2005. This goal could be achieved by a combination of public R&D funding and stimulation of private investment and by increasing research activities in polytechnics and the funding of competence centres.

In Denmark the Danish Research Commission has proposed an overall strategy for Danish research. The strategy is built on the basis of certain principles, one of which is a commitment to increasing investment in research. It was recommended that Denmark should increase its investment in research to reach the R&D/GDP ratio of 3% by 2010, of which 40% should be financed through public funding, including an increase in the basic funding of research institutions.

In Belgium, substantial efforts such as an increase of public investment in R&D, have been made in order to achieve the R&D intensity target of 2% by 2002. Finally, in Finland, the government increased public R&D funding considerably during the period 1997–1999, with one of its aims being to reach a 2.9% level of R&D intensity by 1999. Indeed, in Finland's case, with an additional contribution by industry, R&D intensity was in excess of 3.2% by the end of the period.

The regional dimension: best performing EU regions

In the EU, R&D intensities vary across countries, though this is even more the case across regions. The following list provides the top 15 EU regions, on a somewhat disaggregated regional level (NUTS II), that invested most in research in the EU in relative terms in 1999.

1. Braunschweig, Germany (6.34%)
2. Stuttgart, Germany (4.84%)
3. Oberbayern, Germany (4.76%)
4. Pohjois-Suomi, Finland (4.29%)
5. Tübingen, Germany (4.23%)
6. Uusimaa, Finland (4.09%)
7. Baden-Württemberg, Germany (3.87%)
8. Midi-Pyrénées, France (3.73%)
9. Berlin, Germany (3.62%)
10. Eastern, United Kingdom (3.56%) (*)
11. Île-de-France (3.53%)
12. Dresden, Germany (3.51%)
13. Rheinessen-Pfalz, Germany (3.46%)
14. Karlsruhe, Germany (3.40%)
15. Köln, Germany (3.28%)

EU average: 1.93% of GDP.
Data: Eurostat; No data available for Austria.
Note: (*) Regional level NUTS I

The list gives an idea of the regional concentration of R&D activities and the resource allocation to R&D in particular regions. Regional disparities in R&D seem to be substantially high, both across Europe and within individual countries. The high concentration of R&D investments within EU countries, i.e. mainly in central locations in each country, suggests that intra-national differences may largely explain the intra-EU disparities in R&D and innovation activities.

The German regions occupy the first three places in this ranking, and thus continue to be the most R&D intensive regions of Europe. The regions making up the top 15 European regions with the highest R&D intensity come as no surprise, since these are often quoted in the literature as prime examples of innovative regions with high technological potential. Top regions also have a high capacity to create and absorb new knowledge and transform it into commercial products or into some other form of competitive advantage.

In addition, these regions have a comparatively high level of economic activity (GDP per capita), as well as, for instance, a useful stock of human resources. There are large numbers of qualified scientists in both higher education institutions and public laboratories, and R&D personnel in the business sector. Large metropolitan areas such as Île-de-France around Paris, the Uusimaa region around Helsinki, and the greater Munich area in Oberbayern, provide firms with a thriving business environment due to economies of scale and scope, and a political power centre.

2. Structure and trends in R&D financing and R&D performance

It is clear that levels of R&D financing by different sources of funds (government, business enterprise, private non-profit, higher education, and from abroad) are not independent from one another. The government sector is generally responsible for financing the science base from which many of the technological opportunities that stimulate R&D spending by others are likely to emerge. In addition, attracting research funds from abroad, for instance, is also partly dependent on the existence of centres of excellence in R&D, and the availability of high quality personnel and collaborators locally.

Although there is no optimal mix for the financing of R&D, it should be recognised that the financing activities of each sector often affect the activities undertaken by the other sectors. For instance, business-funded research is unlikely to increase dramatically in isolation. It is necessary, moreover, to pay attention to the links between government funding and incentives for business funding. If implemented in the right way, government research funding activities can provide new incentive structures for businesses to participate both as financiers and as performers of high-quality research. According to the expert group set up by the European Commission (2002c), "… private investment in many emerging fields will take place only after consistent and extensive public investment in human resources, infra-technologies and […] generic technologies to provide the knowledge infrastructure to support the exploitation of the field."

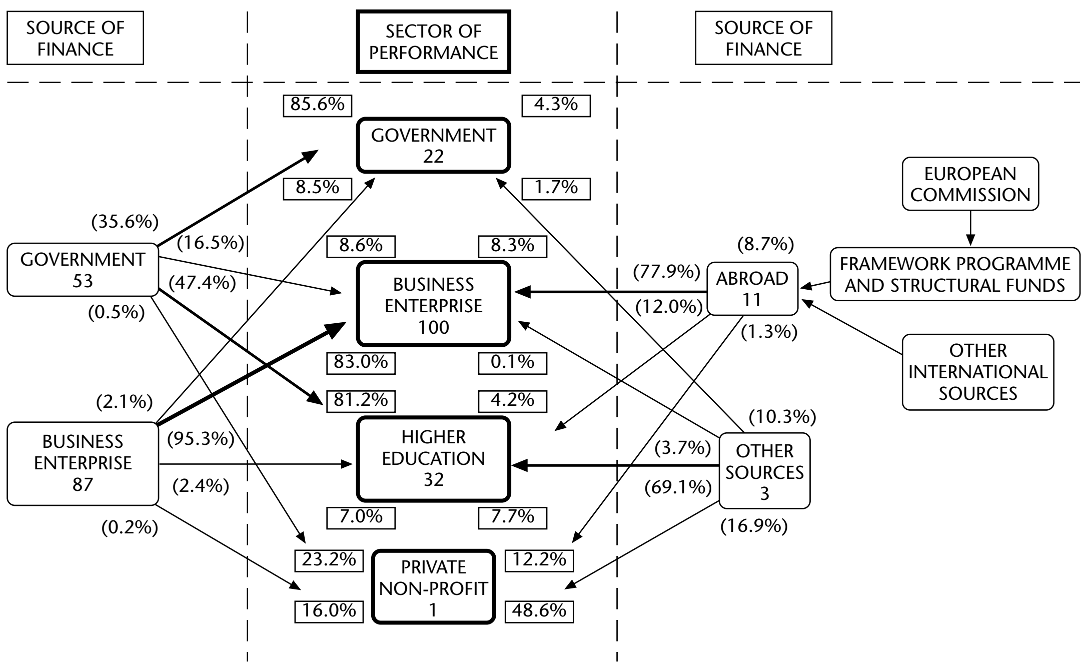
This sub-section provides an overview of the structure and trends in R&D financing by main sources of funds, as well as by main sectors of performance, comparing the EU, the US, and Japan, and by looking at trends within the EU. The following sections of this chapter give a more detailed analysis of the main public investors and performers, namely the government and the higher education sector. The dominant investor and performer, the business enterprise sector, is analysed in Chapter 3.

The linkages between all of those involved in financing and performing R&D are somewhat complex, as is clear in figures 2.1.9a to 2.1.9c. They provide snapshot images of the flow of financing and location of R&D performance within the R&D systems in the EU, the US and Japan in 1999.

In analysing EU and US financing and performance structures of R&D (figures 2.1.9a and b), certain major differences are discernible between the economic blocs. In terms of government financing, the difference between the EU and the US was 13 billion euro (in current terms) in favour of the latter. From the perspective of R&D performance, the situation was the opposite: the government sector in the EU was larger (by 4 billion euro) than that of the US.

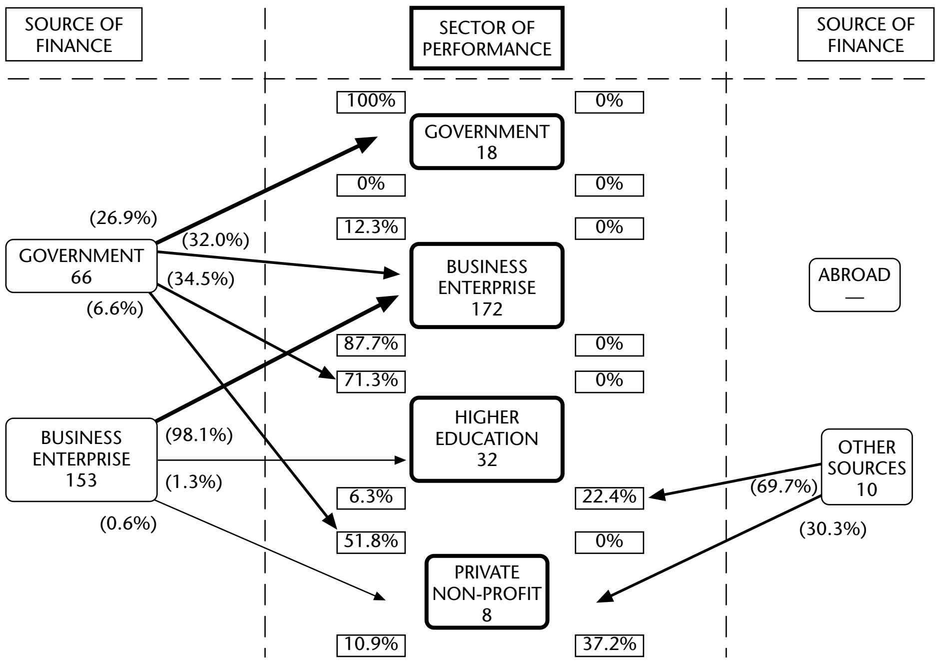
The biggest element in the investment gap between the EU and the US, and the reason behind it, was the overall amount of research financed and performed by the business sector. In 1999, the gap in favour of the US was some 6 billion euro higher in execution of R&D than it was in its financing. In current terms (and excluding funding from abroad), the gap was 66 billion euro in R&D financing (causing 77% of the "investment gap") and 71 billion euro in performance (causing 89% of the "performance gap").

Figure 2.1.9a Financing and performance structures of R&D in the EU-15 (1) (€ billion, in current terms), 1999



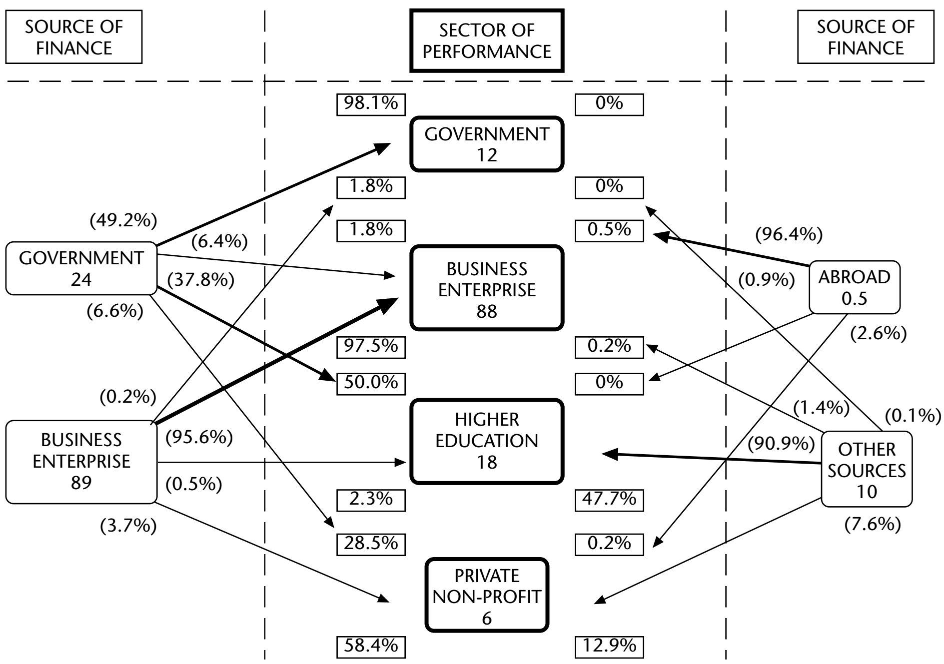
Source: DG Research
Data: OECD – MSTI database (STI, EAS Division) with DG Research provisional estimates
Notes: (1) L data are not included in EU-15 average; A is not included in the calculations of the % shares.
Totals for source of funding and sector of performance do not correspond exactly due to rounding.
Third European Report on S&T Indicators, 2003

Figure 2.1.9b Financing and performance of R&D in the US (€ billion, in current terms), 1999



Source: DG Research
Data: OECD – MSTI database (STI, EAS Division) with DG Research provisional estimates
Notes: Totals for source of funding and sector of performance do not correspond exactly due to rounding. – Data not available.
Third European Report on S&T Indicators, 2003

Figure 2.1.9c Financing and performance of R&D in Japan (€ billion, in current terms), 1999



Source: DG Research
Data: OECD – MSTI database (STI, EAS Division) with DG Research provisional estimates
Note: Totals for source of funding and sector of performance do not correspond exactly due to rounding.
Third European Report on S&T Indicators, 2003

What were the trends prior to the situation in 1999?

Figure 2.1.10 shows the share of each source of total R&D financing and its growth in the period 1995–1999. As can be seen, business sector investment on R&D is the largest component. However, compared to the US and Japan, the EU figure (56%) is much lower. The reverse is true for the second largest financier, the government, which is far more dominant in the EU (34%) than in the US or in Japan. Changes in the various sectors' share of total R&D in the period 1995–1999 reveal an increase in the business sector share and a decline in government share in the US and in the EU. The opposite is true for Japan.

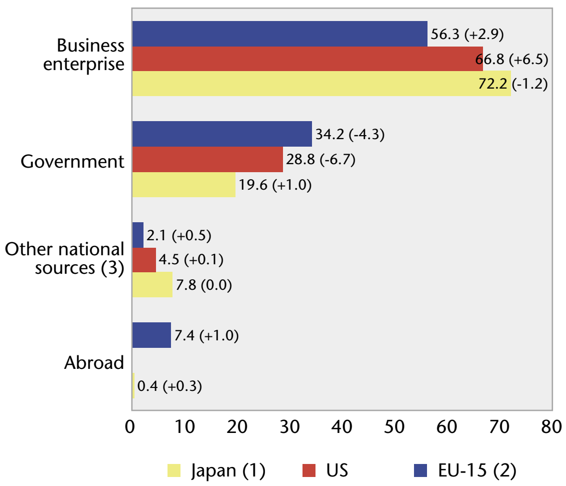
Figures for R&D financing from abroad are not available for the US. Foreign sources constitute an important part of R&D financing in the EU. The latter is largely made up of the Framework Programmes for R&D and structural funds of the European Commission and also certain accounting practices of European multinational companies.

On the basis of figure 2.1.11, one may conclude that the upward trend in R&D activities experienced in the EU, the US and Japan has been mainly due to the increase in investment by the business sector. The clearest case is the US, where the increase in total R&D effort has been far more dependent on private investment than it has been in the EU or Japan. The average annual rate of real growth of R&D financing in the US was over 8% in the period 1995–1999 (from PPS 103 billion to 142 billion). The figure recorded for Japan was a modest 2% (from PPS 51 billion to 58 billion), which clearly lags behind the growth rate of the EU (5% per year; from 62 billion to 76 billion).

Contrary trends may be observed for the government sector: the real growth rates for government-financed R&D for the EU and the US are the lowest of all other sectors (figure 2.1.11). In Japan, growth has been very positive, although, Japan's result may still be interpreted as a converging trend. The stable pattern of high business sector investment and low government involvement in R&D financing has been changing gradually. However, even when taking into account these changes in Japan, the figures confirm that in relative terms, the role of the government sector in R&D financing has not increased significantly (cf. also Section II).

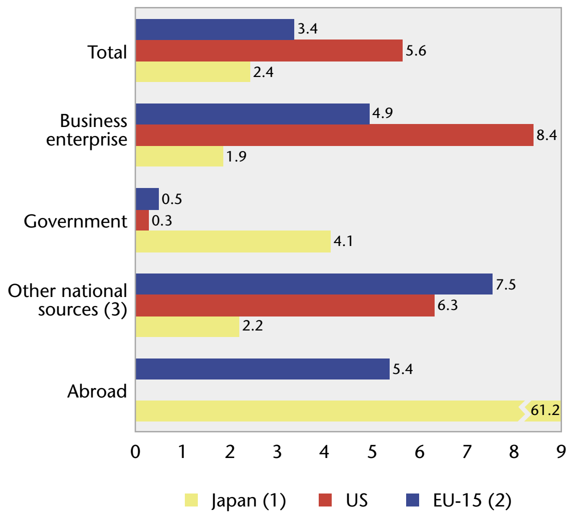
The shares and volumes of "other national sources" – including financing by the private non-profit and higher education sectors – and "sources from abroad" of total R&D financing, are lower than those of the business and the government sectors (figures 2.1.9a, b, c and 2.1.10). As a result of this, high growth rates for "other national sources" and "abroad" (figure 2.1.11) have had neither a substantial impact on the development of total R&D volume, nor have they explained the investment gaps that exist between the economic blocs.

Figure 2.1.10 R&D financing – share (%) of each source of total financing, 1999 Growth of source's share from 1995 to 1999 in brackets (percentage points)



Source: DG Research
Data: OECD – MSTI database (STI, EAS Division) with DG Research provisional estimates
Notes: (1) Growth for Japan refers to 1996–1999. (2) L data are not included in EU-15 average. (3) Other national sources: includes financing by the higher education and private non-profit sectors.
Third European Report on S&T Indicators, 2003

Figure 2.1.11 R&D financing by main sources of funds – average annual real growth (%), 1995–1999



Source: DG Research
Data: OECD – MSTI database (STI, EAS Division) with DG Research provisional estimates
Notes: (1) Growth for Japan refers to 1996–1999. (2) L data are not included in EU-15 average. (3) Other national sources: includes financing by the higher education and private non-profit sectors.
Third European Report on S&T Indicators, 2003

What are the structures of R&D financing and performance in the EU?

In terms of financing, the business sector is the most important sector in most EU Member States. The EU average for the share of the business sector in R&D financing is exceeded by six countries, i.e. the Nordic EU Members, Belgium, Germany and Ireland (figure 2.1.12). The government sector plays an important role in Italy, Greece and Portugal. For several countries, investment from "abroad" plays a fairly significant role. In Greece, for example, investment from "abroad" has an even higher share than the business sector.

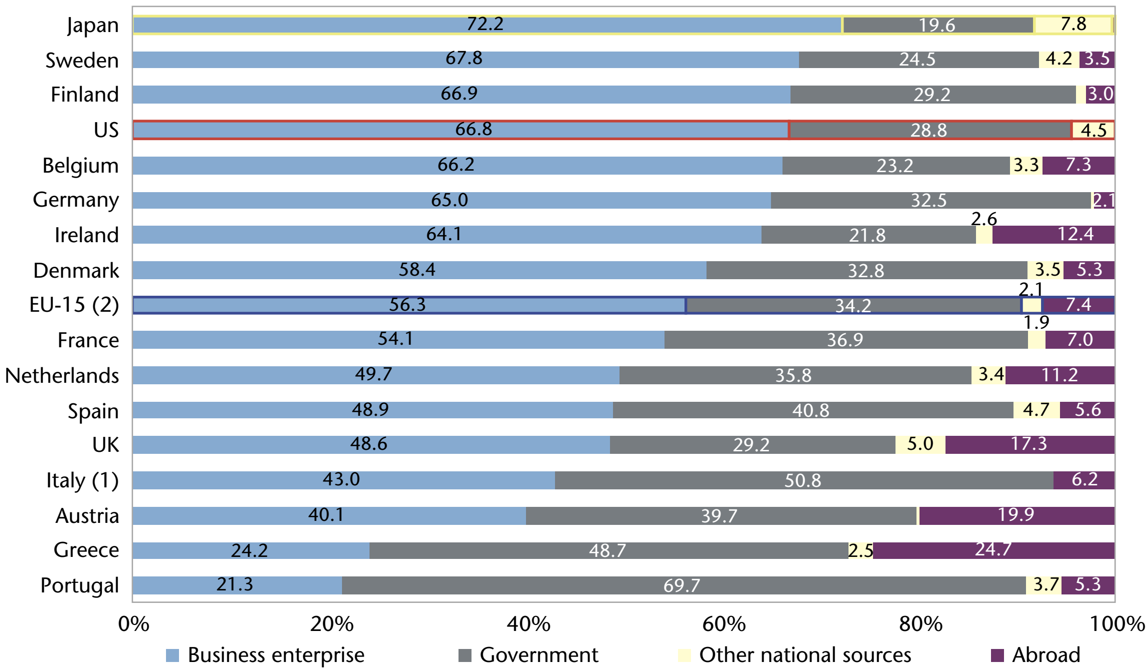
The financing structure depicted in figure 2.1.12 resembles the structure of R&D expenditure shown in figure 2.1.13 (reflecting R&D expenditures broken down by sectors of performance). However, for the UK, the share of businesses in R&D performance and R&D financing differs considerably. While the business sector share of execution of R&D is fairly high (66%) and above the EU average, the sector accounts for only 49% of total R&D financing. In Austria, there is also a big difference in business sector shares of R&D performance (64%) and R&D financing (40%). Apart from Portugal, Greece, Italy, Spain and the Netherlands, the business sector has more than a 60% share of performance in all the other countries. Sweden scores the overall EU highest share, with 75%, the only figure close to that of the US.

It is noteworthy that in the EU, R&D expenditure by the higher education sector (33.5 billion euro, in current terms) accounted for 20% of total R&D expenditure in 2000 (figure 2.1.13). This figure was significantly higher than in the cases of the US and Japan. Compared to the EU, the figure for the US (39 billion euro) was seven percentage points lower, and for Japan (22.4 billion euro), six percentage points lower. Indeed, not a single EU country had such a low higher education sector share of total R&D as the US and Japan, the shares recorded for Germany (16%) and France (17%) being the closest (figure 2.1.13).

In Greece, Portugal and Italy the shares of the higher education sector, at more than 30%, were at an exceptionally high level, with Spain and Austria following closely. In this respect, universities, which are responsible for most R&D done in the higher education sector, play a more important role in the innovation system and in R&D performance in the EU than in the other two economic blocs.

In the EU, R&D conducted by the government sector accounted for less than 14% of total R&D in 2000 (figure 2.1.13). The figures for the US and Japan were even lower, at below 10%. What is notable here is that the government sector was the only sector of R&D performance where the volume of R&D in 2000 (22.4 billion euro) was higher than in the US (21.5 billion euro).

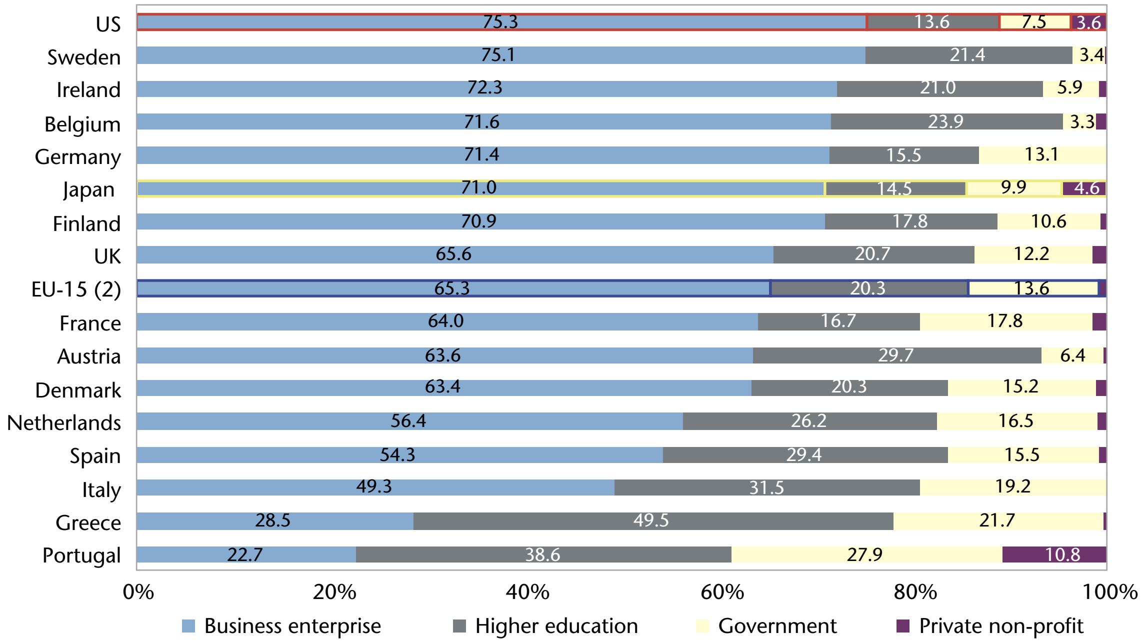
Figure 2.1.12 Financing of R&D – share (%) of each source of total financing, 1999
Countries in decreasing order according to the share of business financing



Source: DG Research
Data: OECD – MSTI database (STI, EAS Division) with DG Research provisional estimates
Notes: (1) Data for Italy refer to 1996. (2) L data are not included in EU-15 average.

Third European Report on S&T Indicators, 2003

Figure 2.1.13 R&D expenditure by main sectors of performance, latest available year (1)
Countries in decreasing order according to the share (%) of the business sector



Source: DG Research
Data: OECD – MSTI database (STI, EAS Division) with DG Research provisional estimates
Notes: (1) A: 1998; F, FIN, UK, JP and EU-15: 2000; D, E: 2001; all other countries: 1999.
(2) EU-15 calculated by DG Research; L not included.

Third European Report on S&T Indicators, 2003

Finally, four categories may be identified, whereby EU countries are clustered on the basis of the structure and patterns of R&D financing and performance:

1) Innovation/R&D system clearly dominated by the business enterprise sector

Both in terms of R&D performance and financing, the share of the business sector of total R&D is above the EU average. While the share of the higher education sector of total R&D expenditure is relatively high, this sector is responsible for most of the public R&D effort. The share of the government sector of total R&D (in terms of both R&D financing and performance) is fairly low, and below the EU average. This group consists of Sweden, Ireland, Belgium, Finland and the UK.

However, in Finland and the UK, R&D expenditure by the higher education and government sectors are more in "balance", or closer to each other, than in the other countries belonging to this group. The UK is an exception in that the share of businesses in total R&D financing is clearly below the EU average. In terms of financing, the pattern in the UK resembles that of groups 2 and 3.

2) Innovation/R&D system on industry–public sector axis

In this group, the business enterprise sector is still relatively dominant in total R&D performance, with a share above 60%, but there is more of a "balance" within public research. The higher education and government sector shares of total R&D expenditure are relatively close to each other. In fact, while the share of the higher education sector of total R&D expenditure is either close to the EU average or below it, the government sector's share of total R&D expenditure is either at the EU average or above it. In terms of the share of businesses in R&D financing, countries differ considerably within this group. The group consists of Germany and France, though Denmark and Austria (with high reservation) could also be included in this category.

Germany's system is a mixture of categories 1 and 2 in the sense that the system there is dominated by the business sector, with a share of total R&D expenditure at 65% (1999), and a share of total R&D financing in excess of 71% (2001).

In relative terms, and compared to the higher education sector, government sector research institutes are very important performers in this category. However, France is the only country where the share of public sector research institutes of total R&D is higher than that of the higher education institutes.

Austria's R&D system is clearly more centred on the industry-higher education axis than in the other countries in this group. The business sector share of R&D funding and performance is also comparatively moderate and below the EU average (resembling that of group 3).

3) Broad-based innovation/R&D system

The shares of total R&D expenditure of the business, higher education and government sectors are closer to each other than in groups 1 and 2. The business sector accounts for less than 50% of R&D financing and less than 60% of total execution of R&D. The shares of the higher education (>26%) and government (>15%) sectors in R&D performance are clearly above the EU average. This group consists of Italy, the Netherlands and Spain.

In Italy, the pattern of R&D financing resembles that of group 4, since the government is the major source of funds (51%).

4) Innovation/R&D system dominated by government-financed R&D and by public research

The share of the business sector, both of R&D performance and R&D financing, is below 30%. Higher education institutions account for over 35% of total R&D performance. Also the share of the government sector is comparatively high, at above 20%. However, at the same time, government is responsible for a bulk of R&D financing. This group consists of Greece and Portugal.

In Portugal, the private non-profit sector is an important actor, with the exceptionally high share of total R&D expenditure of 11%. The Portuguese innovation/R&D system may be considered a broad-based system, as the shares of various sectors of R&D performance tend to be comparatively close to each other.

One of the distinctive features of R&D expenditure in the EU, in comparison to Japan and the US, is the ratio between the public sector (including both the government and the higher education sector) and the private sector. In the EU, public research accounts for a much larger share of R&D than in either Japan or the US. At the turn of the millennium, public research accounted for over one-third of EU-level R&D performance, while the figures for Japan and the US were 24% and 21%, respectively.

The figures for R&D performance by the business enterprise sector reveal a reverse situation. The EU (at 65%) clearly lags behind the figures for the US (75%) and Japan (71%). From the perspective of financing by businesses, the position of the EU is even worse. The business share of total R&D funding in the EU (56%) was almost 11 percentage points lower than the corresponding figure for the US, and 16 percentage points lower than the figure for Japan.

In conclusion, since the mid-1990s, the EU has lagged increasingly behind the US in terms of the absolute volume of R&D, and also in the rate of growth of R&D activities and R&D intensity. Consequently, during the late 1990s, the gaps in financing and performance increased both in absolute and relative terms. The widening of these gaps between the EU and the US has been mostly due to 1) the moderate growth of R&D activities in the main EU economies, and 2) the low volume and slow growth of the financing and execution of research by business enterprises. In addition to these factors, the gap has also increased rapidly in favour of the US because of the very slow development of government-financed R&D in the EU.

In terms of intra-EU development, it is clear that the EU countries converged during the latter part of the 1990s. Moreover, those countries that are "catching up" recorded favourable rates of growth in many indicators describing the development of R&D activities.

ENDNOTES:

[1] *EU: The volume of estimated resources allocated to R&D at the EU level or in individual countries is affected by national characteristics. At individual country level, the cases of Sweden and Finland are distinct. R&D data for Sweden are underestimated (approximately 9% of total R&D expenditure) for a number of reasons. For instance, R&D in the government sector covers central government units only, and full coverage of small- and medium-sized enterprises might add about 7% to expenditure on R&D in the business enterprise sector. In Finland, since 1997, the higher education sector has covered also central university hospitals. Thus, the increase in total R&D expenditure and in expenditures by the higher education sector from 1995 to 1997 is partially explained by this modification, leading to an "additional" increase of total R&D expenditure by 2.2% and expenditure on R&D in the higher education sector by 11.2%. For more details on national specifications and changes in the methods of measuring R&D expenditure in individual EU countries, see Main Science and Technology Indicators publications by the OECD. The same reservations and specifications discussed above apply to all the data and figures for the EU in this chapter.*

[2] *US: R&D data for the US are somewhat underestimated for a number of reasons. 1) The figures exclude most or all capital expenditure. 2) R&D conducted by the government sector covers only federal government activities. State and local government establishments are excluded. 3) In the higher education sector, R&D in the humanities is not included. 4) In the business enterprise sector, the wider coverage of firms, especially in the services sector, affects the magnitude of R&D resources. 5) According to the NSF (2000), "There are no data on foreign sources of U.S. R&D performance. The [following] figures […] to approximate foreign involvement are derived from the estimated percentage of U.S. industrial performance undertaken by majority-owned (i.e., 50% or more) non-bank U.S. affiliates of foreign companies. [A]pproximately 8% of funds spent on industry R&D performance in 1996 are estimated to have come from majority-owned affiliates of foreign firms investing domestically. This amount was considerably more than the 3% funding share provided by foreign firms in 1980." For more details on the data for the US, see OECD (2002a). The reservations and specifications discussed above apply to all the data and figures for the US presented in this chapter.*

Section II The role of government and the public sector in R&D

1. New role, rationale and challenges for government

Scientific and technological knowledge and its wide dissemination play a vital role in the knowledge-based economy and in its performance. Public sector research provides scientific and technological knowledge that should be disseminated and utilised widely in the economy. The contribution of public research to the economy, however, is not only through the direct provision of immediately applicable results, but also through the diffusion and adoption of skills and techniques, and through professional networks and other forms of communication channels created by academic research. The priority of government-financed research in this sphere is to enrich the knowledge base by supporting R&D carried out at universities and research institutes and in business enterprises, by encouraging exploration of new and challenging scientific and technological areas, and by creating suitable conditions for training future employees.

In considering the role of government and the public sector in R&D financing and performance, it should be borne in mind that government also has tasks and objectives based on non-economic rationales. Governments are responsible for acting as monitor and controller in matters concerning research which are in the interest of society at large, and which may affect social welfare, quality of life and physical environment. In addition, it is important for governments to promote scientific and education culture, and to make it possible for people to become more familiar with science and technology. In order to increase society's confidence in scientific research and technological development, governments foster dialogue with citizens and between science and society (e.g. European Commission, 2002b).

Due to developments in the economy – such as the increased role of knowledge as a factor of production, the closer interplay between economic actors, and the various effects of globalisation on RTD – the role of research has taken on new political, economic and technology related significance in the EU. Public authorities are paying more attention to R&D, as well as to increasing demands for education, the role of life-long learning, the skills profile of the labour force and, in general terms, to human resources in innovation.

Traditionally, the primary economic objective of science, technology and innovation policies and the rationale for government involvement in R&D has been – in addition to fulfilling the public health and defence related needs of society – to rectify market failures and imperfections. This issue is tackled with increasing public R&D funding in those sectors of the economy that experience a lower level of R&D activity than is socially desirable. Thus, the public sector has funded research in order to redress market imbalances and to complement market mechanisms.

Market failures are typically twofold (Pottelsberghe et al. 2001). First, imperfect appropriability – or the diffusion of knowledge beyond the control of the inventor – implies that the private rate of return on R&D is lower than its social return. Second, the high risks involved in R&D discourage firms from engaging in such activities. This is particularly detrimental to small firms, which experience great difficulty in obtaining access to funding. For both reasons, the amount invested by firms in R&D in a competitive framework is likely to be below the socially optimal level (Arrow 1962).

In recent years, policy-makers have come to recognise the limitations of the market failure rationale. Consequently, this rationale has been supplemented by the systems failure perspective. Smith (2000) articulates this in terms of four manifestations:

- failure in infrastructure provision;
- failure to achieve transitions to new technological regimes;
- failure from lock-in to existing technological paradigms;
- institutional failure (regulations, standards and policy culture).

In systems failure terms, the new role of the public sector becomes visible in efforts to promote multilateral co-operation between organisations within national and regional systems of innovation. Governments are now focusing on finding ways of avoiding inefficiencies resulting from, for example, systemic failures, mismatches and incompatibilities within the innovation systems, and lack of co-operative relations and mutual interests between the various players.

In an effort to address systemic failures in innovation systems, governments are paying more attention to mechanisms that are crucial to the transfer of knowledge and know-how. In other words, the question is how to enhance the knowledge distribution capacity of the innovation systems and economies as a whole. However, there is no single clear-cut set of measures, for instance, that would help governments tackle the problem of inefficient transfer mechanisms. Governments should rather have a flexible and evolving tool-kit of measures that would enable them, amongst others, to:

- support and promote networking and active interplay between companies and R&D organisations (e.g. RTD projects, cluster programmes);
- develop technology transfer organisations (e.g. regional centres set up for the promotion of technology, innovation ombudsmen, university business incubators);
- update the legislation and regulatory frameworks that help to generate spin-off firms, to facilitate public-private partnerships, and to intensify economy-wide exploitation of research results (e.g. intellectual property rights).

Thus, government's contribution involves much more than just funding of research. It also comprises financial aid in the form of grants and tax relief, contracts and procurement, launching programmes aimed at knowledge distribution, and support to upgrade infrastructure for science, technology and innovation. In addition, it should be borne in mind that policy measures carried out by governments to enhance R&D activities must also be in line with measures introduced in other sectors, such as economic, employment, trade, industrial, regional and social policy. This is a clear indication that effective co-ordination between various policy tools as well as between various policy sectors would improve their overall effect on R&D (e.g. PREST et al. 2002).

The views above hold good at individual country level as well as at the level of the EU as a whole. However, the European system of public R&D-related policies can be very complex, and the mechanisms used across the EU countries very diverse. Nevertheless, policy implications tend to converge towards recommending better and more coherent use of available public instruments and resources, as highlighted in the European Commission Report, “Towards a European Research Area” (see European Commission, 2000). Therefore, the exchange and spread of good practices should be encouraged.

In summary, governments should aim at creating suitable conditions for R&D and innovation, and removing obstacles to the broader introduction, dissemination and application of knowledge and technology. Traditional government funding – although awarded more and more on a competitive basis – is still important for non-market based activities, such as the scientific research conducted by universities and public research institutes. In addition, since European private venture capital markets are not sufficiently developed to account for the risks faced by high-tech seed and start-up firms, government financing of new R&D intensive activities is appropriate and in great demand.

2. Trends in R&D expenditure financed by government

This section first compares the development of R&D financing by government in the EU, the US and Japan. Secondly, it focuses on trends in government-financed R&D in individual EU countries. The main topics are the absolute and relative volume of government-financed R&D, the distribution of government support for R&D, and the share of government financing of total R&D expenditure. These themes are also discussed in Section I, but on a more general level. The aim of this section is to give more detailed information of government-financed R&D expenditure and to deepen the analysis of the role of governments in R&D funding.

Government-financed R&D: the large differences between world regions remain unchanged

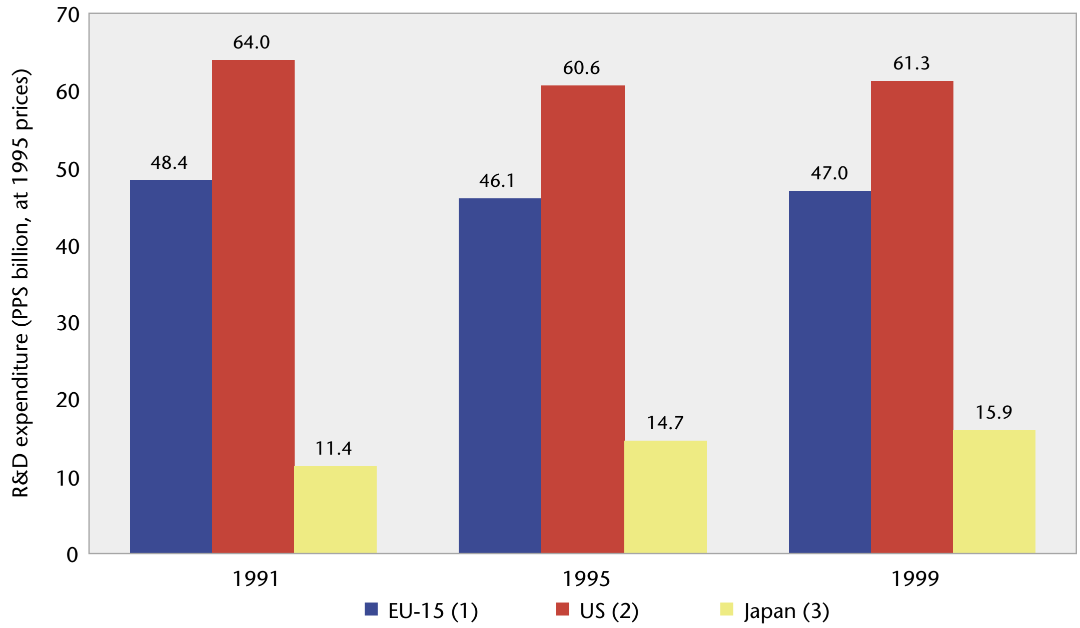
The structure and trends of government-financed R&D reveal fairly large differences between the three major economic blocs on the one hand, and across the EU countries on the other. The EU governments clearly invest less in R&D in absolute terms than the US government. A comparison of the volume of R&D expenditure in real terms (PPS, at 1995 prices) between the EU and the US, and between the EU and Japan, in the 1990s is shown in figure 2.2.1. In 1999, EU governments invested PPS 47 billion (53 billion euro in current terms) in R&D. The figure for the US was PPS 61.3 billion (66 billion euro), and for Japan PPS 15.9 billion (24.3 billion euro). Thus, the investment gap between the US and the EU was over PPS 14 billion in favour of the US, and between the EU and Japan some PPS 31 billion in favour of the EU (figure 2.2.2).

The R&D investment gap between the US and the EU remained more or less at the same level for the whole decade, i.e. within the range of PPS 14–16 billion. The EU governments were not very successful in decreasing the gap between themselves and the US in the 1990s, even though the EU governments have not only launched new political measures to increase their support for R&D, but also promoted co-operation between companies, universities, and public sector research institutes. As far as direct R&D funding and narrowing the gap with the US are concerned, it seems that – owing, for example, to problems in the public economy – EU governments have not been able to make substantial increases in R&D funding. In addition, it seems to have been difficult for governments – as a prerequisite to injecting new money into the R&D system – to raise the status of R&D and to improve the ranking of R&D in the priority list of public investment.

Consequently, the role of the government sector as a performer of R&D has diminished recently compared to those of the business enterprise and higher education sectors (Sections III and IV). The future does not appear to be much brighter for the EU in this respect either, since the US has decided to increase significantly its federal support of R&D over the next few years. According to the Battelle R&D funding forecast (2002), “while the increases in total R&D [in the US] had been influenced almost entirely by industrial funding in recent earlier years, the increase for 2002 will be driven primarily by federal funding.” For instance, the total R&D budget of the federal government will be almost 13% higher in 2002 than in the previous year.

A further somewhat disquieting trend is the weakening position of the EU in relation to Japan. A comparison of the volume of R&D financing shows that Japan managed almost continuously throughout the decade to narrow the R&D investment gap between itself and the EU, with the smallest differences in the 1990s occurring in 1998 and 1999. During the 1991–1999 period, the gap between the EU and Japan decreased by PPS 6 billion. Thus, compared to the EU and the US, the position of Japan with regard to government contribution to R&D and support to enhance the development of the knowledge-based economy became slightly stronger during the 1990s.

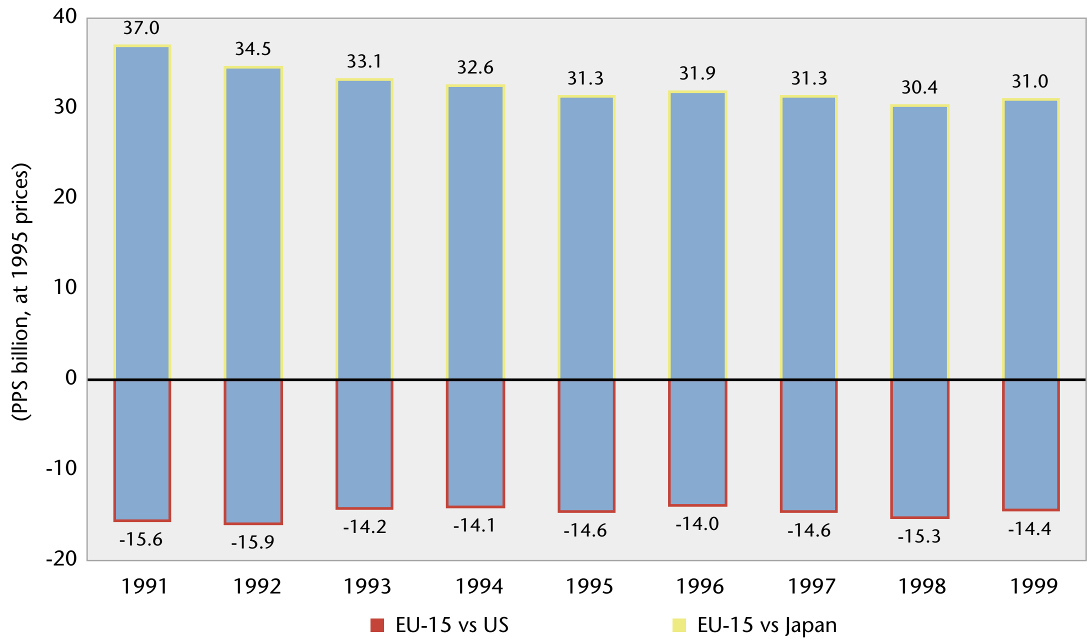
Figure 2.2.1 Government-financed expenditure on R&D in real terms in the 1990s (PPS billion, at 1995 prices)



Source: DG Research
Data: OECD; DG Research
Notes: (1) L data are not included in EU-15 average. (2) US: excludes most or all capital expenditure.
(3) JP: break in series (1996) reduces the comparability of the results.

Third European Report on S&T Indicators, 2003

Figure 2.2.2 Government-financed R&D – investment gaps between EU-15 (1) and the US (2) and between EU-15 and Japan (3) in the 1990s



Source: DG Research
Data: OECD; DG Research
Notes: (1) L data are not included in EU-15 average. (2) US: excludes most or all capital expenditure.
(3) JP: break in series (1996) reduces the comparability of the results.

Third European Report on S&T Indicators, 2003

There are certain reasons behind the Japanese government's increased contribution to R&D activities. In the mid-1990s, Japan initiated numerous new measures in its first Science and Technology Basic Plan (1996–2000) in order to encourage investment. In March 2001, the Japanese government decided on the basic lines of the second-term Basic Plan (2002–2006). This plan directed attention to the measures that had already been launched in the first plan. For one thing, it was decided to increase competitive funds, subject to the selective and efficient allocation of resources. There was also more emphasis on the development of relations between industry, academia and the government (MEXT, 2001; see also OECD, 2000; Polt et al., 2002). In addition to the Basic Plan, the Ministry of the Economy, Trade and Industry has recently brought in measures to reform the innovation system, and to enhance the (joint university-corporate) commercialisation of research, for instance (METI, 2002). The Ministry also invests in the four priority fields of research (life sciences, information technology, environmental sciences, and nanotechnology and materials), all of which offer high potential for commercialisation.

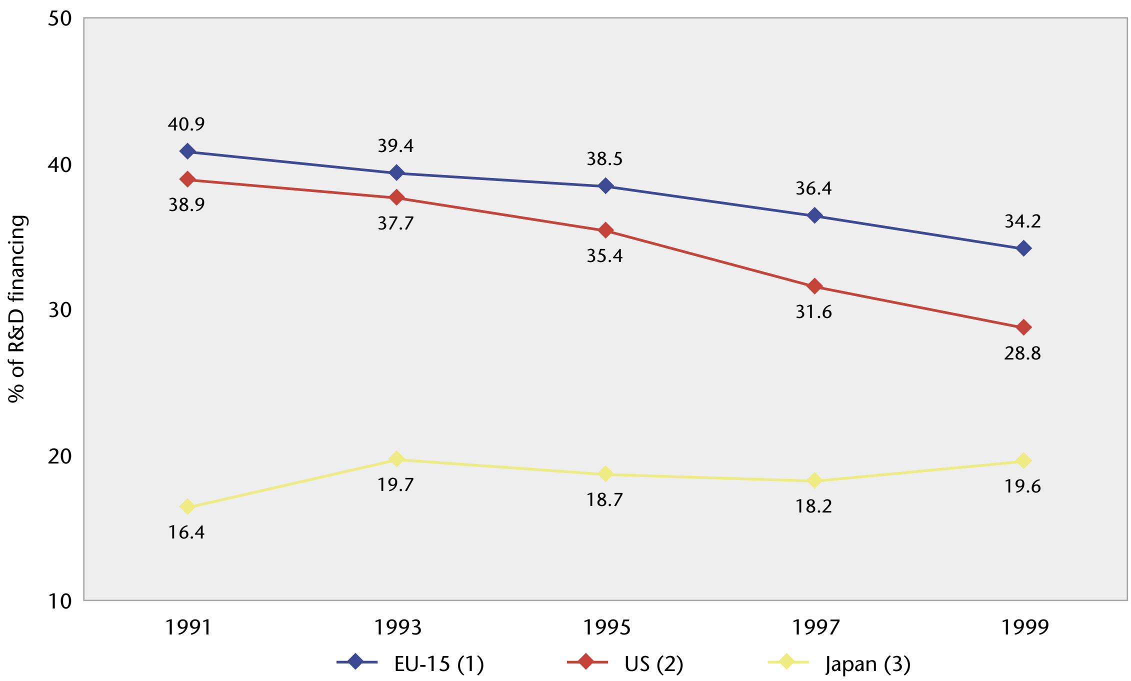
Figure 2.2.3 shows the share of government in total R&D financing. The public sector in the EU accounts for a larger proportion of R&D financing than in the US or Japan. In 1991, the public sector accounted for 41% of total R&D financing in the EU, while the figure for Japan was 16%, and the US 39%. During the 1990s, the situation in the EU and the US changed considerably. In 1999, the public sector accounted for some 34% of total R&D financing in the EU. The figures for Japan and for the US were 20% and 29%, respectively. Thus, while the public sector share of total R&D financing decreased significantly in the EU (by 7 percentage points), the decline was even more substantial in the US, where the public sector share decreased by 10 percentage points during the decade. In the periods 1991–1993 and since 1997, the trend in Japan was the opposite to that of the EU and the US.

Figures in the US were fairly close to those of the EU throughout the 1990s. However, government's share of total R&D financing in 1999 represented the largest distinction between the EU and the US in this decade: the difference increased from two percentage points in 1991 to over five percentage points in 1999 (figure 2.2.3).

While government's share has decreased continuously in the EU and the US, the role of other sources of financing – especially that of the business sector – has increased significantly (figure 2.1.10). In the US, this shift has been more marked than in the EU.

In 1999, government financing of R&D in relation to GDP was the highest in the US (0.8%) (figure 2.2.4). The figures for the EU and Japan were 0.7% and 0.6%, respectively. In

Figure 2.2.3 Share (%) of government in total R&D financing in the 1990s



Source: DG Research
Data: OECD; DG Research
Notes: (1) L data are not included in EU-15 average. (2) US: excludes most or all capital expenditure.
(3) JP: 1996 instead of 1995 (due to a break in series).

Third European Report on S&T Indicators, 2003

Japan, throughout the 1990s the financing of expenditure on R&D by government, as a percentage of GDP, was at a lower level than in the US and the EU. However, the upward trend in Japan was the opposite of trends in the other two economic blocs.

It must be stressed that the three economic blocs converged during the 1990s, both in terms of the percentage of total R&D financed by government, and government-financed R&D as a percentage of GDP. On the one hand, regarding the share of total R&D financing, the difference between the EU and Japan in 1991 was almost 25 percentage points (41% vs. 16%). In 1999, the difference was reduced to less than 15 percentage points (34% vs. 20%). On the other hand, in the case of government-financed R&D as a percentage of GDP, the difference between the US and Japan in 1991 was some 0.6 percentage points (1.05% vs. 0.45%). In 1999, the gap was less than 0.2 percentage points (0.76% vs. 0.58%).

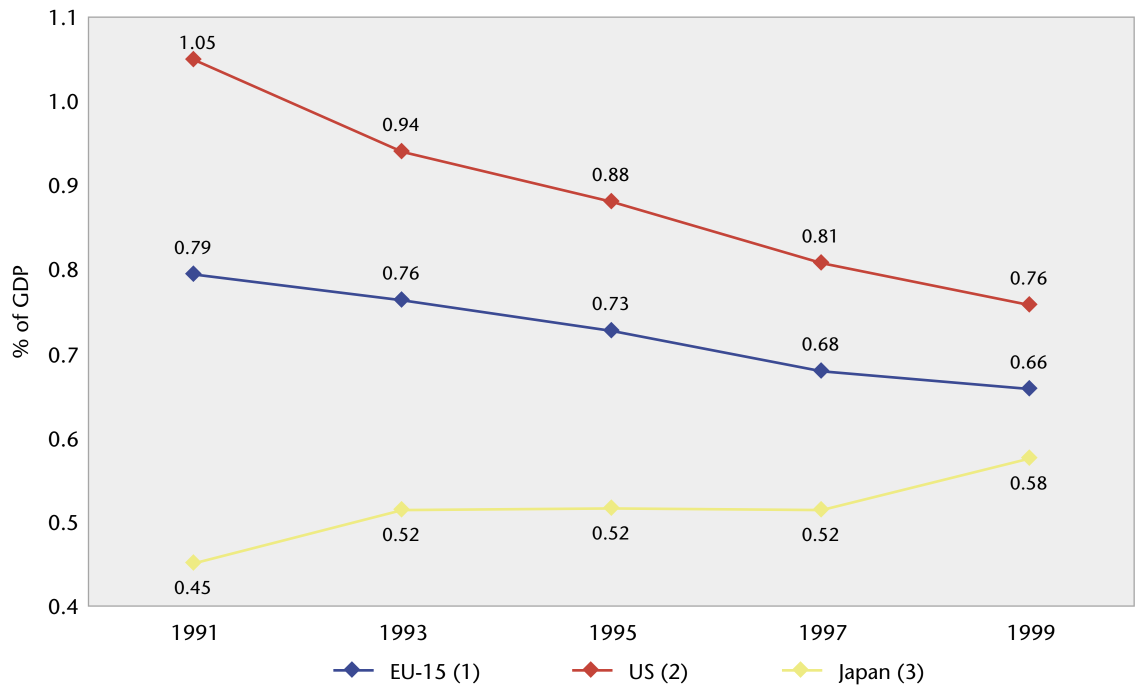
In the same way as in Section I (see R&D intensity forecasts), likely scenarios for the future ratio between government R&D financing and GDP will be examined next (figure 2.2.5). Calculations of the volume of government R&D investment in relation to the development of national income are based on a range of growth rates from the 1990s. The projections cover the period 2000–2010.

Figure 2.2.5 shows two scenarios for the possible evolution of total R&D expenditure financed by government for the EU, the US and Japan. Japan is the only country where the government seems to be assuming an increasingly important role in R&D financing. In both the US and the EU, the government sector appears set to decrease its share of financing of total R&D, unless there are major changes in policy or in the investment behaviour of financiers.

The importance of this potential decrease should be viewed in the broader context of the eventual level of R&D expenditure and the structure of its financing. It is important that levels of government-funded R&D expenditure should be maintained, as they are a material component of total R&D, and also provide important multiplier effects by stimulating further business-funded research. However, since this indicator is a share of the total, it should be borne in mind that, while the total amount of government funding might increase, it would still reflect as a decreasing share if the total funding of the business sector increases at a faster rate.

On the other hand, considering the target agreed by the Barcelona European Council to increase R&D spending in the EU to 3% of GDP by the year 2010, figure 2.2.5 carries an alarming message. According to the target set in the Barcelona summit, two thirds of R&D spending should be funded by the business sector, while a third of total spending

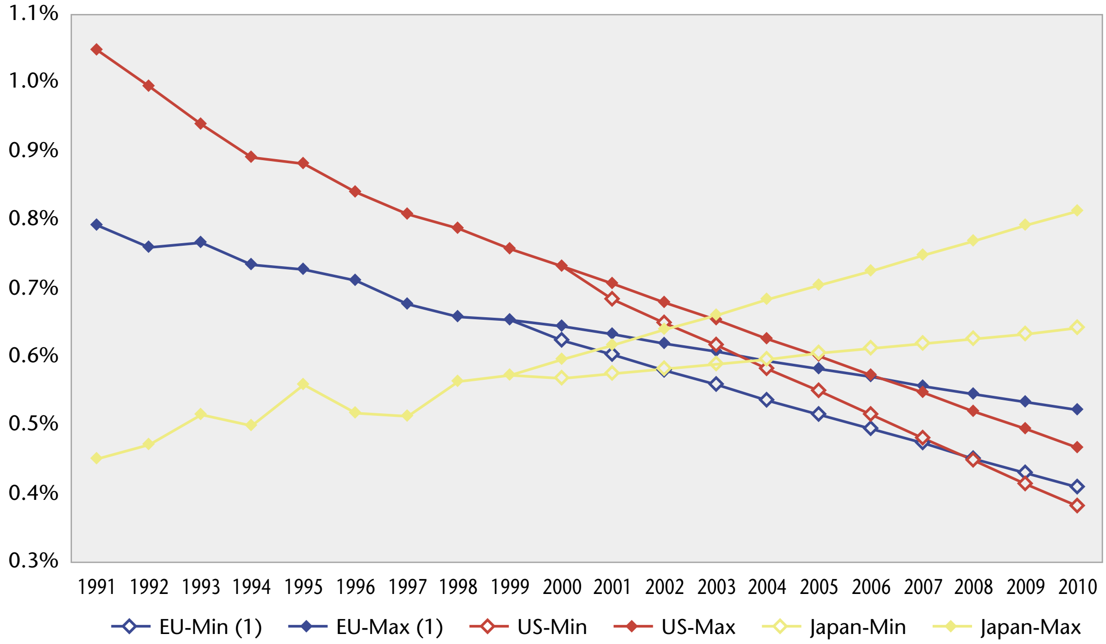
Figure 2.2.4 Government-financed R&D as a % of GDP in the 1990s



Source: DG Research
Data: OECD; DG Research
Notes: (1) L data are not included in EU-15 average. (2) US: excludes most or all capital expenditure.
(3) JP: 1996 instead of 1995.

Third European Report on S&T Indicators, 2003

Figure 2.2.5 Government-financed R&D in relation to GDP – forecast from 2000 to 2010 with minimum and maximum projections, and with the presumption that no major changes in policy or in the R&D environment occur



Source: DG Research
Data: Basic data: OECD, with DG Research provisional estimates. Projections: DG Research
Note: (1) L data are not included in EU-15 average.

Third European Report on S&T Indicators, 2003

should be funded from other sources. In practical terms, the bulk of the remaining third of funds – i.e. R&D investments of approximately 1% of GDP by the year 2010 – should be contributed by the public sector. If the downward trend of the 1990s continues, government-financed R&D in relation to GDP will be between 0.4% ("worst-case scenario") and slightly over 0.5% ("best-case scenario"). Thus, the results indicate that, if the EU is to approach the 3% target by 2010, governments should also increase their R&D financing.

The share of government-financed R&D in total R&D funding is in decline in the EU

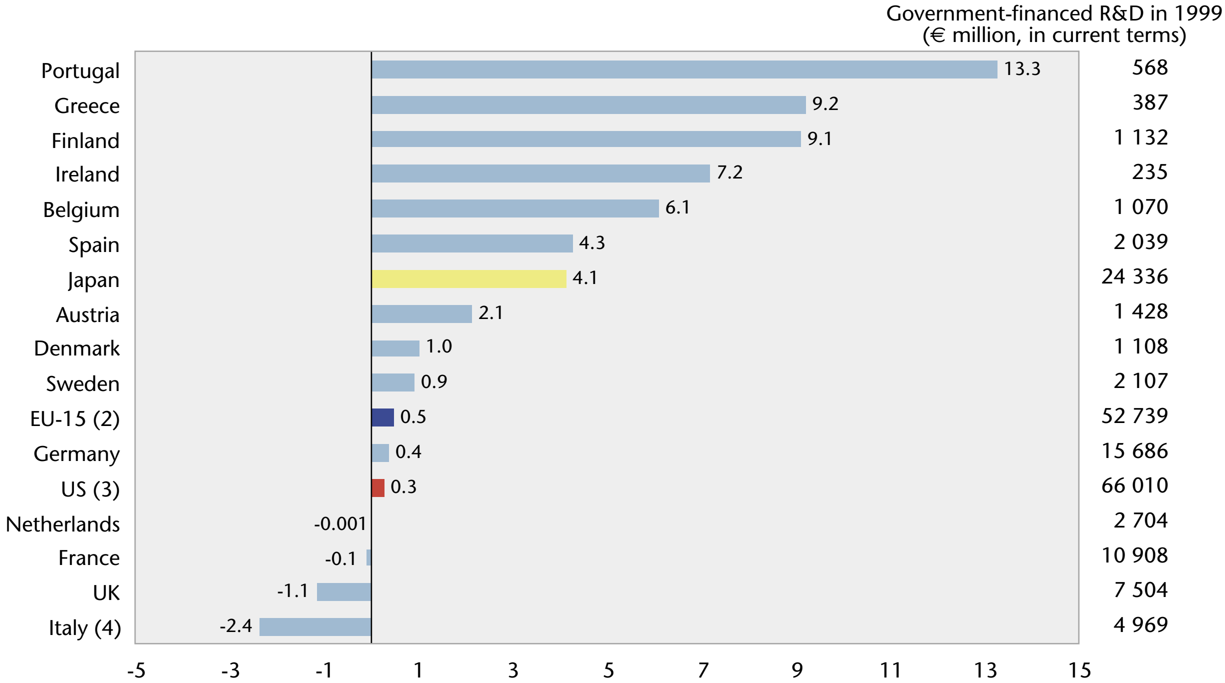
The average annual real growth of government-financed R&D for individual countries in 1995–1999 is shown in figure 2.2.6. Government financing increased most notably in smaller economies and in countries catching up from a low level of investment, as is the case with many indicators (figures 2.1.3, 2.1.4 and 2.1.8). The former group consists of countries such as Austria, Belgium and Finland, where government invested less than 1.5 billion euro in R&D in 1999. The latter group includes Portugal and Greece. The growth rates for Portugal (13% per year), Greece (9%), Finland (9%), Ireland (7%) and Belgium (6%) stand out in the EU group.

Compared to the figure for Japan (4%) over the 1996–1999 period, the relative rate of growth in government-financed R&D was slower in 8 of the 14 EU countries for which data are available. This group includes all the major EU economies. Consequently, the growth rate recorded for Japan was substantially higher than the EU average and the US, where it was barely above zero.

The comparatively poor EU growth rate was due largely to the UK and France[2], which together accounted for over a third of EU-level government-financed R&D in 1999, recording negative growth rates in the late 1990s. In Germany, which is the biggest public R&D investor in the EU, accounting for 30% of total EU government financing of R&D with 15.7 billion euro in 1999, the average annual real growth in public R&D investment was at the relatively low level of 0.4%.

[2] *Italy also belongs to this group of countries. However, a break in series (1997) reduces the comparability of the results for Italy. The same problem is experienced with regard to France. When breaks in series are not taken into account, government-financed R&D in the period 1995–1999 increased from PPS 5.5 billion to 5.9 billion in Italy, and decreased from PPS 10.5 billion to 9.6 billion in France.*

Figure 2.2.6 Government-financed R&D – average annual real growth (%), 1995–1999 (1)



Source: DG Research
Data: OECD; DG Research
Notes: (1) I: 1995–96; JP: 1996–97; F: 1997–99. (2) L data are not included in EU-15 average.
(3) US: excludes most or all capital expenditure. (4) I: 1996

Third European Report on S&T Indicators, 2003

Government-financed R&D as a percentage of total funding in 1999, and the change in government share of R&D funding over the 1995–1999 period are shown in figures 2.2.7 and 2.2.8. The government share of total funding in 1999 was the highest in Portugal (70%), followed by Italy (51%, in 1996), Greece (49%), and Spain (41%), i.e. in the catching-up countries representing a low level of R&D intensity. In Austria, France and the Netherlands, the share of government in total R&D funding was also at a fairly high level and above the EU average, in the range of 36–40%.

The share was lowest in Japan, where the government was responsible for less than 20% of R&D financing. The only EU countries close to Japan's figure were Ireland, Belgium and Sweden. The government share was also below 30% in the UK, Finland and the US.

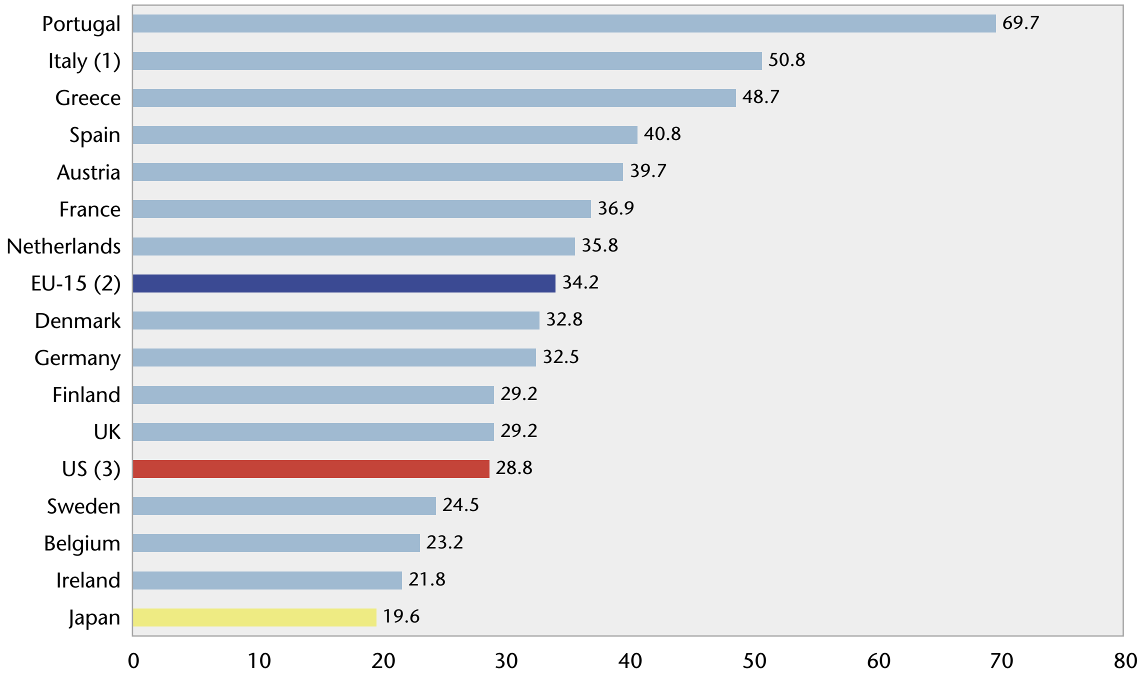
In the late 1990s, the share of government R&D funding declined in all the countries under review, except Portugal, Ireland and Belgium. The share dropped most notably in Austria (–8 percentage points), Denmark (–7), the United States (–7) and the Netherlands (–6). In Finland and Greece as well, the government share of total R&D financing decreased by five percentage points or more between 1995–1999.

The negative growth in the government share indicates its diminishing role in the R&D system as a whole. This has occurred simultaneously with the favourable development in the business sector, other national sources (funding by private non-profit and higher education institutes), and foreign sources of research financing. The decreasing government share also indicates that the rate of growth in government-financed R&D has been slower than that of the other sources/sectors of funding.

Recent patterns of the level of government-financed R&D as a percentage of GDP differ significantly across the EU countries. The highest share in 1999 was recorded for Finland (0.94%) and Sweden (0.93%), followed at some distance by France and Germany (figure 2.2.9). These four countries were the only EU members that recorded higher GDP shares than the US. At the opposite end of the spectrum, Ireland, Greece and Spain represent the lowest GDP shares of government financing, with figures of below 0.4%.

In most of the EU countries, government-financed R&D as a percentage of GDP declined during the latter part of the 1990s (figure 2.2.10). Among the group of EU countries investing most in R&D in relative terms, Finland is the only country where government-financed R&D as a percentage of GDP increased during the period 1995–1999. This, together with favourable growth in the volume of government's R&D financing, was the result of a deliberate policy to increase government expenditure on R&D by 25% in the period (see Science and Technology Policy Council of Finland, 1996). In the EU group, the figure was also positive for Portugal, Greece and Spain, i.e. countries with low levels of R&D intensity, and Belgium. In other countries, the GDP share of government R&D financing has declined. Negative growth has been most apparent in the US (–0.12 percentage points), followed by the Netherlands and the UK.

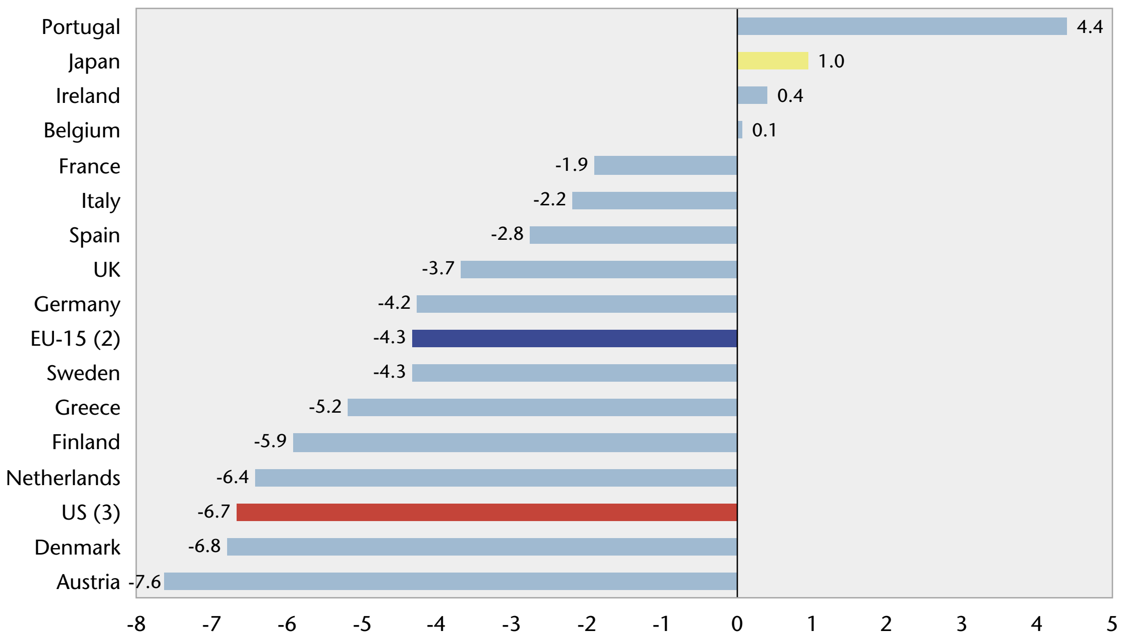
Figure 2.2.7 Government-financed R&D – % of total R&D funding, 1999



Source: DG Research
Data: OECD; DG Research
Notes: (1) I: 1996. (2) L data are not included in EU-15 average. (3) US: excludes most or all capital expenditure.

Third European Report on S&T Indicators, 2003

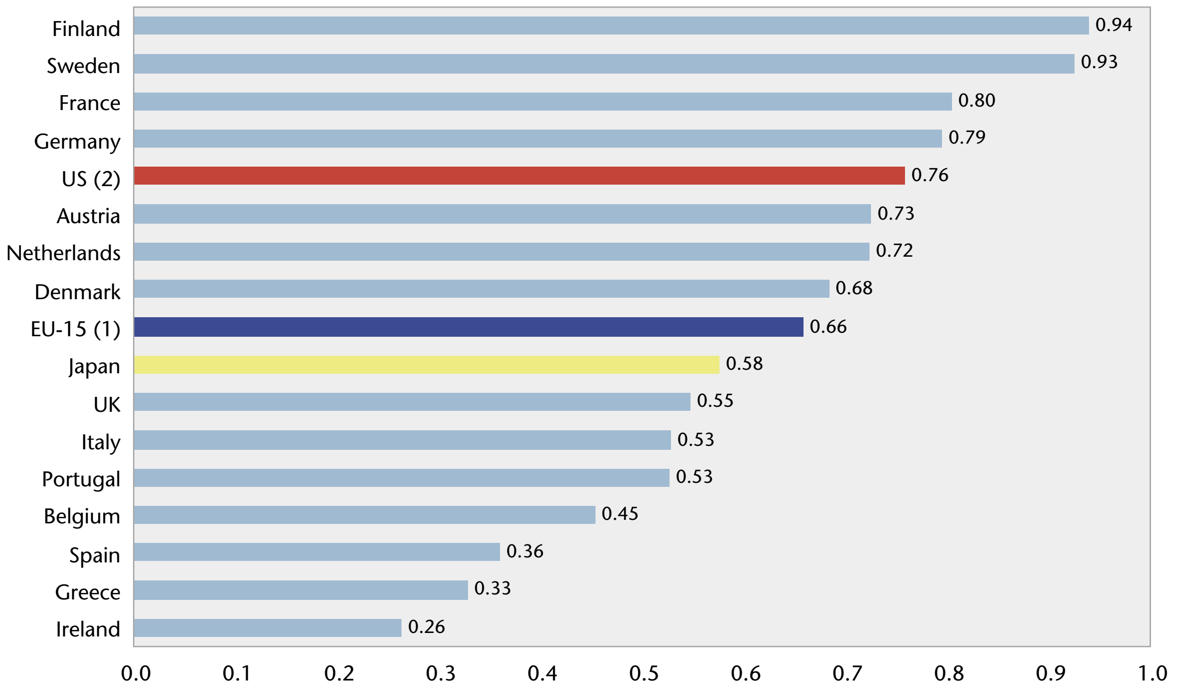
Figure 2.2.8 Government-financed R&D – change in the share (percentage points) of government of total R&D funding, from 1995 to 1999 (1)



Source: DG Research
Data: OECD; DG Research
Notes: (1) I: 1995–1996; JP: 1996–1999; F: 1997–1999. (2) L data are not included in EU-15 average.
(3) US: excludes most or all capital expenditure.

Third European Report on S&T Indicators, 2003

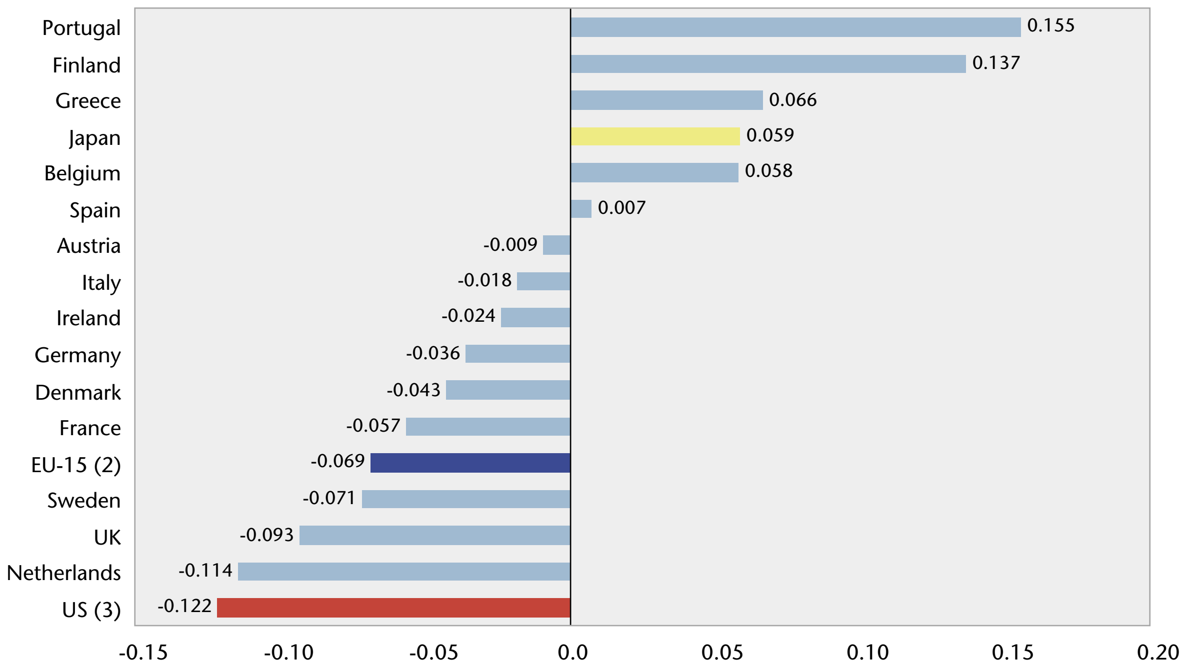
Figure 2.2.9 Government-financed R&D as a % of GDP, 1999



Source: DG Research
Data: OECD; DG Research
Notes: (1) L data are not included in EU-15 average. (2) US: excludes most or all capital expenditure.

Third European Report on S&T Indicators, 2003

Figure 2.2.10 Government-financed R&D as a % of GDP – change in the share (percentage points) of GDP from 1995 to 1999 (1)



Source: DG Research
Data: OECD; DG Research
Notes: (1) I: 1995–1996; JP: 1996–1999; F: 1997–1999. (2) L data are not included in EU-15 average.
(3) US: excludes most or all capital expenditure.

Third European Report on S&T Indicators, 2003

Section III Government R&D performance

1. The changing role of government research centres

Research centres form an integral part of systems of innovation. In recent years there have been extensive attempts to understand their operation and contribution to both knowledge accumulation and economic competitiveness (Bozeman & Crow, 1998). It has been argued that research centres and laboratories are to science what firms are to the economy: the units of production (Larédo et al., 1992).

Laboratories outside the higher education sector usually have a mission beyond the performance of basic research. While some such institutions were founded early in the 20th century, or even before, there was a massive expansion of public sector research establishments in the second half of that century. Missions such as the development of civil nuclear power were added to the existing portfolio of support for government policy in sectors such as agriculture, construction, health and defence and for industry through the provision of technological support or infrastructure such as measurement standards.

More recently, in the past 20 years or so, the environment for research centres has changed, as has their position within that environment. In many European countries (and elsewhere in the developed world), different notions of what constitutes the role of public research, new government research priorities, and pressure on public funding have had a major impact in re-shaping the system. While trends such as an increased requirement to generate commercial income and, more generally, to emulate business practices, have been common to all, a wide variety of outcomes have emerged in Europe.

The most radical changes are seen where institutions have left the public sector altogether as a result of privatisation. Changes in ownership or governance have not necessarily signified a withdrawal of government from the mission in question. Privatisation has usually been accompanied by the continuation of government sponsorship on a contractual basis.

A series of challenges currently faces the sector (Cox et al. 2001):

- A changing relationship with other actors in the innovation system, including a convergence in function with universities;
- Renewal of infrastructure and human resources, including both the challenge of renewing equipment and how to construct valid research careers;
- The challenges of commercialisation of research, including a trade-off between the provision of knowledge to existing firms and starting new commercial ventures;
- The development of adequate systems to measure and evaluate the processes and effects of research;
- Testing the limits of the market model for organising research in what may still be regarded as a social experiment.

Relatively speaking, this sector has received less attention than the business and higher education sectors. One barrier to understanding is the wide range of structures existing in Europe, which vary by country, nature of mission and type of research. Furthermore, this sector is often less visible in public indicators (such as the number of scientific publications and patents) because the principal outputs of its scientific and technological activities are consumed by government itself in terms of advice, or by private clients for technological consultancy.[3]

This section investigates more closely the resources devoted to R&D by government sector research institutes. It will discuss the latest trends and levels of government sector R&D in the EU countries, the US and Japan, and compare the developments that have taken place in the three economic blocs. It reviews the evolution of research centres, and issues such as their orientation in terms of the types of activities they undertake. In addition, it examines the ownership, governance and reform of such centres in the 1990s.

2. Government sector expenditure on R&D

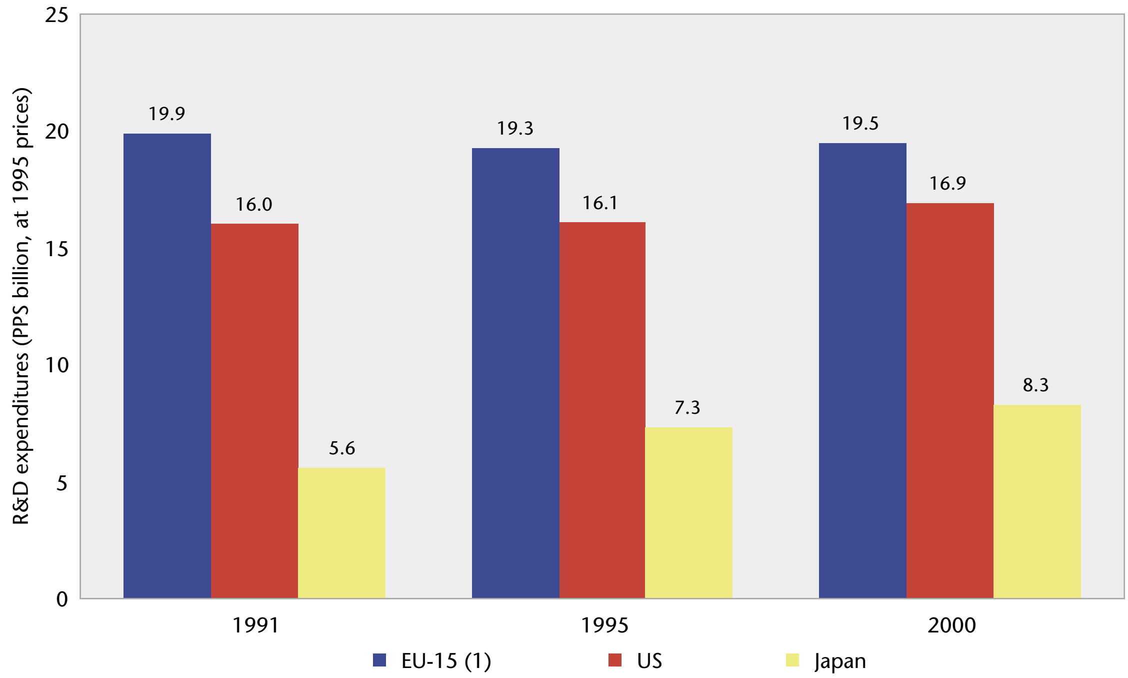
Conflicting trends in government sector R&D in different world regions

The real volume of intramural government expenditure on R&D (GOVERD), and GOVERD as a percentage of GDP in the EU, the US and Japan for the period 1991–2000 are shown in figures 2.3.1 and 2.3.2. In 2000, governments in the EU spent a larger amount on intramural research (PPS 19.5 billion, at 1995 prices; 22.4 billion euro, in current terms) than the US (PPS 16.9 billion; 21.5 billion euro) or Japan (PPS 8.3 billion; 15.2 billion euro).

In real volume terms, the three economic blocs experienced different trends over the decade. Japan is the only region that showed an increasing trend as its laboratories benefited from science and technology policy initiatives over the decade. While R&D expenditure for the US was largely stable over the period 1991–2000, the real volume recorded for the EU showed a slight downward trend (by PPS 323 million). Despite changes in government sector R&D not having been that remarkable in general terms, the R&D performance gap between the EU and the US diminished by PPS 1.2 billion in the period 1991–2000. That is to say, the gap diminished from PPS 3.8 billion in 1991 to 2.6 billion in 2000 in favour of the EU.

[3] *The paragraphs above are based on texts prepared by the Eurolabs project (see European Commission 2002a).*

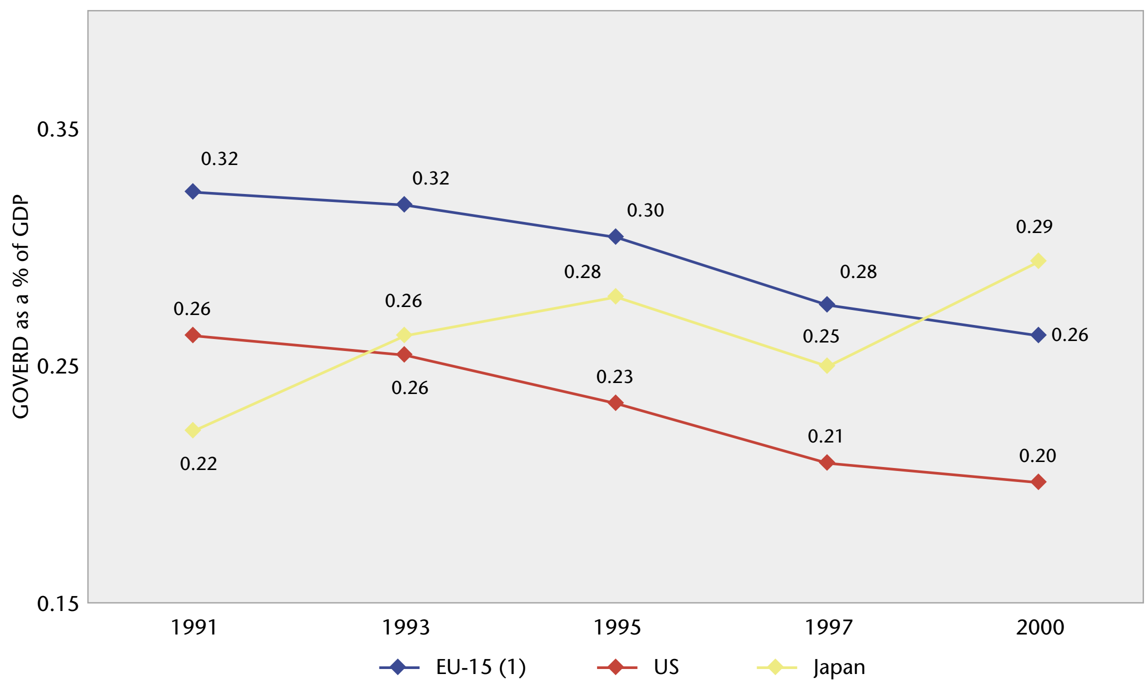
Figure 2.3.1 Government sector R&D expenditure in real terms, 1991, 1995 and 2000 (PPS billion, at 1995 prices)



Source: DG Research
Data: OECD, with DG Research provisional estimates
Note: (1) L data are not included in EU-15 average.

Third European Report on S&T Indicators, 2003

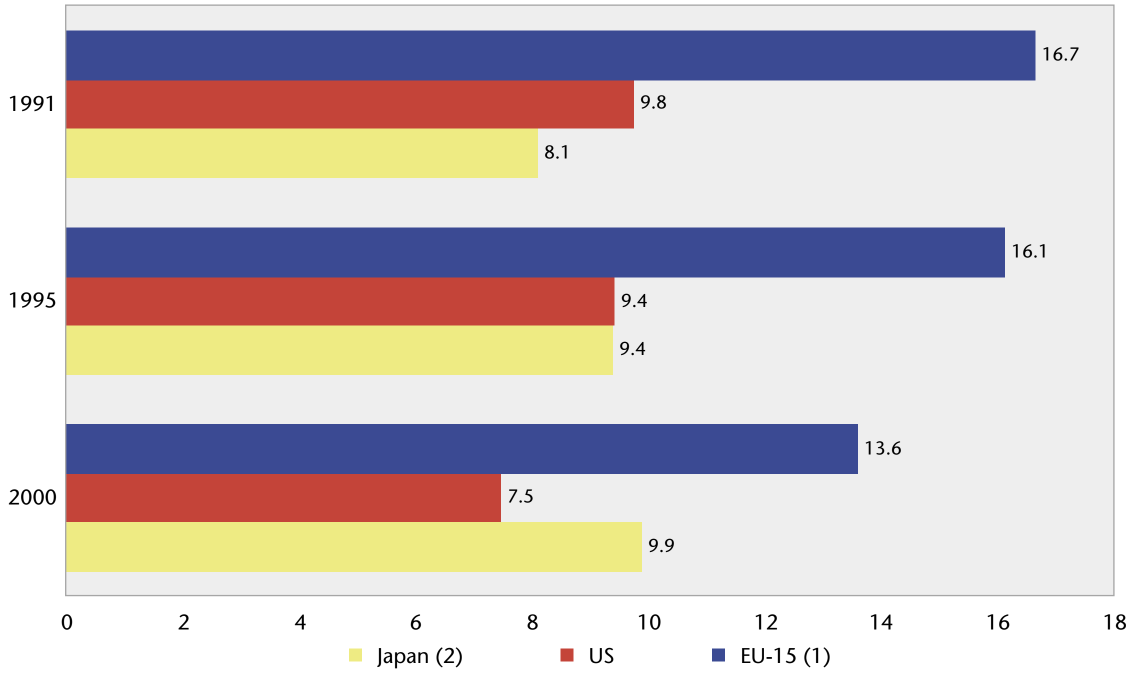
Figure 2.3.2 Government sector R&D expenditure as % of GDP, 1991–2000



Source: DG Research
Data: OECD, with DG Research provisional estimates
Note: (1) L data are not included in EU-15 average.

Third European Report on S&T Indicators, 2003

Figure 2.3.3 Share (%) of the government sector in total R&D expenditure, 1991, 1995 and 2000



Source: DG Research
Data: OECD, with DG Research provisional estimates
Notes: (1) L data are not included in EU-15 average. (2) JP: the value for Japan for 1995 in fact refers to 1996.
Third European Report on S&T Indicators, 2003

In 2000, government R&D expenditure as a percentage of GDP was the highest in Japan (0.29%) (figure 2.3.2). The figures for the EU and the US were 0.26% and 0.20%, respectively. Since 1991, Japan was the only one of the three economic blocs where GOVERD increased in relation to GDP, reflecting public research institutes' increasing R&D performance and growing role in the innovation system. In the EU and the US, government R&D performance in relation to GDP declined over the last decade. The same developments in the role of government research institutes are evident from figure 2.3.3, which describes the share of government R&D expenditure in total R&D.

When examining the share of the government sector in total R&D expenditure, it becomes apparent that the economic blocs converged slightly in the 1990s (figure 2.2.3). In the 1991–2000 period, both the EU and the US showed a lower proportion of total government R&D intramural spending, a fall of 3.1 and of 2.3 percentage points respectively, while Japan registered a 1.8 percentage point increase. In the EU and the US, the major change which took place in the share is a recent one: the share has decreased notably after the mid-1990s. In 2000, the government sector accounted for less than 14% of the total R&D expenditure in the EU area. This figure still outweighs the share of the government sector in the US (7.5%) and Japan (9.9%).

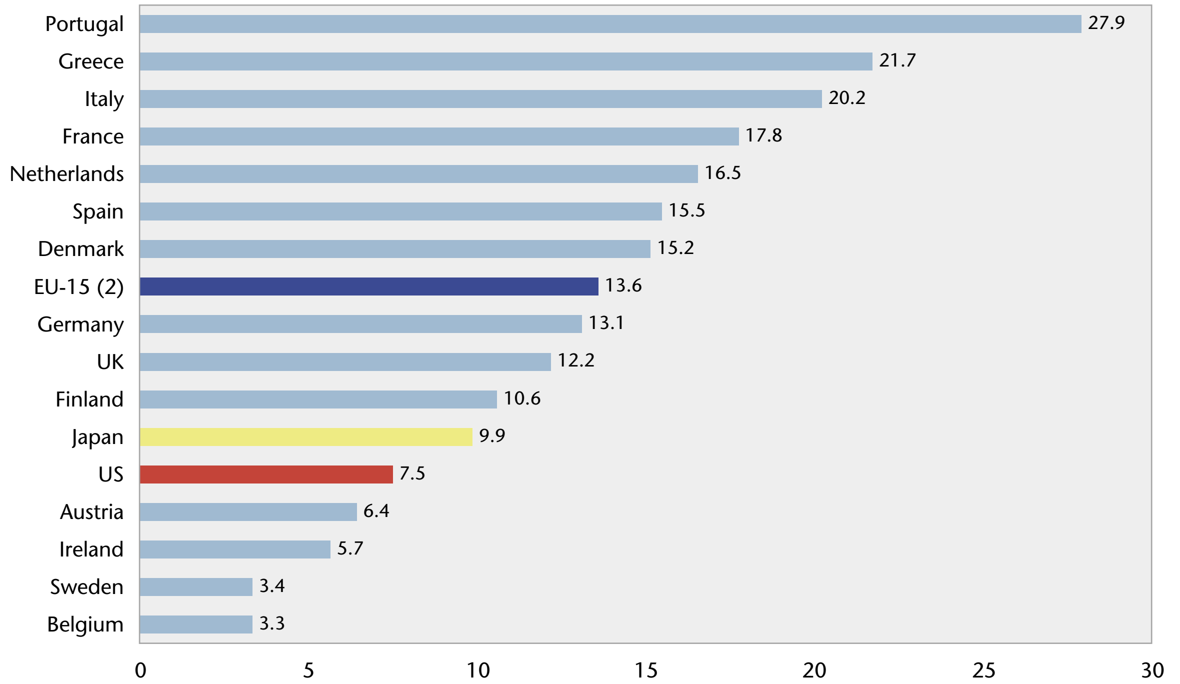
Government sector R&D expenditure within the EU gives mixed signals

An examination of the share of the government sector in total R&D expenditure reveals considerable variation within the EU area (figure 2.3.4). Portugal, Greece and Italy recorded the highest shares by far for the government sector. Theirs have been the only EU economies where public sector research institutes have been responsible for more than one fifth of total R&D.

At the other end of the scale, Belgium, Sweden, Ireland and Austria spend very low proportions of total R&D (below 7%) in government laboratories. These figures deviate significantly from those for other EU Member States. In these four countries, public research institutes play even more of a minor role in total R&D performance than in the US and Japan.

Portugal is the only EU country where the government research institutes' share of total R&D performance increased in the late 1990s (figure 2.3.5). However, this increase was barely noticeable, being at a level below one percentage point. In absolute terms, the greatest relative decline has been in Finland (–6.1 percentage points). Greece and Spain also recorded relative declines of over three percentage points. In the EU, the GOVERD share of total R&D decreased by 2.5 percentage points. In the US, the share decline was smaller in absolute terms.

Figure 2.3.4 Share of the government sector in total R&D expenditure, latest available year (1)



Source: DG Research
Data: OECD
Notes: (1) D, E: 2001; B, DK, EL, NL, P, S: 1999; A: 1998. (2) EU-15 calculated by DG Research; L data are not included in the EU-15 average.

Third European Report on S&T Indicators, 2003

An investigation of the development of the share of government sector research in total R&D in the long term reveals that Greece has had the sharpest decline, from over 40% at the start of the 1990s to less than 22% in 1999. During the same period, a high proportionate decline – but from a much lower starting base than in Greece – was also experienced in Finland (from 20% to 11% in 2000), Spain (from 21% to 15% in 2001) and Ireland (from 11% in 1992 to 6% in 2000).

The share of government research institutions in public sector R&D expenditure (i.e. the combined higher education and government sectors) in the EU countries, the US and Japan is shown in figure 2.3.6. Among the EU countries, government laboratories in France, Germany, Denmark, and Portugal play a substantial role in national innovation systems. However, France is the only country where the share of the government sector in public R&D (and total R&D as well) is higher than that of the higher education sector. This is mainly caused by the special situation of CNRS (National Centre for Scientific Research), which performs research of an academic nature and mainly in an academic setting, but is a national research organisation.

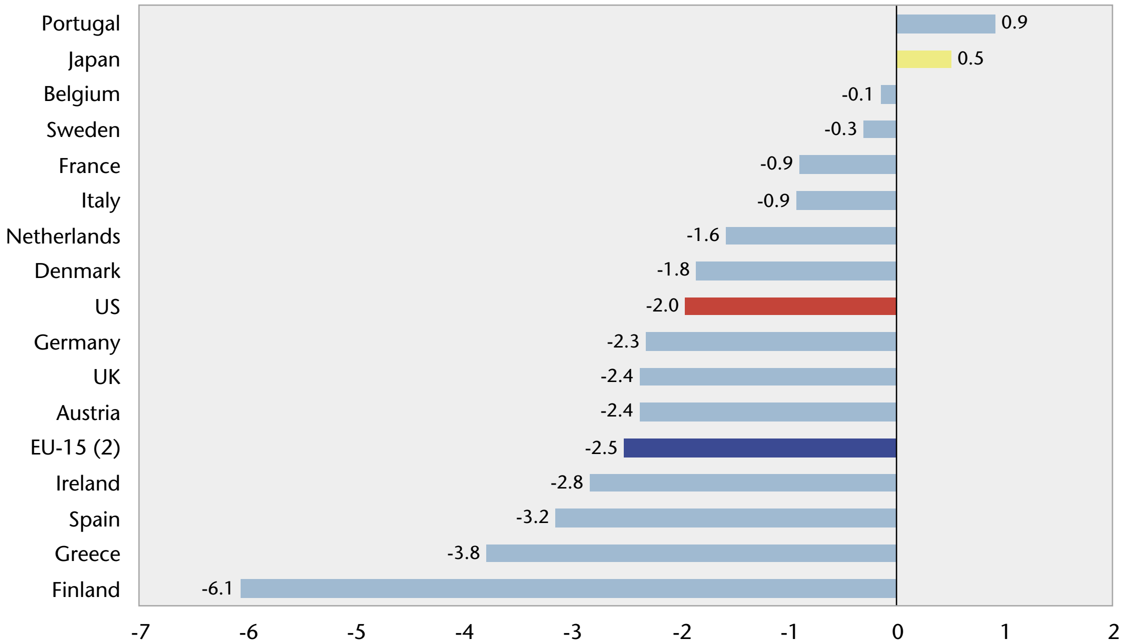
The situation is the opposite in Sweden, Austria, Ireland and Belgium, where the GOVERD share of total R&D is very low, and where the higher education sector is responsible for the bulk of R&D conducted by the public sector institutions.

In Greece and Ireland, public sector R&D is fairly heavily dominated by higher education institutions, with government laboratories responsible for less than a third of public research. Thus, from the viewpoint of public research and the institutional set-up of national innovation systems, the role of the government sector varies considerably across the EU.

The average annual real growth of GOVERD is shown in figure 2.3.7. In spite of the decline in its share of total R&D, expenditure on R&D by the government sector increased in most of the EU countries, as well as in the US and Japan in the late 1990s. As for GOVERD, figures increased most – once again – in Portugal (averaging 12% per year) and Greece (8%). The figure for Belgium also stands out in the EU group.

As has been the case in most instances, comparatively small EU economies and the countries catching up from a low level of investment have recorded the highest rates of growth. The opposite trend is true of the UK (–1.7%), Ireland and Austria. Since government research institutes receive most of their funding directly from government sources (figure 2.3.8), it is understandable that the poor development of GOVERD in the UK and in France, for instance, relates specifically to the limited real growth of R&D financing by government.

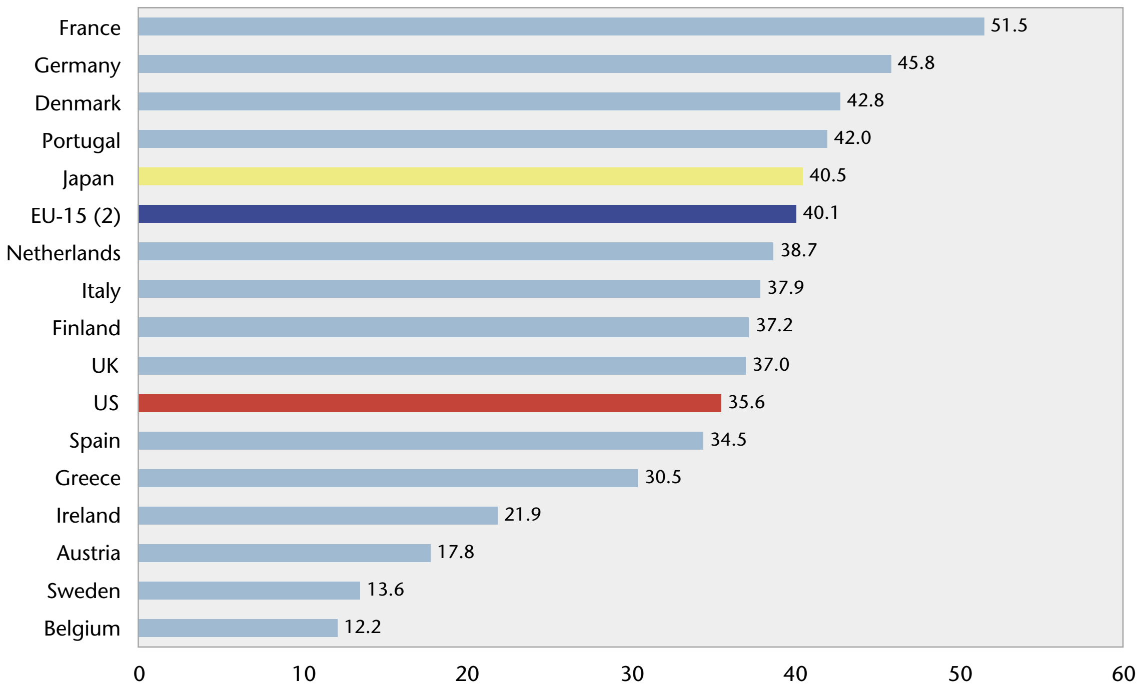
Figure 2.3.5 R&D expenditure by the government sector – change in the GOVERD share (percentage points) of total R&D expenditure, from 1995 to latest available year (1)



Source: DG Research
Data: OECD
Notes: (1) D, E: 1995–2001; IRL, I, FIN, UK, US, EU-15: 1995–2000; F: 1997–2000; JP: 1996–2000; A: 1993–1998; all other countries: 1995–1999. (2) EU-15 calculated by DG Research; L data are not included in the EU-15 average.

Third European Report on S&T Indicators, 2003

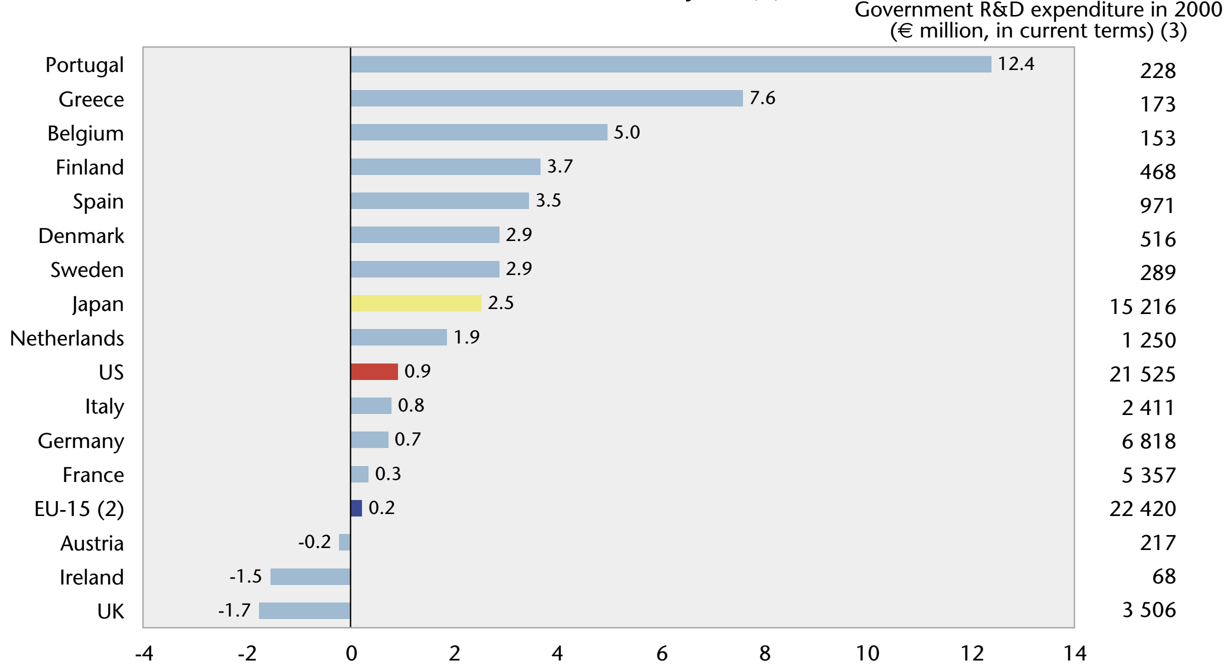
Figure 2.3.6 The government sector share (%) of total public R&D, latest available year (1)



Source: DG Research
Data: OECD
Notes: (1) D, E: 2001; B, DK, EL, IRL, I, NL, P, S: 1999; A: 1998. (2) EU-15 calculated by DG Research; L data are not included in the EU-15 average.

Third European Report on S&T Indicators, 2003

Figure 2.3.7 Government intramural expenditure on R&D – average annual real growth (%), 1995 to latest available year (1)



Source: DG Research
Data: OECD, with DG Research provisional estimates
Notes: (1) D, E, I: 1995–2001; B, DK, EL, NL, P, S: 1995–1999; F: 1997–2000; A: 1993–1998; all other countries and EU-15: 1995–2000. (2) EU-15 calculated by DG Research; L data are not included in the EU-15 average. (3) B, DK, EL, NL, P, S: 1999; D, E, I: 2001; A: 1998.

Third European Report on S&T Indicators, 2003

The growth rate recorded for Japan (2.5%) was substantially higher than the EU average and the US (figure 2.3.7). Japan has slightly narrowed the gap between itself and the EU and the US in terms of R&D performance by public sector research institutes. This is apparently so in spite of the fact that both the economy and GDP growth in Japan have stagnated since 1997.

The low rate of growth for the EU is mostly due to poor performance by the UK and France, as discussed previously. These two countries, which together accounted for approximately 40% of EU-level GOVERD, spent a total of PPS 825 million less in real terms (636 million euro less in current terms) on government sector R&D in 2000 than they did five years earlier. Italy still lags behind the 1991 absolute volume of GOVERD in real terms. In Germany, although R&D spending by public sector research institutes has not increased much in relative terms (0.7%), the development in absolute terms has been fairly favourable (from PPS 5.4 million in 1997 to over 5.7 billion in 2001).

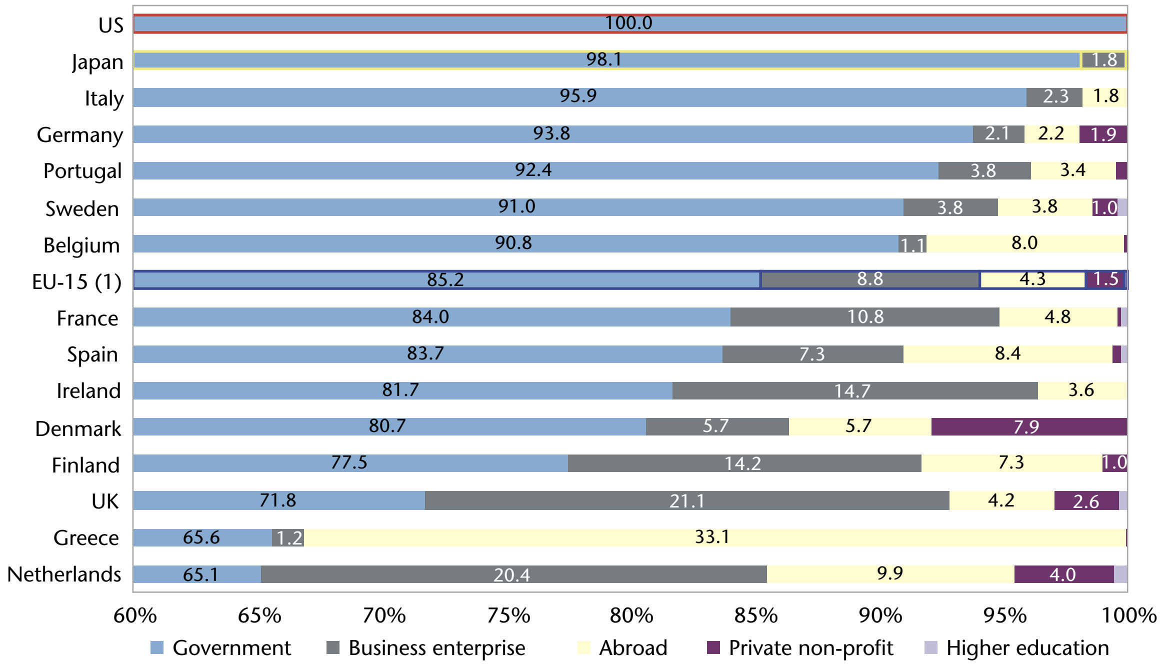
Government contribution to public sector research institutes is diminishing

Figure 2.3.8 and table 2.3.1 show expenditure on R&D by the government sector by source of funds in 1999 and the average annual real growth of financing by source of funds in the 1990s. Although most of the funds for public sector research institutes come from governmental sources (65–96% of all the funds, depending on the country concerned), certain inter-country differences remain apparent in the EU. The share of GOVERD financed by government is the highest in the US and in Japan. In the EU, share of governmental sources of GOVERD is clearly at a lower level at around 85%.

The business sector has played an increasing role in the funding of public sector institutions. In 1999, business sector funding accounted for almost 9% of GOVERD in the EU. In addition, the growth of business sector funding has increased substantially at a real annual rate of 8.3% in the 1990s (table 2.3.1). The highest annual growth rates of businesses financing were recorded for Denmark (10%), Spain (9%) and France (9%). In the Netherlands, the upward trend in GOVERD in the 1990s was due mostly to an increase in business sector funding.

This development indicates that a prominent recent feature of the EU research has been the growing role of the business sector, not only as a performer, but also as a financier of research (see Section I and Chapter 3). The increased share of funding by business enterprises also indicates that firms are willing to exploit the research performed by the government sector. This is linked to the strong growth of R&D outsourcing (e.g. Howells & James 2001). In addition, public sector research institutions are eager to get additional funding for R&D by intensifying collaborative efforts with the business sector, and by commercialising their knowledge base.

Figure 2.3.8 Government sector R&D expenditure by source of funds, 1999
Countries in decreasing order according to the share (%) of direct government funding



Source: DG Research
Data: OECD
Note: (1) EU-15 calculated by DG Research; A and L data are not included in EU-15 average.

Third European Report on S&T Indicators, 2003

Table 2.3.1 R&D conducted by the government sector – annual average real growth (%) of financing by source of funds, from 1991 to latest year available (1)

	Total financing	Financed by direct government	Financed by business enterprise	Financed by funds from abroad	Financed by higher education	Financed by private non-profit
Belgium	3.0	2.5	-4.1	12.9	:	-18.0
Denmark	3.4	3.0	9.6	7.1	:	2.2
Germany	1.1	1.0	-4.8	8.4	:	5.8
Greece	2.1	0.8	4.6	5.2	:	:
Spain	0.2	-1.3	8.5	18.7	:	18.5
France (2)	-1.5	-2.5	8.5	0.5	14.2	17.0
Ireland	1.0	2.5	-3.6	-2.9	:	:
Italy (3)	-2.7	-2.8	-0.3	-0.9	:	:
Netherlands	1.1	-0.7	4.8	4.5	4.7	10.2
Austria	:	:	:	:	:	:
Portugal (4)	9.4	10.9	0.1	-5.0	:	57.9
Finland	1.3	0.0	4.4	19.9	:	2.2
Sweden (5)	2.3	1.8	3.5	13.2	12.1	39.9
UK (6)	-0.7	-2.4	6.6	10.7	:	-4.5
EU-15 (7)	-0.2	-1.2	8.3	6.5	13.1	7.3
US	0.6	0.6	:	:	:	:
Japan	4.4	4.5	1.9	17.8	1.1	1.2

Source: DG Research
Data: OECD, with DG Research provisional estimates
Notes: (1) Data cover the following years: US: 1991–2000; D, IRL: 1992–2000; F, P: 1992–1999; DK, E, EL, FIN, I, JP, NL, UK: 1991–1999; B, S, EU-15: 1993–1999. (2) F: break in series between 1997 and the previous years for the government sector. (3) I: breakdown by sector for 1999 extrapolated by DG Research. (4) P: break in series between 1997 and the previous years for the government sector and for abroad. (5) S: break in series between 1997 and the previous years for the government sector. (6) UK: breakdown by sector for 1999 extrapolated by DG Research. (7) A and L data are not included in EU-15 average.
: Data not available.

Third European Report on S&T Indicators, 2003

The shares of research funding for government laboratories received from abroad, from the higher education sector and from the private non-profit sector were all comparatively in 1999 (figure 2.3.8). In the case of funding from abroad, the EU average was 4.3%. The figure recorded for Greece (33%) stands out among the group of countries under review. This is largely due to funding awarded by the EU. In the Netherlands (10%), Spain (8%), Belgium (8%) and Finland (7%) too, funding from abroad accounts for a notable proportion of total funding, while figures for the other countries are generally close to the EU average.

In most cases, funding from the private non-profit sector accounts for less than 2% of total GOVERD. It is only in Denmark (8%), the Netherlands (4%) and the UK (3%) that funds flowing from the private non-profit sector to government laboratories have been comparatively large. The share of funding from the higher education sector, on the other hand, remained in the range of 0.5% or less in all of the countries.

In general terms, in countries where government sources were responsible for less than 85% of total funding for GOVERD, public sector research institutes received substantial funding from several sources. The most obvious case is the Netherlands, where the share of GOVERD financed by government is the lowest in the EU, but where the shares of other sources of funding were very high compared to those of the other countries. In the UK and Finland as well, non-governmental sources (such as funds from the business sector and from abroad) have provided important support for government laboratories.

In general terms, during the whole of the 1990s period, R&D financing of government research institutions in the EU decreased in real terms, although only slightly (table 2.3.1). This trend was due entirely to the diminishing contribution of governments of major EU countries towards research conducted by the government sector. As far as public R&D and its financing are concerned, governments have consistently shown more interest in research conducted by universities than in government sector R&D (section IV in this chapter). However, in 7 out of 13 EU countries, the real growth of direct government funding of public sector research institutes has been positive over the past decade.

Impressive average annual growth rates for sources of funds other than "direct government" have not been high enough to compensate for the decrease in direct government funding that took place during the past decade (table 2.3.1). This is a direct consequence of the initially low share of non-governmental sources of total financing received by government laboratories.

Obviously, it has been extremely difficult to bridge the gap in funding volumes caused by the decline of direct government funding. This is especially the case in countries such as the UK, France and Italy, which have recorded negative growth of GOVERD. On the other hand, in countries such as the Netherlands, Spain and Finland, the total R&D financing of governmental institutions has grown, in spite of the negative trend or zero growth of direct government funding. The ability to access business or non-governmental funding is clearly dependent upon both the legal position and the capabilities and sector within which laboratories operate (cf. discussion of research centres in the box "Characteristics and evolution of research centers").

It is only in Portugal (10.9% per year) and Ireland (2.5%) that the real growth rate of funding by government has outpaced the growth rate of total financing. This means that government laboratories in these two countries are still increasingly dependent on direct government funding than in others. In all the other EU countries, increases in the resources allocated by business enterprises and/or funds received from abroad have been the major funding sources compensating for the stagnation of government funding of public research laboratories.

Characteristics and evolution of research centres (*)

The EUROLABS research project has been undertaken as part of the "Common Basis for Science, Technology and Innovation Indicators" programme in the EU's Fifth Framework Programme (CBSTII) contract ERBHPV2-CT-200-01) to investigate the evolution of research centres. The main objectives have been to conduct a comparative analysis of public, semi-public and recently privatised research centres, and to compile a database to describe the main features of major research centres. Currently, 769 centres are included in the database.

The centres in the database employ over 100 000 qualified scientists in the 557 centres for which data are available. While the greatest number of centres (237) employ between 10 and 49 scientists, the greatest number of scientists work either in large organisations (45 241 in 18 organisations) or in centres with 100–499 scientists (33 785 in 151 centres). The largest numbers of scientists in specific organisations are employed in the French Atomic Energy Commission (CEA) and the National Institute for Agricultural Research (INRA) in France, and in the Gottfried Wilhelm Leibniz Scientific Association and the Fraunhofer Society in Germany.

The two dominant ownership categories are central government and non-profit foundations. Smaller numbers of laboratories have passed from government into the private sector, or are owned by regional government or universities. There is a wide variety of ownership profiles across EU countries. In Germany, Spain, Sweden, the Netherlands and Portugal, ownership by central government is relatively infrequent (less than 25% of entries). At the other extreme, this is the only model in Greece, while Italy, Ireland and Finland all have more than 80% in this category. Non-profit foundations are the dominant models in Germany, Portugal and France. Regional ownership is significant only in Belgium, the UK (mainly Scotland), and Spain.

Eight countries have some private sector presence but only five (Austria, the Netherlands, Italy, Sweden and the UK) report the change of status described as privatisation, covering 32 laboratories in all in the period 1989–2001. Ownership by a university is a comparatively rare category, but may represent a growing trend of convergence with the academic sector.

The UK provides an example in the Southampton Oceanography Centre. This is the UK's national oceanography laboratory, which has moved from being a Research Council Institute to being a joint venture between the University of Southampton and a public sector research organisation, the Natural Environment Research Council. The motivation has been to seek scientific synergy by combining the laboratory with the largest academic department in the field. The dual status has opened a wider range of opportunities for funding and commercialisation.

In the UK, the privatisation of many of the largest national laboratories in the past decade has been driven by the political conviction that the application of the principles of new public management should extend beyond the customer-contractor principle to question whether the ministry should own the contractor. However, there is no single process or outcome in this matter (Gummet et al. 2000). A wide range of science and technology organisations has been subjected to a succession of reviews and many of these, particularly those with basic research as their principal mission, have remained in the public sector.

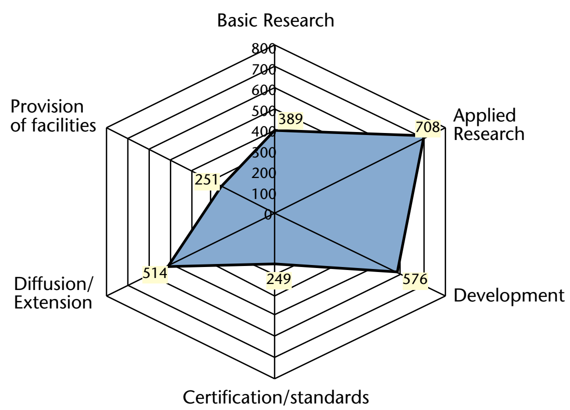
Ownership may also be mixed or "semi-public". The emergence of this model can be seen in the case of industrial research institutes in Sweden. Originally established as R&D resources for specific industry sectors, but now organised around technological competence, they receive around one third of their income from government and obtain the rest from contracts for applied research and knowledge transfer. The Austrian Research Centres Siebersdorf (ARCS) has an ownership structure in which central government holds 51% of the shares, while a consortium of the country's leading industrial and commercial organisations retains a 49% interest. The aim of this structure is, once again, to promote linkage with and input from industry.

In Spain, a reverse sequence has taken place. Independent non-profit industrial research associations, with their origins in the co-operative movement, have drawn closer to national or regional government. As an example from the regional level, IKERLAN, a private co-operative, has evolved strong links with the regional government of the Basque Country. The effect of the introduction of public financing (around 50% of the budget) has been to raise the technological level and, critically, to open its services beyond the co-operative membership group.

To explore where research centres fit into the innovation system, it is useful to examine their orientation in terms of the types of activity they undertake, their scientific and technological capabilities, and the sectors they address. Since many laboratories have multiple orientations, the data show the overall situation. Figure 2.3.9 indicates that the most frequent orientation of this sector is applied research, which is carried out by almost all 772 laboratories in the database, thus reflecting the mission orientation of the majority.

By contrast, basic research is only carried out by about half of the laboratories, which fall into two main categories. First, there are centres where basic research is the central mission. They include national organisations such as the Max Planck Society in Germany and the Higher Council for Scientific Research in Spain. The second group of centres is mission-oriented institutions, which nonetheless perform some basic research in order to maintain their scientific capability. This pertains particularly to laboratories working in health and life sciences.

Figure 2.3.9 Function of research centres



Source: PREST
Third European Report on S&T Indicators, 2003

Centres are also heavily engaged in the application of their capabilities: development and diffusion/extension activities are both performed by about 70% of the research centres included in the database. A variety of mechanisms are cited for diffusion. Most common are the provision of training and education for users, and the presentation of outputs and other technical information through information services, publications, reports, seminars and conferences. The other main mechanism is through commercial activities including consultancy and technology transfer. The provision of facilities for use by other researchers provides one of the rationales for the existence of research centres. This represents activities carried out by approximately 30% of the research centres included in the database.

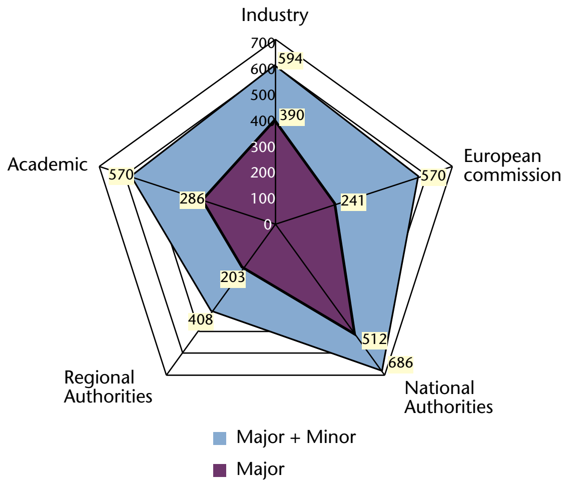
Engineering and technology (485 institutions involved) and natural sciences (449) are the predominant skills base of research centres. However, more specialised capabilities in agriculture, medicine and social sciences (208–244) are also well-represented, and even the humanities are covered, with 75 centres involved in topics such as languages, culture and societal issues.

Ireland, Italy and the UK have substantial numbers of centres addressing agriculture, while Spain and Sweden have higher than average percentages of centres addressing industry. Government and public services are most strongly emphasised in Finland and Denmark, while public health is addressed most frequently by centres in Germany, the UK, Ireland and France.

The only area forming the focus of more than half of the entries in the database is that of support for industry (over 450 entries). The next categories are natural resources and energy, and support for government or other public services. Specialised concerns follow, with health and agriculture the focus of about one-third of the centres. One-third of the centres address only one sector, the most common being industry (88) and agriculture (44). One-quarter address two sectors, the most frequent combination being that of industry with natural resources and energy (33 cases). Nineteen laboratories address every sector except defence, and 14 address all sectors. Institutes dedicated to information technology and biotechnology have emerged during the past 10 or more years. The fact that almost half the centres in the database have been founded in the last two decades reflects both the dynamics of science and technology, and the rate of reform and renewal.

The orientation of the research centres, and their linkages with other actors in the innovation system, is shown in figure 2.3.10. Both for major linkages and overall, national authorities are the most important contact for the centres (92% of centres with known linkages fall into this category). This is not surprising, since most centres exist principally to serve the needs of national policy.

Figure 2.3.10 Linkages of research centres



Source: PREST
Third European Report on S&T Indicators, 2003

Industry provides the second most important direction for major linkages (57%) and overall (84%). Similar proportions have major linkages with academia and the European Commission (43% and 37% respectively). Again, the great majority has some form of linkage. While regional authorities are less evident, one third of centres still register them as a major link.

(*) This section is based on the document prepared by the Eurolabs project and compiled by PREST/University of Manchester (see European Commission 2002a)

Section IV The Higher Education Sector

This section uses R&D indicators on higher education in order to look at the changes in a broader context. The changing role of the higher education institutions in the innovation system, changing expectations and changing realities in terms of funding have a large impact on universities. The role and impact of universities as a primary supplier of research cannot be understood and evaluated properly by using only input data such as financing. The section starts by outlining the major trends and challenges faced by the higher education sector.

1. The (r)evolution of the university system

The modern university differs considerably from what it was some twenty years ago. At the time, science and industry were for the most part two separate worlds with distinct aims and roles, and a more or less clear division of labour. While it is the particular function of the university to produce (new) knowledge, and of industry to create employment, goods and services, there is a natural link between the two systems, since the universities supply industry with graduates.

This has not always been the case. Whereas before the industrial revolution, the universities produced the elite, the political leaders, and the intelligentsia of a country in particular, their role changed with the emergence of the technical and agricultural applied fields that resulted from the industrial revolution. The establishment of polytechnics, technical colleges, and technical universities reflects these changes, which nonetheless follow rather different paths within the EU countries (Innocult, 1999).

Following the industrial revolution and scientific progress, European countries reacted at different rates and with differences in their individual designs of innovation systems. Within these systems, the knowledge-producing sub-system traditionally assigned to universities became more diverse with the establishment of public research institutes.

It may be argued that this move strengthened the one role of universities that remains the most common direct link between themselves and industry: the provision of qualified graduates. However, the knowledge-production function of universities is embedded not only in their graduates, i.e. masters and doctoral students, but also in several products and processes at different time intervals, and accessible via several channels (see box 'Forms of university-industry transfer').

Two interlocking forces, i.e. industrial change and changes in public policy, are the main drivers of the changes in university-industry relationships. These forces often leave universities in a difficult position.

From an industrial perspective, the most significant changes lie in world-wide shifts in the division of labour, as well as the accelerating diffusion of new knowledge, and the shortening of product life cycles. All demand faster incorporation of scientific knowledge into new products and processes. While these are global trends, their intensity in transforming established industry structures and research patterns differ across the EU Member States. The patterns of science-industry relationships depend heavily on industrial dynamics and on the way the science world conceives of itself within a given country.

The science base of an industry, the concentration and size of firms, as well as their absorptive capacity, are all variables that explain the fact that university-industry relationships and scientific and technological transfer differ in various national innovation systems. The level and patterns of the relationship depend largely on the structural features of the different systems, and their industrial and scientific specialisation. Not all industries have a need for sophisticated production processes, and not all firms are capable of introducing superior organisational processes. What may prove suitable to a particular industry or firm is not necessarily so for another.

However, there are certain incontestable facts, one of which is that the more science based an industry is, the larger the gains from intensive science-industry relationships. The levels of science-industry relationships depend to a large extent on the demands of industry: an industrial specialisation that requires a lesser degree of scientific knowledge will not push for higher levels of co-operation, and will not necessarily demand high numbers of qualified graduates or researchers.

Co-operation is very important in technology fields where radical innovations can be achieved, such as biotechnology, new materials, and ICT (Polt et al., 2001). Moreover, the

A European Higher Education Area

In May 1999, 29 European ministers of education met in Bologna and issued a declaration on "The European Higher Education Area". It expressed their desire to create a European higher education area leading to greater compatibility and comparability of systems and thereby to promote the mobility and employability of their citizens. The Bologna process led to a subsequent meeting in Prague in 2001, where 32 countries outlined the following goals:

- Simplifying the patchwork of higher education qualifications
- Improving mobility within Europe and attracting students from around the world
- Ensuring high standards.

Progress will be assessed in Berlin in 2003. While the aim of the Bologna process is a certain harmonisation at the European level – while ensuring that different cultures and habits are respected – it also pinpoints the important role of higher education.

demand for educated and qualified graduates is increasing in all industries – those facing technological and organisational change – as well as "traditionally" high- and medium-tech industries.

A decrease or increase of public R&D investment in different countries primarily ilustrates changes in public policy. During the latter half of the 1990s, Japan increased its R&D budget quite significantly, while the US and EU countries faced poor development in terms of real growth and growth rates. The unfavourable trends in R&D financed by government in both Europe and the US pose severe difficulties for the higher education sector, and encourages the search for sources other than national governments.

The policy changes often link financial aspects to required structural changes at the university and to the system as a whole. The evaluation of research performance in the UK since the mid-1990s, for example, has direct financial consequences for all university departments. However, a systems evaluation, which also examines incentive structures in universities – such as the career patterns of researchers – is a more recent feature in Germany, for example.

The pace and intensity of changes in public policies differ across EU countries. This reflects different public opinions and attitudes. While it may be an advantage in Sweden or the UK if a professor or post-doctoral student creates a spin-off that exploits commercially academic research outcome, this kind of "less academic" activity is not part of the core duties of a professor in Spain or Italy. It may be difficult sometimes for public servants such as university professors to justify the commercialisation of their research outcomes. However, a change in attitude is becoming increasingly evident, and there is virtually no country left where universities do not have to face evaluation of their activities when competing for funds and students.

The universities find themselves caught in the middle. While structural change opens up new demands and opportunities for research institutions, certain difficulties persist. General technological advances bring with them certain highly sophisticated products and processes that are needed for increasingly sophisticated research processes. Research institutions are then required to update instruments and other technical tools required by the research process more frequently, in order to keep research processes up to date. Moreover, the larger number of opportunities often requires additional staff and infrastructure.

However, these new advantages render the research process more complex and also more costly. Thus, as the volume of public funding decreases, universities increasingly have to look for alternative public or private funding sources, which include industry, foundations, or the EU.

Universities under pressure

The demand for and push towards an intensified science-industry relationship had as one of its major stimuli the successful US model. By enabling universities and public research institutes to commercialise their scientific output over the past 20 years (notably through the Bayh-Dole Act of 1980), it has been possible to increase the number of patents emerging from public research institutions, and also to create hundreds of university spin-offs and new technology-based firms. The latter has led to a considerable increase in the employment rate, especially in the US high-tech sector – something that still needs to be achieved in Europe.

During the 1990s, the relationship between science and technology and between universities and business enterprises in the EU became closer and more interactive than ever before. At the same time, universities were facing pressure to change, with the spotlight being put on R&D in an entirely new way. In recent years, decision-makers, policy advisers and the end-users of research results and new knowledge have stressed the importance of obtaining research findings with practical applicability and utility. Organisations engaged in R&D are required to come up with results that have social, economic and industrial relevance. According to the OECD "universities are under pressure to contribute more directly to the innovation systems of their national economies" (OECD, 1998).

At the same time, as academe tried to cope with the changing situation, universities and science administrations both started to emphasise the need to maintain high standards of research, as well as the importance of sufficient long-term funding and close international research co-operation. Consequently, the importance of developing new tools for science and technology policies has been widely recognised.

Funding for universities is allocated increasingly on a competitive basis. Most extramural funding, core funding, and financing between faculties tends to be allocated on the basis of quantitative measures and repeated evaluations. In addition, management by results (adopted both by ministries of education and universities) has led to increased accountability in universities. The new management philosophy, at least to some degree, has raised research standards, given more attention to performance, and increased productivity in the allocation of resources. A common criticism against management by results is that in its strict application, it gives too much weight to short-term activities and quantitative results at the expense of quality and long-term development (Husso et al., 2000).

It has been argued that the European innovation gap is due to an insufficient and inefficient scientific and technological transfer. While on the one hand, Europeans produce a large volume of new knowledge (see Chapter 5), the transformation of this knowledge into new products, processes and services is poor relative to Europe's main competitors. This is being countered by efficient and successful transfer systems in certain countries, and for different industries.

Forms of university-industry transfer

What are the main channels, and who benefits from them?

Besides the direct outcome of research efforts – publications and patents – the other main channels for the science-industry relationship may broadly be classified into formal and informal collaboration. Collaboration can be achieved, for example, through contract or co-operative research, R&D consulting, networks, and exchange of information. Personnel mobility can be achieved through temporary or permanent personnel exchange, while training and education includes vocational and professional training as well as masters and doctoral theses carried out in industry. Finally, the commercialisation of results can occur through licensing and by creating spin-offs.

The choice of one or the other depends largely on the type of knowledge to be exchanged – whether tacit or codified – as well as viable exploitation, incentives to co-operate and the absorptive capacities of the parties involved. Evidence from a German survey (Schmoch et al. 2000) suggests that research institutions estimate the importance of different transfer channels differently. From the university's perspective, scientific publications dominate as the main means of transfer, far ahead of co-operative research. Less significant, but with a high potential of becoming far more significant, is the mobility of researchers to industry.

Technical universities assessed scientific publications and co-operative research as being of equal significance. Applied-oriented research organisations considered co-operative and contract research to be most significant. Presentations in firms and industry-oriented organisations came second, though they were deemed to be far more significant than scientific publications. The main basic research institutes, on the other hand, opted directly for scientific publications as the most significant channel. Overall, publications were clearly the channel most commonly named by the different organisations (BMBF, 2001).

The various assessments of transfer channels reflect cultural attitudes as well as the original missions of different research institutions, notably universities. In most countries these are reflected in the legal framework of the institutions and the way they are allowed to handle intellectual property rights (IPR). In some European countries, such as Finland and Sweden, university employees have the privilege of being able to apply for a patent on their own. In other countries such as Belgium and the UK, the innovation belongs to the university.

It remains unclear which regulation is preferable: while the number of patent applications per university researcher might be higher in countries that allow this privilege, there are very few incentives to commercialise the innovation (Polt et al., 2001). For example, in order to push for greater exploitation of innovations, Germany abolished this individual privilege in 2001 and granted IPR to universities instead.

Creating professional patent and licensing agencies on a regional basis (thus commercialising innovations for several universities) would strengthen commercialisation. In the UK, for instance, the approach has been to create specialised technology licensing offices, and these have proved to be an effective means. In several countries, such as Finland, Italy, Germany and Austria, mobility between universities and industry is frequently hampered, especially for the academic partner. Most university professors and other employees have the status of civil servants, and are neither encouraged nor allowed to work temporarily within industry.

There are both benefits and difficulties in science-industry relationships. The latter exist since scientists and researchers publish their results, and industry uses their findings. They do exist equally on an informal basis when the different researchers meet at conferences and similar gatherings. Nevertheless, in past years many policy-makers in various countries have voiced the demand for an intensified relationship, though certainly to varying degrees. Whereas positive outcomes and mutual benefits can be expected to result from intensive exchange, certain fears persist on both sides.

The benefits of extended tasks include higher returns for the university or for individual departments. The amounts involved can be significant. However, there are certain long-term side effects too. As universities begin to commercialise their output more and more, so the former public character of their work becomes increasingly private.

As universities come to depend more and more on industrial demand and the income derived from it, they risk abandoning their long-term, independent, and non-oriented research. Publicly funded universities risk receiving even less in the way of public funding as their characteristic public nature declines and income from private sources rises. Universities risk becoming mere providers of practically-oriented knowledge that is important for the immediate success of firms.

In turn, firms lose the important fringe benefits of long-term, non-oriented research. In the long run, the outcome and quality of the innovation process, as well as the volume of innovations, may decrease. Empirical evidence from the University of California patent system reveals that, although patent applications at Californian universities have increased significantly over the past 20 years, the quality of the patents, measured by their citations, has declined (Henderson et al., 1998).

In addition, it is important to bear in mind the key role of the higher education sector in the education of a new labour force and in upgrading the skills of those taking courses on the basis of continuing education. To enhance the development of a knowledge-based society and economy, it is vitally important to have sufficient numbers of individuals available with the skills required to meet the demands of labour markets. For instance, the training of new researchers and the mobility of researchers in the labour market may be regarded as indirect consequences of research, or mechanisms whereby knowledge and research results are disseminated across the economy.

Gains from basic research

Basic research conducted by the higher education sector contributes to the development of society in multiple ways. However, in most cases it is virtually impossible to make an accurate assessment of advances in understanding. In general, the various types of research impact may be defined as follows (see Husso et al., 2000):

- scientific impact (accumulation and renewal of knowledge);
- technical impact (new technological solutions, products and processes);
- societal impact (social, cultural, regional, political, organisational, public health);
- economic impact.

The benefits of R&D, especially those of scientific research, are primarily of an indirect nature. In general, research benefits society (e.g., Pavitt, 1991; Rosenberg, 1992; Martin et al., 1996; NSF, 1998; Husso et al., 2000; Salter et al., 2000; Arnold, 2001) by producing:

- new knowledge about the characteristics and mechanisms of phenomena;
- new knowledge that confirms or refutes theories based on prior understanding;
- new instrumentation, methods, methodologies and techniques that may be widely introduced in society;
- highly-skilled people for the labour markets, especially for knowledge-intensive jobs requiring special expertise;
- access to networks of experts and information;
- information that can support political decision making;
- information for assessing the social, cultural and ecological impacts of R&D;
- intellectual capital that may lead to breakthroughs in future R&D;
- various spin-off effects such as patenting, licensing, and new companies based on the latest research findings.

The next section investigates the trends and levels of R&D expenditure by the higher education sector across the EU, and between the EU, the US and Japan. Indirectly, R&D expenditures may be considered to be the resources the higher education sector needs in order to show continuously stronger commitment to the various demands and expectations of society.

2. Expenditure on R&D by the higher education sector

Taking into account the various tasks of the higher education system, as well as the challenges of a knowledge-based society, large increases in public R&D spending in the higher education sector might be expected. Consequently, the actual figures and shares are somewhat surprising.

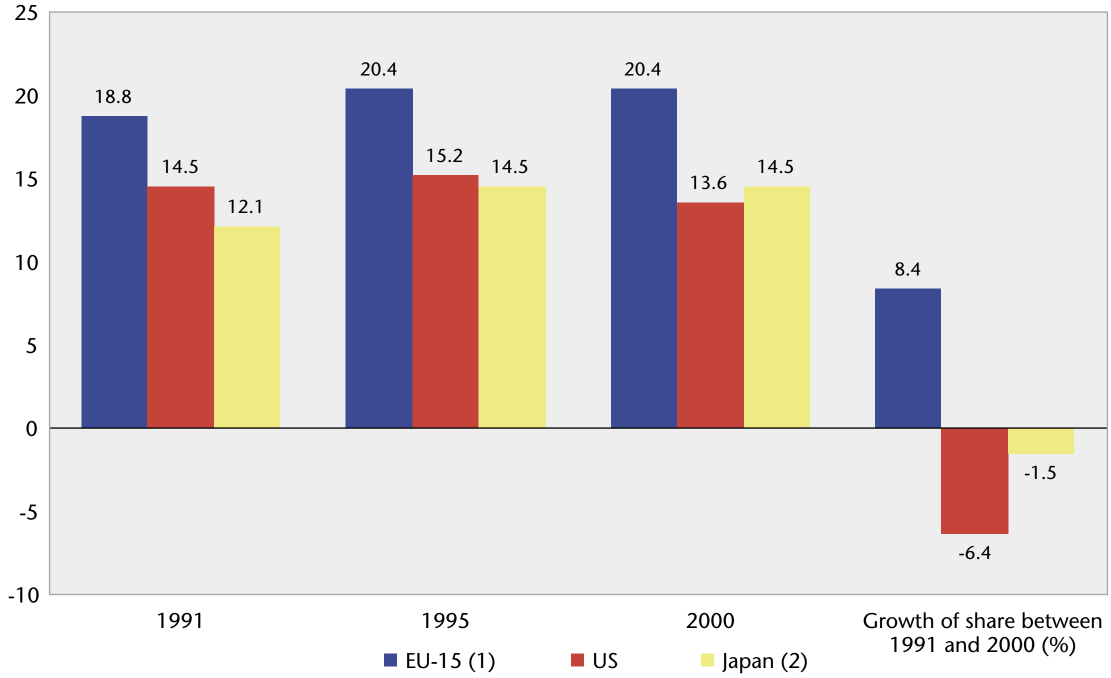
A comparison of the EU and the US in the 1990s shows the increasing shares of the higher education sector in total R&D expenditure during the period 1991–1995 (figure 2.4.1).

When considering the growth of share in the period 1991–2000, the US accounted for a negative growth of over 6%, while the EU managed a growth of 8%. The growth of the share in the EU resulted from the favourable development during 1991–1995.

In terms of R&D expenditure by the higher education sector, the US spent the most, followed closely by the EU. It is a stable pattern that can be explained by the differences in size of various countries or blocs of countries. Nevertheless, interesting changes are apparent here as well. In 1991, the EU spent an amount representing more than 93% of the total US expenditure and Japan only 35%. In 1999, Europe experienced a slight increase to 95%, while by the end of the 1990s, Japan had increased its expenditure to 40% of the US budget (figure 2.4.2).

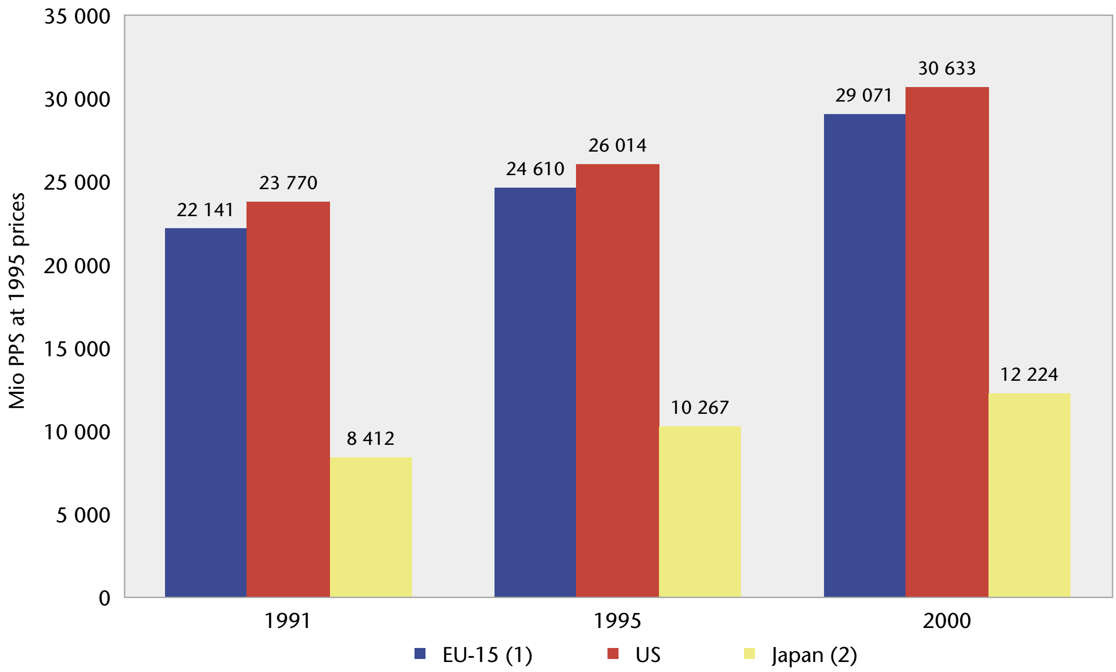
As mentioned earlier, EU countries' higher education sector is primarily financed through public funding. Higher education expenditure as a percentage of total expenditure on R&D is very high in the case of Greece and Portugal, whereas the Nordic countries are closer to the EU average (figure 2.4.4). In Greece, the share of the higher education sector in total R&D was almost 50%, while this share was in the range of only 18–21% in the Nordic countries. In most EU countries the share of GERD spent on higher education declined, but in Greece, Ireland, the UK, Italy and Portugal it was still growing.

Figure 2.4.1 Higher education expenditure on R&D (HERD) as % of total R&D (GERD)



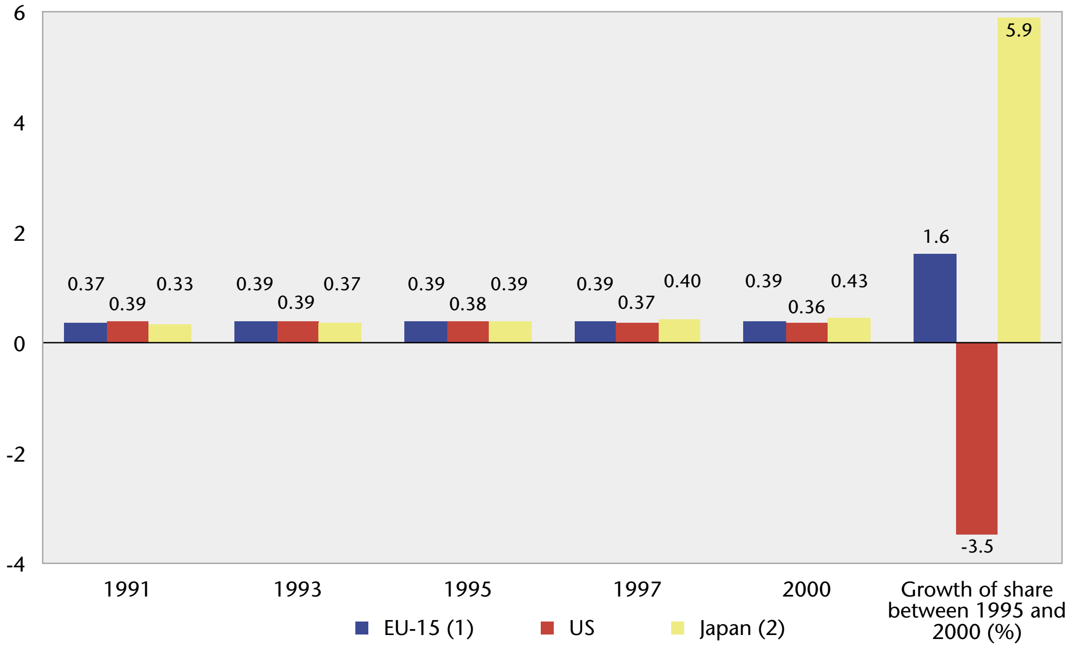
Source: DG Research
Data: OECD, with DG Research provisional estimates
Notes: (1) L data are not included in EU-15 average
(2) JP: (a) Data for 1991 and 1995 adjusted by OECD; (b) Growth of share refers to 1996-1999.
Third European Report on S&T Indicators, 2003

Figure 2.4.2 R&D expenditure by the higher education sector (million PPS at 1995 prices), 1991, 1995 and 2000, in the EU-15, the US and Japan



Source: DG Research
Data: OECD, MSTI database (STI, EAS Division) with DG Research provisional estimates
Notes: (1) L data are not included in EU-15 average. (2) JP: Data for 1991 and 1995 were adjusted by OECD.
Third European Report on S&T Indicators, 2003

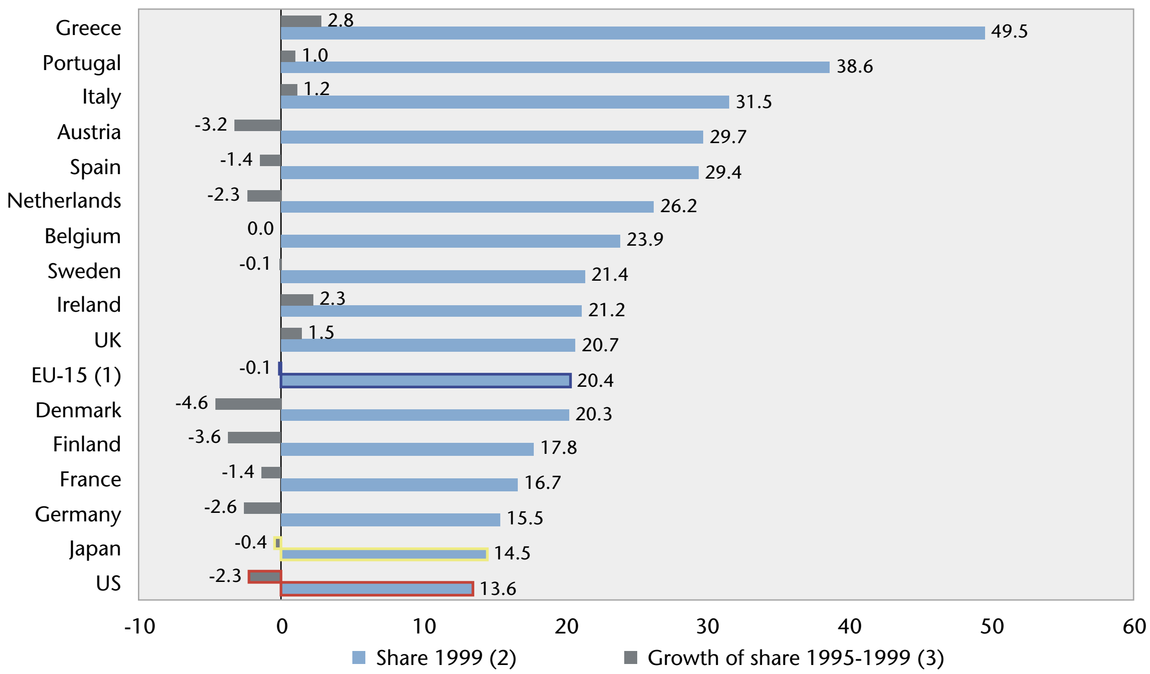
Figure 2.4.3 R&D expenditure by the higher education sector – % of GDP, 1991–2000, in EU-15, the US and Japan



Source: DG Research
Data: OECD; MSTI database (STI, EAS Division) with DG Research provisional estimates
Notes: (1) L data are not included in EU-15 average. (2) JP: (a) Data for 1991, 1993 and 1995 were adjusted by OECD; (b) Growth of share refers to 1996-2000.

Third European Report on S&T Indicators, 2003

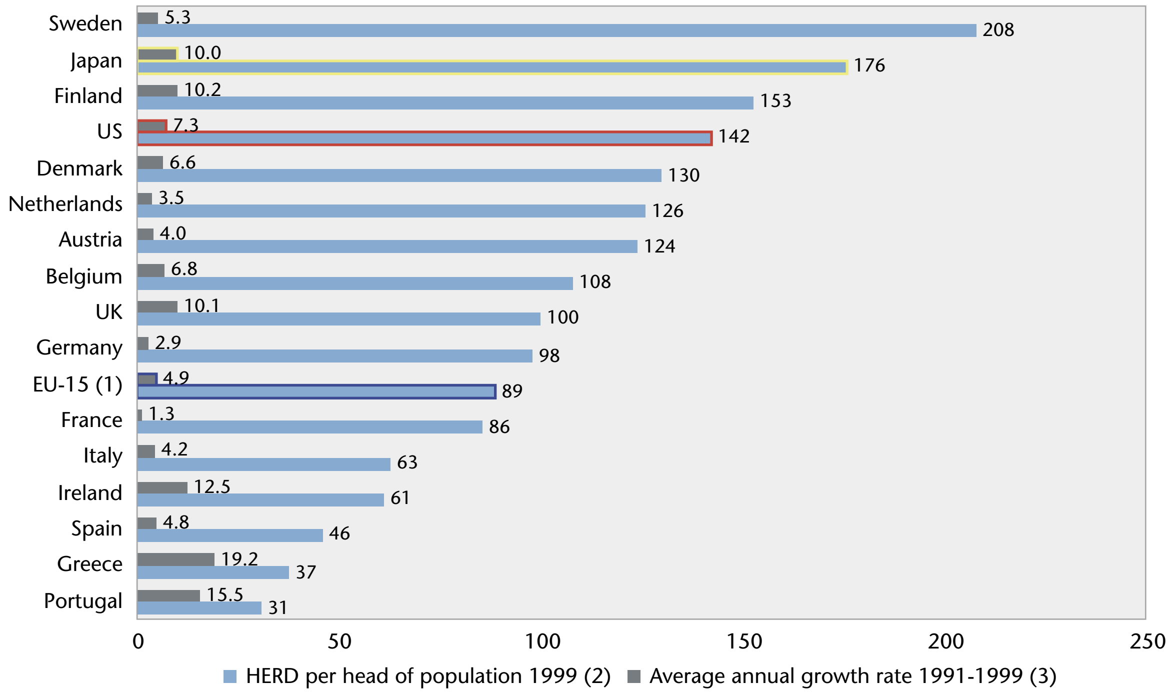
Figure 2.4.4 Higher education expenditure on R&D (HERD) as % of total R&D (GERD) and average annual growth of share, %



Source: DG Research
Data: OECD; MSTI database (STI, EAS Division) with DG Research provisional estimates
Notes: (1) L data are not included in EU-15 average. (2) A: 1998, F, FIN, UK, EU-15, US, JP: 2000; D, E: 2001. (3) UK, EU-15, US: 1995-2000; JP: 1996-2000; F, FIN: 1997-2000; D, E: 1995-2001; I, S: 1997-1999; A: 1993-1998.

Third European Report on S&T Indicators, 2003

Figure 2.4.5 HERD per head of population (€) 1999 and growth rates, 1991-1999



Source: DG Research
Data: OECD; MSTI database (STI, EAS Division) with DG Research provisional estimates
Notes: (1) L data are not included in EU-15 average.
(2) A: 1998; F, FIN, UK, EU-15, US, JP: 2000; D, E: 2001. (3) EU-15, US: 1991-2000; D: 1991-2001; E: 1992-2001;
A: 1993-1998; B: 1993-1999; UK: 1993-2000; EL, P: 1995-1999; JP: 1996-2000; I, S: 1997-1999; F, FIN: 1997-2000.
Third European Report on S&T Indicators, 2003

If population is taken into account, the money spent on the higher education sector is by far the highest in Sweden, Finland, and Denmark. It is lowest in Portugal, Greece, Spain and Ireland, which are all below the EU average. Besides Sweden and Finland, all the remaining EU countries invest less per population compared to Japan and the US (figure 2.4.5).

The higher education share of total public R&D expenditures mirrors the structure of government spending on public research (figure 2.4.6). Those countries with the lowest percentages in government research institutions have the highest shares in terms of spending on higher education. Belgium, Sweden, and Austria, with shares of above 80%, exceed the EU average of 59% by far.

Real growth rates in the second half of the 1990s reveal different patterns (figure 2.4.7). Greece and Portugal showed the highest growth. The smallest growth occurred in France, followed by Germany, Denmark and the Netherlands.

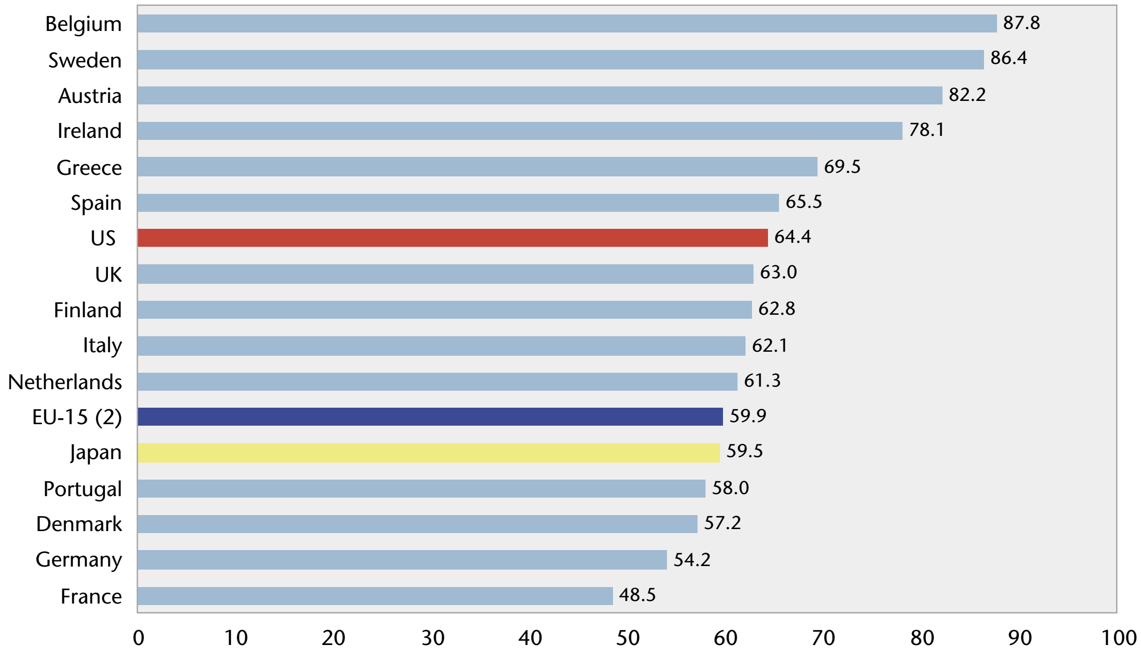
Certain figures are somewhat surprising. For example, Germany is the largest EU country in terms of total amount spent, while the Netherlands ranks fifth. High growth rates would not normally be anticipated for the larger countries. The UK, which comes second to Germany in terms of absolute spending, has a much higher growth rate than the latter. The opposite is true in respect of Denmark, which is the fourth smallest spender and ranks lower down in terms of growth.

A further important and interesting aspect is the financing of higher education by various sources. In all EU countries, the government finances the bulk of R&D conducted in the higher education sector, whereas in some countries other sources also play a vital role. This is explored in figure 2.4.8.

At the beginning of the 1990s, the EU average for government expenditure was around 89%. Ireland, with 66%, recorded the lowest level, while Austria was the highest at 97%. The US and Japan, at 74% and 49% respectively, were below the EU average, although “other national sources” played an important role in both countries. Differences in statistical definitions could mean that a larger share of these “other national sources” might be public money. This would push up the government share in the US and Japan considerably, to reach the upper range of the graph.

As stated at the beginning of this section, the higher education sector plays an important role in the transfer of science knowledge. If it is assumed that companies pay not only for endowed chairs, but also for joint research projects, the training of doctorates, and post-doctorates, etc., the share of the business sector becomes a significant indicator. Again, the EU average of 5.9% is slightly above that of the US (5.3%), and is far higher than the Japanese average of 2.4%. In the EU, Belgium and Spain were above the 10% level, followed by Ireland, the UK and Germany.

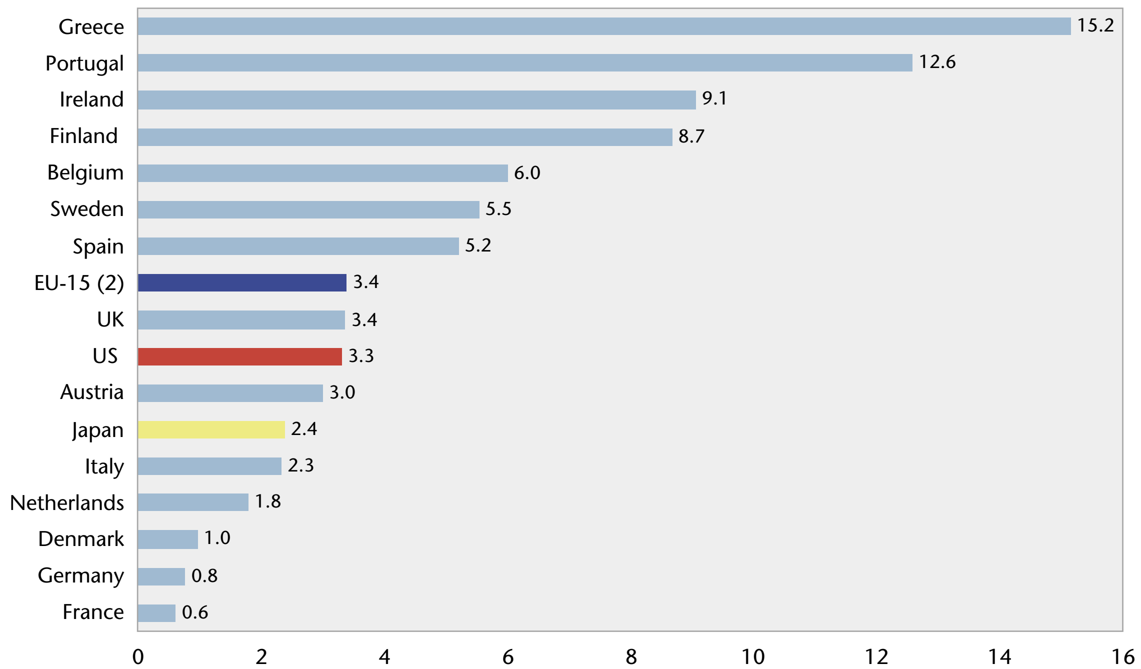
Figure 2.4.6 Higher education expenditure on R&D (HERD) as % of total public R&D expenditure, 1999 (1)



Source: DG Research
Data: OECD; MSTI database (STI, EAS Division)
Notes: (1) A: 1998; F, FIN, UK, EU-15, US, JP: 2000; D, E: 2001. (2) EU-15 calculated by DG Research; L data are not included in EU-15 average.

Third European Report on S&T Indicators, 2003

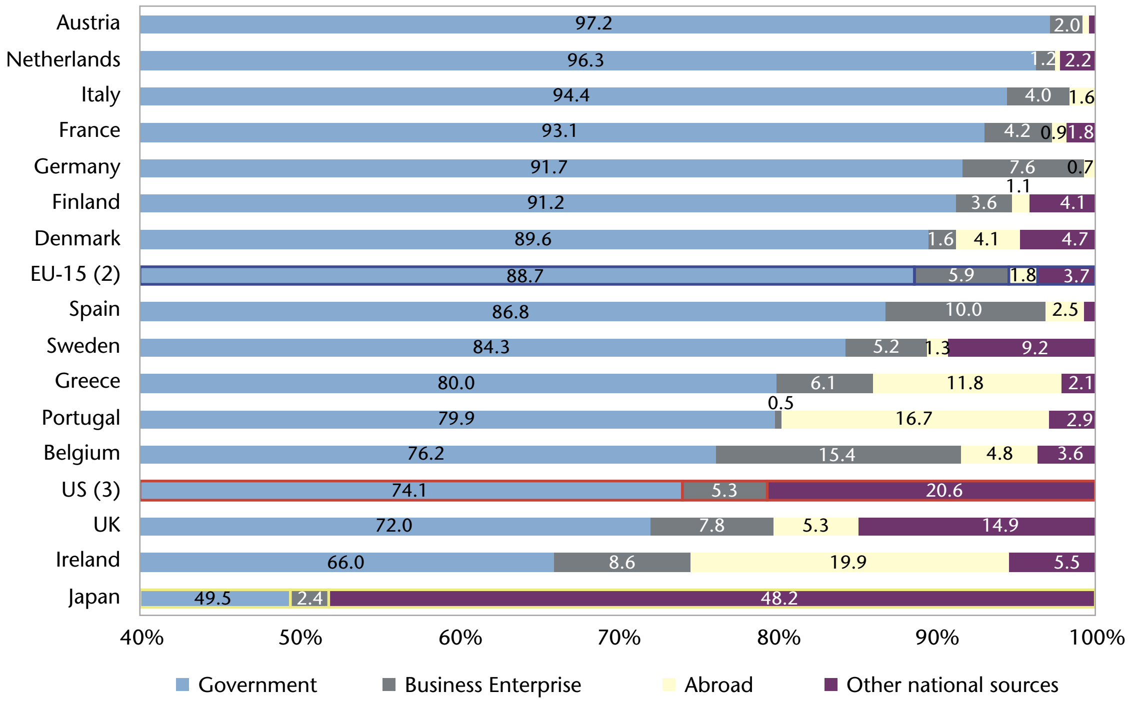
Figure 2.4.7 Higher education expenditure on R&D (HERD) – average annual real growth (%), 1995–1999 (1)



Source: DG Research
Data: OECD; MSTI database (STI, EAS Division) with provisional estimates
Notes: (1) UK, EU-15, US: 1995-2000; D, E: 1995-2001; JP: 1996-2000; I, S: 1997-1999; F, FIN: 1997-2000; A: 1993-1998.
(2) L data are not included in EU-15 average.

Third European Report on S&T Indicators, 2003

Figure 2.4.8 Higher education expenditure on R&D by source of funds, %, 1991 (1)



Source: DG Research
Data: OECD, BSTS
Notes: (1) D, P: 1992; A: 1993. (2) L and A are not included in EU-15 average. (3) US: Most or all capital expenditure is excluded.
Third European Report on S&T Indicators, 2003

The "financing from abroad" category played a very important role in Ireland, Portugal, and Greece, but a far lesser one in the UK, Denmark and Belgium. At the beginning of the 1990s, monies from the European Community seem to have played an important role. As mentioned earlier, "other national sources" – the fourth category of sources – constituted a significant share in the US and Japan. In the EU, the average share was 3.7%. Only the UK, Sweden and Ireland were above this figure, the UK being the only country with a share above 10%. The allocation by sources changed significantly during the 1990s as is evident from the position at the end of the 1990s illustrated in figure 2.4.9.

In 1999, the overall range of the government share showed a slight decrease. The EU average dropped to 81%, while the US and Japan figures remained relatively unchanged. The US dropped to 71%, while in Japan the government's share increased by 0.5 percentage points to 50%. However, this increase may be explained by the break in series before 1996. Despite an overall drop in government share within the EU, Portugal's share increased, while Italy and Ireland remained fairly stable. With statistics in respect of Austria not being available, the highest share within the EU of 94% was recorded in Italy and the lowest share of 65% in the UK.

In 1991-1999 a more interesting change developed with regard to the remaining three funding sources. First, a change took place at business enterprise level. Both the EU and US averages increased by about one percentage point – the EU to 7%, and the US to 6.3%. Japan experienced a slight decrease of 0.1%. Within the EU, six countries recorded increases. Germany had the highest increase, followed by the Netherlands, Finland, Italy, Denmark and Portugal. The remaining countries all displayed lower shares compared to 1991.

Similarly, the "funding from abroad" category also seemed to become more significant in the EU area, although a substantial decline can be observed in the case of Portugal. Smaller decline took place in Denmark, Ireland and Italy. Significant increase were recorded in Greece.

During the 1990s, the category of "other national sources" also gained in importance, especially in the UK, Sweden, Spain and Belgium, where it ranged between 14% and 20% of total funding in 1999. It should be kept in mind that the category of "other national sources" depends on national statistics. At issue is whether public R&D funding being funnelled through a third party is counted as "other national sources" or as part of government spending.

The significant drop in the government shares of Belgium and Spain are strikingly similar to the increases in the "other national sources" category. It is possible that the decline relates to a strengthening of the regions during the 1990s and, accordingly, to changing financial flows. There may be different explanations for other countries. For example, foundations and charities compensate to a large extent for the comparably low government shares in the UK, which is also true for the US. According to the Higher Education Funding Council for England, charities provide 25% of research grants and contract income to universities. In the biomedical sciences in particular, charities funded more research than the research councils themselves at the end of the decade (JM Consulting 2002).

While a comparison of funding sources' shares from 1991 to 1999 is revealing, changes in growth rates over the decade express more clearly the trends and the overall changes that have occurred. Figure 2.4.10 reveals certain significant trends. In terms of government share, the EU, the US and Japan all show increases. Japan leads with an average annual increase of 3.2% (1996–1999), while the EU average accounted for a mere 1.8%.

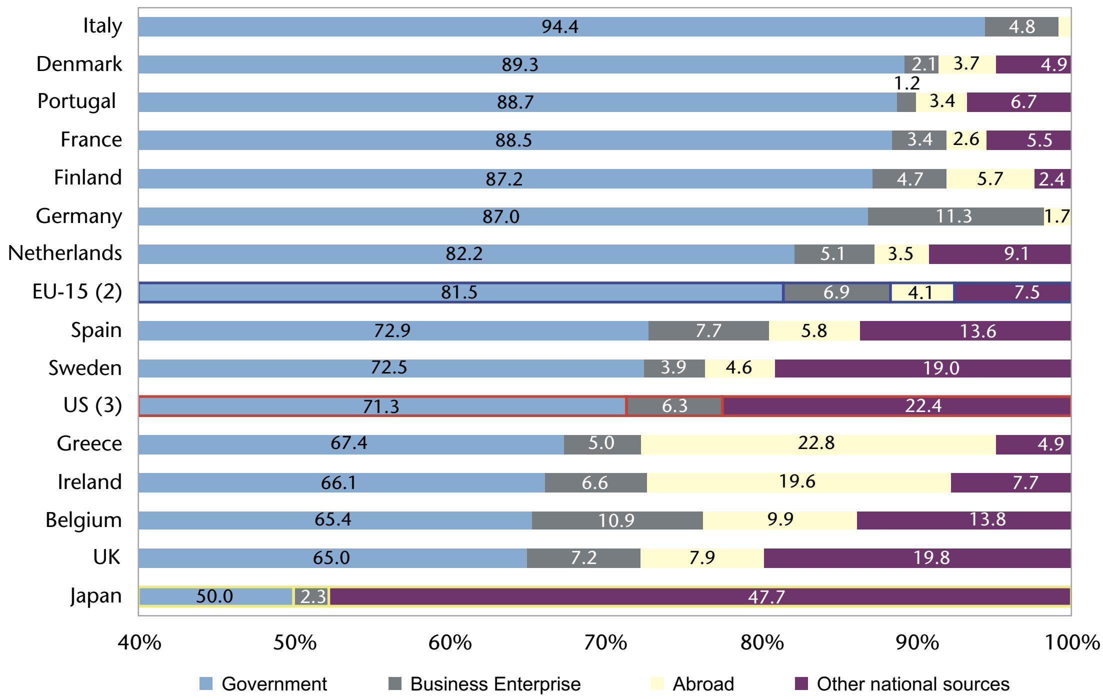
The Netherlands is the only country with a negative growth rate. Nevertheless, the difference between the position in the Netherlands and the marginally positive growth rates in Germany (0.4%) and Italy (1.3%) is quite small. The largest increases are found in Portugal, Greece, Finland and Ireland, which are all above 10%. The increases in Finland are due partly to changes in statistics, as R&D executed by university hospitals has been included in the higher education sector from 1997.

Changes in the volume of R&D funding for higher education received from the business enterprise sector indicate a significant shift in respect of EU Member States. In the business category, the EU average increased by 6.2%, while that of the US grew by 5%. In Japan the change was small, with an increase of only 1% (1996–1999). While the Netherlands had a negative growth in terms of government funding, at 22% it was the most progressive country in terms of growth in funding by businesses. Sweden and Portugal experienced the biggest declines (about 5% in each case), while France decreased by an insignificant 0.2%.

Likewise, significant changes were recorded in the category "funding from abroad". Although figures for the US were not available, the EU average increased by 6.9% and the Japanese figure by as much as 14%. However, one needs to bear in mind that the volume of funding from abroad is very limited in Japan. Two EU countries – Italy and Spain – showed negative trends, while the rest had growth rates ranging from 2.7% (Denmark) to almost 37% (the Netherlands).

High growth rates in the higher education system in the Netherlands should come as no surprise. Public policies encourage academe-industry relationships. In addition, customary Dutch receptivity to working in languages other than Dutch helps to facilitate exchanges. In turn, this helps not only those large multinational firms already present in the Netherlands, but also encourages those abroad to work with Dutch higher education institutions.

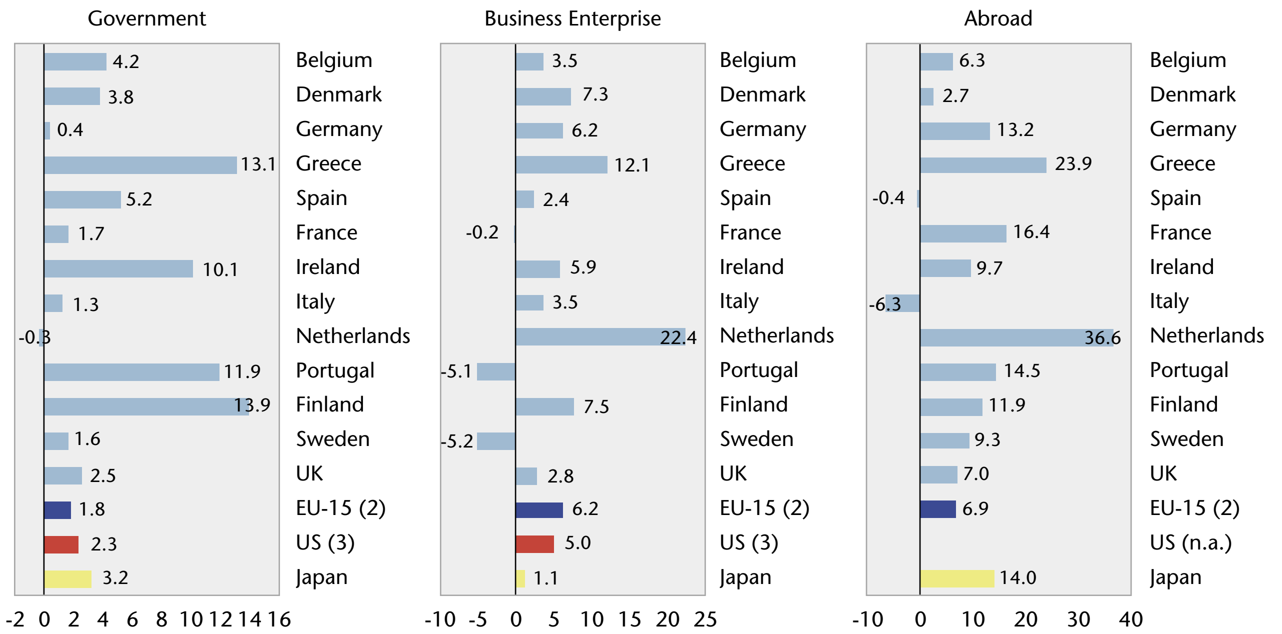
Figure 2.4.9 Higher education expenditure on R&D by source of funds, %, 1999



Source: DG Research
Data: OECD, BSTS
Notes: (1) IRL: 1998. (2) L and A are not included in EU-15 average. (3) US: Most or all capital expenditure is excluded.

Third European Report on S&T Indicators, 2003

Figure 2.4.10 Changes in higher education expenditure on R&D by source of funds, %, 1991-1999 (1) (2)



Source: DG Research
Data: OECD
Notes: (1) DK, F, I, NL: 1991-1999; IRL: 1991-1998; US: 1991-2000; D: 1992-2000; B, UK: 1993-1999; EL, E, EU-15: 1995-1999; JP: 1996-1999; P, FIN, S: 1993-1999. (2) L and A are not included in EU-15 average. (3) US: Excludes most or all capital expenditure.

Third European Report on S&T Indicators, 2003

Finally, the category "other national sources" has become increasingly important for all countries, as the available data suggests. This is especially true for those EU countries where, on average, this category rose by more than 8%. Taken all together, the data clearly indicate that the higher education sector in the EU has developed a more diversified financing strategy in order to obtain funds from various sources.

Conclusions

Some broad trends are discernible in the EU on the basis of the developments and levels of R&D performance and R&D intensity. Since the mid-1990s, trends in Member States have shown a convergence in relative terms. Although smaller EU economies and low-performing countries have increased their R&D efforts, larger European economies, especially France, Italy and the UK, have experienced markedly slower growth in R&D activities. Thus, one may argue that this convergence has not always taken place for the right reasons.

Since the mid-1990s, the gap between the EU and the US in terms of R&D investment has increased significantly in favour of the US. The EU figure is below that of the US regarding the volume and rate of growth of resources devoted to R&D, as well as the level and growth of R&D intensity. Consequently, the gap has widened for the past eight years or so in both absolute and relative terms. Recently, the gap between the EU and the US has widened rapidly. In 2000, for instance, the gap was almost PPS 8 billion larger than the previous year. In volume terms, this was the biggest year-to-year change since 1995.

Since the beginning of the 1990s, total R&D expenditure in relation to GDP in the EU has been stable at around 1.9%. Based on trends in the 1990s, projections for EU average R&D intensity in 2010 would range between 1.8% and 2.2%. Thus, unless major policy changes are implemented and R&D efforts in the EU are increased in the near future, the gap between the EU and the US, both in terms of R&D investment and consequently of R&D intensity, will continue to widen.

To ensure that the EU economies improve their competitiveness vis-à-vis the US, let alone achieve the Lisbon objective of becoming the most competitive knowledge-based economy in the world, the EU needs to increase substantially the quantity and quality of investment in research. As was agreed at the Heads of State Summit in Barcelona in 2002, the overall spending on R&D in the EU should be increased with the aim of approaching the level of 3% of GDP by 2010. Two-thirds of this investment should come from private sector sources. A significant increase in R&D investment by the business sector is a demanding challenge. However, it is not simply a matter of individual firms spending more on research. A study by Muldur (2001) points out that research investment by the largest European multinational firms is comparable to those in the US. In reality, though, there are simply more companies spending large amounts of money in a number of different industrial sectors in the US (see Chapter 3 for a detailed review on business R&D).

In addition to the fact that the private sector should contribute the bulk of new investment and that business should enhance its R&D performance, research by the higher education and the government sectors should also be strengthened.

Public funding is important not only to achieve the overall target of 3%, but it can also play an important role in creating systemic improvements and new incentives that will boost business sector investment. A "multiplier effect" through joint financing schemes and research infrastructure support is also a crucial part of creating a fertile environment for new R&D-intensive businesses.

Because of the potential systemic failures of national innovation systems (e.g. mismatches, inefficiencies, lack of collaboration), an increase in funding in itself is not enough. While availability of sufficient funding is a precondition for success in innovation, efficiency of financing and implementation are also crucial factors.

Since the mid-1990s, progress has been made in the way public funding is allocated. Currently, more funds are awarded on a competitive basis and through intermediate public funding bodies, i.e. not directly from the government budget. On the other hand, more attention could be paid to ways in which to increase the capacity of national innovation systems to produce, disseminate and introduce new knowledge. Thus, in order to become the most competitive and dynamic knowledge-based economy in the world, the EU needs, among other things, to:

1) strengthen private-sector effort in R&D through updated policy measures (loans, guarantee schemes, fiscal incentives, venture capital support, public subsidies) and through creating a favourable environment for increasing R&D investment by the private sector;
2) create fruitful conditions for strengthening the production of knowledge by public research, and to implement strategies for a more efficient system of public research (e.g. incentive mechanisms, management and evaluation in public research institutes);
3) ensure a favourable environment for the process of transformation of new knowledge into technological advancement and innovation (e.g. issues such as regulatory environment for R&D, especially intellectual property rights);
4) enhance the transmission of knowledge and know-how through encouraging increasing interplay and collaboration between various players of the innovation system, and through education, training and life-long learning.

Trends in government-financed R&D and developments in expenditure on R&D by government laboratories and higher education institutions need to be discussed as well. In the EU, the role of governments in R&D financing has diminished since the mid-1990s. This is reflected in the negative growth of the government share of total R&D financing and in the poor real growth of R&D financed by government. However, there are marked differences between individual EU countries. Since 1995, smaller EU economies (e.g. Belgium, Finland) and countries that are catching up from a low level of investment (e.g. Portugal, Greece, Ireland) recorded the highest growth rates of R&D investments. At the same time, the larger EU economies have struggled, showing either moderate or negative growth rates for public investments.

In the EU, the moderate growth rate of R&D expenditure by government laboratories, as well as the declining share of these laboratories in respect of total R&D performance, suggest that the role of the government sector in national innovation systems has decreased, especially in relative terms. Government research institutes seem to have experienced difficulties in re-defining their position in the context of new modes of knowledge production, new societal and/or governmental demands of R&D, and increased co-operation between various actors throughout the R&D system (including R&D performers and financing bodies).

The government sector still plays a major role in R&D performance, especially in Portugal, Spain, Italy and France. However, France is the only EU country where the government sector's share of public R&D (and of total R&D) is higher than that of the higher education sector. The situation is the opposite in Sweden, Austria, Ireland and Belgium, where the government sector's share of total R&D performance is very low, and where higher education institutions account for most public R&D.

There is much diversity within the EU with regard to R&D expenditure by the higher education sector. In some countries, funding for higher education has increased favourably, while in others it has either stagnated or even declined. Since the mid-1990s, countries such as Greece and Portugal have displayed the highest growth rates, even though their volume of investment is quite small in terms of absolute spending. The higher education sector plays an important role in the innovation system especially in Greece, Portugal, Italy, Austria, Spain and the Netherlands. In these countries, the sector accounts for over 25% of total R&D performance. In addition, because of the moderate role of government laboratories in R&D, the higher education sector's share of total public R&D in Belgium, Sweden and Austria exceeds the 80% mark. In practical terms, this means that universities in Belgium, Sweden and Austria are expected to assume a broader responsibility of what is called the "third mission". Thus, universities are expected to show an increasing commitment to the needs of the economy and society at large, and to collaborating with other R&D performers and users of research findings.

A prominent recent feature of the R&D system in the EU has been the increased role of the business sector as a financier of research by public sector organisations. The growing share of funding by business enterprises also indicates that firms are willing to exploit public research, and that public research institutes are willing to intensify co-operative activities with businesses and to commercialise their expertise. In so doing, both government laboratories and higher education institutions are increasing their impact on the economy and extending their traditional role. For instance, government laboratories do this by focusing on research positioned between the R&D conducted by business firms, on the one hand, and universities on the other, in addition to fulfilling various missions assigned to them by government.

Selected Bibliography

Arnold, E. (2001) *Can we measure the socio-economic effects of basic science?* Technopolis, Brighton.

Arrow, K. (1962) Economic welfare and the allocation of resources to innovation, in: Nelson, R. (ed.): *The rate and direction of inventive activity*. Princeton University Press, New York.

Battelle (2002) Battelle R&D funding forecast, *R&D Magazine*, F1–11.

BMBF (Bundesministerium für Bildung und Forschung) (2001) *Zur technologischen Leistungsfähigkeit Deutschlands* (2000). BMBF, Bonn.

Bozeman, B. & M. Crow (1998) *Limited by design – R&D laboratories in the US national innovation system.* Columbia University Press, New York.

Cox, D., P. Gummett & K. Barker (2001) *Government laboratories – transition and transformation*. IOS Press, Amsterdam.

David, P., & B.H. Hall (1999) *Heart of darkness: public-private interactions inside the R&D black box*. Stanford University, Department of Economics, Discussion Paper 1999-W16.

European Commission (2000) *Towards a European research area.* Communication from the Commission to the Council, the Economic and Social Committee and the Committee of the Regions. European Commission, Luxembourg.

European Commission (2002a) *A comparative analysis of public, semi-public and recently privatised centres*. Final project report, Part I: Summary report of the CBSTII contract ERBHPV2-CT-200-01. Compiled by PREST on behalf of the “Eurolabs” project consortium European Commission, DG-Research.

European Commission(2002b) *Science and Society Action Plan*. Luxembourg.

European Commission (2002c) Benchmarking of National Policies: Public and Private Investments in R&D. Final report by the expert group appointed by the European Commission. *http://www.cordis.lu/rtd2002/era-developments/benchmarking*.

Eurostat (1994) *NABS: Nomenclature for the Analysis and Comparison of Scientific Programmes and Budgets*. Luxembourg.

Eurostat (2000) *Statistics on science and technology in Europe. Data 1985–1999*. Luxembourg.

Eurostat (2001) *Research and Development: Annual Statistics, Data 1990–2000* Luxembourg.

Eurostat (2002) *Science and Technology in Europe. Statistical Pocketbook, Data 1990–2000*, Luxembourg.

Gummet, P. et al. (2000) The changing central government of science and technology, in: Rhodes, R.A.W. (ed.): *Transforming British Government. Vol.2: Changing roles and relationships*. MacMillan, Houndsmills.

Henderson, R., A.B. Jaffe & M. Trajtenberg (1998) University patenting amid changing incentives for commercialisation, in: Barba Navaretti, G. et al (eds.): *Creation and transfer of knowledge: institutions and incentives*. Springer, Berlin.

Howells, J. & A. James (2001). Corporate Decision-making on the Sourcing of Technological Knowledge. *PREST/University of Manchester, Discussion Paper* 01-2001.

Husso, K., S. Karjalainen & T. Parkkari (eds.) (2000) *The state and quality of scientific research in Finland. A review of scientific research and its environment in the late 1990s.* Academy of Finland.

Innocult (Internationalisation of Research: Institutional Innovation, Culture and Agency in the Framework of Competition and Co-operation project consortia) (1999) *Analysing National Research Systems, Culture and RTD Co-operation*, http://www.iccr-international.org/innocult/index.html.

JM Consulting (2002) *Research relationships between higher education institutions and the charitable sector*. Higher Education Funding Council for England (HEFCE).

Larédo, P. et al. (1992) Defining the strategic profile of research labs: the Research Compass Card Method, in: Van Raan, A.F.J. et al (eds.): *Science and technology in a policy context*. DSWO Press, Leiden.

Martin, B. et al. (1996) *The relationship between publicly funded basic research and economic performance.* Report prepared for HM Treasury. Science Policy Research Unit, University of Sussex.

METI (Ministry of Economy, Trade and Industry of Japan) (2002) *Structural reform issues and economic and industrial policy*. METI, http://www.meti.go.jp.

MEXT (Ministry of Education, Culture, Sports, Science and Technology of Japan) (2001) *Annual report on the promotion of science and technology*. MEXT, http://mext.go.jp/english/news.

Muldur, U. (2001) 'Is capital optimally allocated in the overall process of European innovation?' in Revue d'Economie Industrielle, numéro spécial: *What Policies in Support for R&D*, No 94 (1er semestre 2001) pp. 115-152.

NSF (1998) *National Science Board, Science and engineering indicators 1998*, volume 1. National Science Foundation, Arlington, VA.

NSF (2000) *National Science Board, Science and engineering indicators 2000*, volume 1. National Science Foundation, Arlington, VA.

NSF (2002) *National Science Board, Science and engineering indicators 2002*, volume 1. National Science Foundation, Arlington, VA.

OECD (1993) *Frascati Manual*. Paris.

OECD (1998) *University research in transition*. Paris.

OECD (1999) *Managing innovation systems*. Paris.

OECD (2000) *Science, Technology and Industry Outlook*. Paris.

OECD (2001a) *Main Science and Technology Indicators* 2001-2. Paris.

OECD (2001b) *Science, Technology and Industry Outlook 2001. Drivers of Growth: Information Technology, Innovation and Entrepreneurship*. Paris.

OECD (2001c) *Science, Technology and Industry Scoreboard 2001. Towards a Knowledge-based Economy.* Paris.

OECD (2002a) *Main Science and Technology Indicators* 2002-1. Paris.

OECD (2002b) *Benchmarking Industry–Science Relationships*, Paris.

OECD (2002c) *Dynamising National Innovation Systems*, Paris.

Pavitt, K. (1991) What makes basic research economically useful? *Research Policy* 20: 2, 109–119.

Polt W. et al. (2001) *Benchmarking industry-science relations – the role of framework conditions*. Project commissioned by the European Commission, DG-Enterprise and the Austrian Federal Ministry for Economic Affairs and Labour (BMWA). Brussels, European Commission. http://www.benchmarking-in-europe.com.

Pottelsberghe, B. van, C. Peeters & A. Romain (2001) *The effectiveness of S&T policies: a macroeconomic perspective*. Unpublished document prepared for the European Commission, DG-Research.

PREST et al. (2002) *Assessing the Socio-economic Impacts of the Framework Programme*. University of Manchester/ PREST, Manchester.

Rosenberg, N. (1992) Scientific instrumentation and university research. *Research Policy* 21: 4, 381–390.

Salter, A. et al. (2000) *Talent, not technology. The impact of publicly funded research on innovation in the UK*. Science Policy Research Unit, University of Sussex.

Schmoch, U., G. Licht & M. Reinhard (2000) *Wissens- und Technologietransfer in Deutschland*. Fraunhofer IRB Verlag, Stuttgart.

Science and Technology Policy Council of Finland (1996) *Finland: a knowledge-based society*, Helsinki.

Smith, K. (2000) Innovation as a systemic phenomenon: rethinking the role of policy. *Enterprise and Innovation Management Studies* 1: 1, 73–102.

DOSSIER I

Government Budget Appropriations for R&D: Stagnant over the Past Decade

Traditionally, a major challenge for governments has been to maintain the level of R&D funding necessary to fuel R&D conducted mainly by the higher education and government sectors, and, to a lesser extent, by the business enterprise sector. Currently, the new role of public authorities is evident from governments' growing efforts to create suitable conditions for innovation, to support dissemination of knowledge throughout the economy, and to increase multilateral collaboration among the parties involved with R&D enterprise (e.g. OECD 2000, 2001b, 2002a).

The priorities of government-financed R&D are to enrich the knowledge base by allocating resources to universities and public sector research institutes, and by encouraging investigation in new scientific and technological areas. Through public-private co-financed programmes, for instance, governments also play an increasingly important role in stimulating R&D investment and knowledge creation in the business sector (see PREST et al., 2002; OECD, 2002b).

This dossier investigates the role of government in R&D from the perspective of Government Budget Appropriations and Outlays on R&D (GBAORD). The dossier analyses GBAORD from three viewpoints. Firstly, the evolution of government R&D budgets in the EU as a whole and the US and Japan are compared. Secondly, the trends of total government R&D budget in individual EU countries are analysed. Thirdly, the developments in government budget appropriations on R&D, broken down by socio-economic objective, are investigated (see the box on "Definitions and general information").

Government R&D budgets are explored by using the following main indicators:

- Volume and average annual growth of government R&D budget,
- Share of government budget allocated to R&D in relation to GDP,
- Government R&D budget by socio-economic objective.

Government budget appropriations and outlays on R&D: definitions and general information

The data on government budget appropriations in respect of R&D (GBAORD) is based on information obtained from central government or federal budget statistics. The data involve all the budget items involving R&D and measuring or estimating their R&D content in terms of funding (see OECD, 1993). Data cover government-financed research in all other sectors of performance, including R&D carried out abroad.

The figures provide information on budget provisions rather than on money actually spent. Thus, GBAORD provides an overall picture of governments' intended spending and on their investment decisions. In most of the cases, there are differences between final actual spending and initial budget figures (for more, see Eurostat 2000, 2001).

Not only does the volume of R&D budgets differ from country to country, but priorities set by governments can also be very different. Because GBAORD can be broken down by socio-economic objectives (so-called NABS categories), it is possible to take a closer look at the structure of R&D financing by government. Government R&D budgeting by socio-economic objectives reveals information on trends and allocation of funds for different purposes, and on R&D-related policy issues and governments' investment priorities (Eurostat, 2001). Government budget appropriations or outlays on R&D can be broken down by socio-economic objectives in many ways. In this dossier, as introduced in the *Nomenclature for the Analysis and Comparison of Scientific Programmes and Budgets* (see Eurostat, 1994), the socio-economic objectives are as follows:

1) Exploration and exploitation of the Earth
2) Infrastructure and general planning of land-use
3) Control and care of the environment
4) Protection and improvement of human health
5) Production, distribution and rational utilisation of energy
6) Agricultural production and technology
7) Industrial production and technology
8) Social structures and relationships
9) Exploration and exploitation of space
10) Research financed from General University Funds (GUF)

11) Non-oriented research
12) Other civil research
13) Defence

Another way to present the socio-economic objectives is to group them into two new objective categories, being 'Human and social objectives' and 'Technological objectives'.

'Human and social objectives': The group comprises the categories of 'Infrastructure and general planning of land-use'; 'Control and care of the environment'; 'Protection and improvement of human health' and 'Social structures and relationships'.

'Technological objectives': This group comprises the four objectives, 'Exploration and exploitation of the Earth'; 'Production, distribution and rational utilisation of energy'; 'Industrial production and technology'; 'Exploration and exploitation of space'.

The classification is otherwise the same as described earlier. In accordance with this method, the number of objectives can be reduced to seven. This grouping is used in this dossier when investigating the R&D budget for civil research.

The data for the US are systematically underestimated. Since the data exclude 'Research financed from general university funds' and 'Other civil research', comparisons with the other countries should be made with caution. The data for Japan exclude R&D in the social sciences and humanities. Also the R&D portion of military contracts is excluded. Hence, the Japanese data are also underestimated and only to some extent comparable with the data for other countries (Eurostat, 2001).

Section I EU and US: no major changes in total government investment between R&D between 1991–2000

Measured in terms of government budget appropriations for R&D, investments in the EU in 2000 amounted to approximately PPS[1] 54 billion, or 62 billion euro, in current terms. This figure was equal to 0.73% of the GDP (figures D1.1.1 & D1.1.2). Compared to the US, it is clear that EU governments invested less in R&D-related activities, both in absolute and in relative terms. In fact, the US maintained its lead over the EU throughout the decade.

Poor development of the volume of GBAORD in the EU is evident from comparisons of the volume of investments in the 1990s. In real terms, the volume of GBAORD for the EU in 2000 was almost PPS 1.3 billion lower than in 1991, with the result that GBAORD decreased by 2.4% over the period. Accordingly, in spite of the turnaround in the mid-1990s and the favourable development of GBAORD in the past few years, the EU has still not managed to return to the funding levels it reached in the early 1990s.

In 2000, the real volume of government R&D investment in the US and Japan were PPS 67 billion (85 billion euro) and PPS 18 billion (33 billion euro), respectively. Thus, in real terms, the US invested almost PPS 13 billion more than the EU. At the same time, the difference in the volume of investment between the EU and Japan was some PPS 36 billion in the EU's favour. This gap has remained more or less the same since 1997, but has diminished in comparison to the situation in the early 1990s. Thus, in the 1990s, the EU managed neither to decrease the investment gap in relation to the US, nor to increase the gap in relation to Japan.

As a proportion of GDP, government budget appropriations for R&D have declined in the EU and the US since the early 1990s (figure D1.1.2). The EU figure decreased from 0.9% in 1991 to 0.7% in 2000; the corresponding figures for the US were 1.1% and 0.8%. In spite of this downward trend, GBAORD remains highest in the US.

Japan has shown the opposite trend. In relation to GDP, GBAORD has increased continuously from a level of 0.4% in 1991 to over 0.6% in 2000. The figure has increased partly because of the stagnation of GDP growth after 1997. However, this does not give the full picture, as shown in figures D1.1.3 and D1.1.4. Compared to development in the EU countries and the US, the average annual real growth of the government R&D budget in Japan was among the highest in the 1990s. In general, there has been a convergence of the figures for the three economic blocs since 1991, as is displayed in figure D1.1.2 (GBAORD as % of GDP).

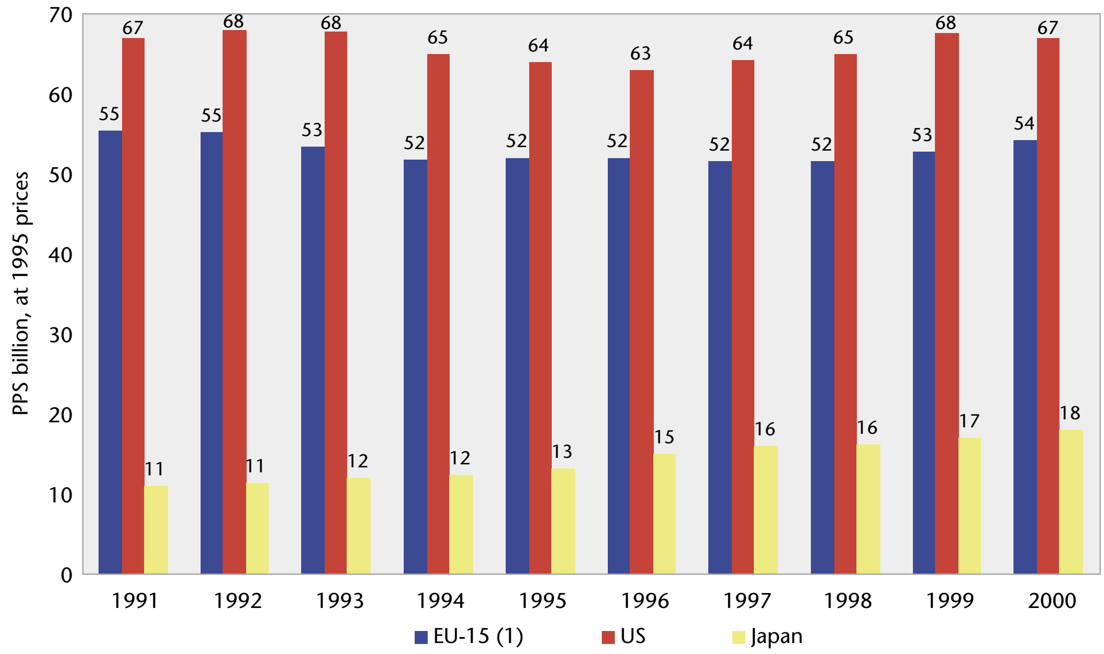
Figure D1.1.3 shows the average annual real growth of GBAORD over two consecutive periods (1991–1995 and 1995–2000) in the EU, the US and Japan. It also compares the growth rates for two distinct EU country groups:

- the group comprising the four largest EU economies and R&D investors (EU-4: Germany, France, Italy, United Kingdom);
- the remaining EU countries (EU-10 excluding EU-4 and Luxembourg).

In the period 1991–1995, the volume of government budget appropriations for R&D declined in EU-15 and the US. The negative rate of growth was the highest for the four major EU economies (–2.2% per year), while in the other EU

[1] *Purchasing Power Standards, at 1995 prices and exchange rates. This applies to all PPS values in this dossier.*

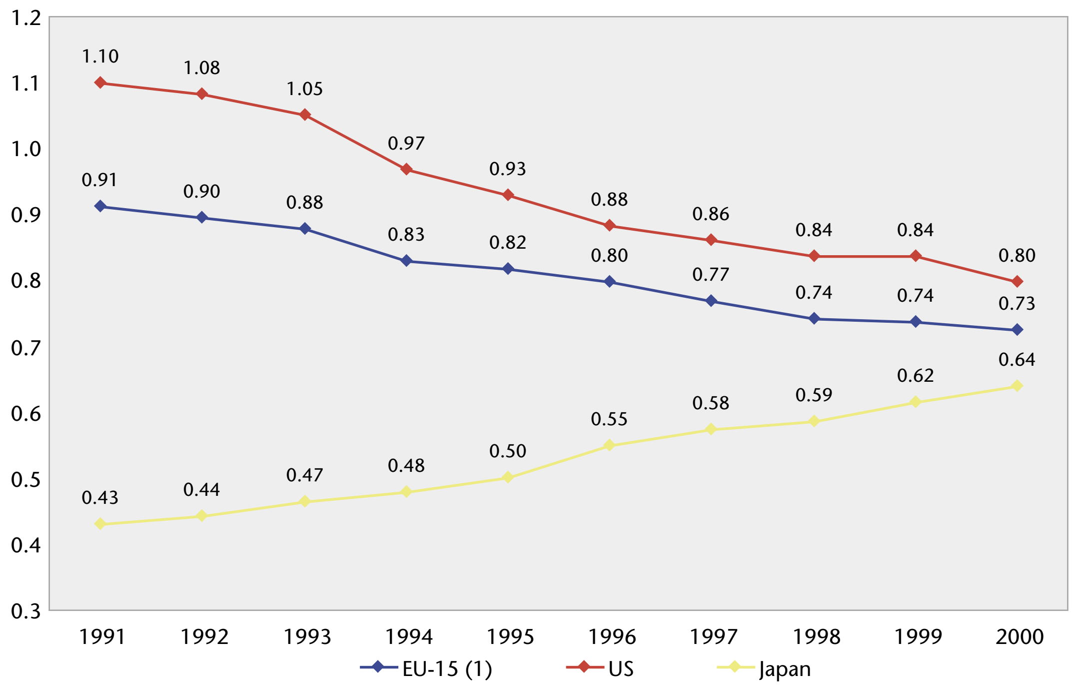
Figure D1.1.1 Government budget appropriations for R&D in real terms (PPS, at 1995 prices), 1991-2000



Source: DG Research
Data: Eurostat (NewCronos), OECD, DG Research provisional estimates
Note: (1) L data are not included in EU-15 average.

Third European Report on S&T Indicators, 2003

Figure D1.1.2 Government budget appropriations for R&D – % of GDP, 1991-2000



Source: DG Research
Data: Eurostat (NewCronos), OECD, DG Research provisional estimates
Note: (1) L data are not included in EU-15 average.

Third European Report on S&T Indicators, 2003

economies the figure was positive, at 1% per year. The situation changed between 1995 and 2000. During the latter half of the decade, all the countries and country groups – with the exception of EU-4 – experienced positive growth rates with regard to GBAORD. For instance, EU-15, the US and Japan recorded average annual real growth rates of 0.8%, 0.9% and 6.5%, respectively. Thus, the EU and the US had approximately the same growth rates, but these were significantly lower than Japan's rate.

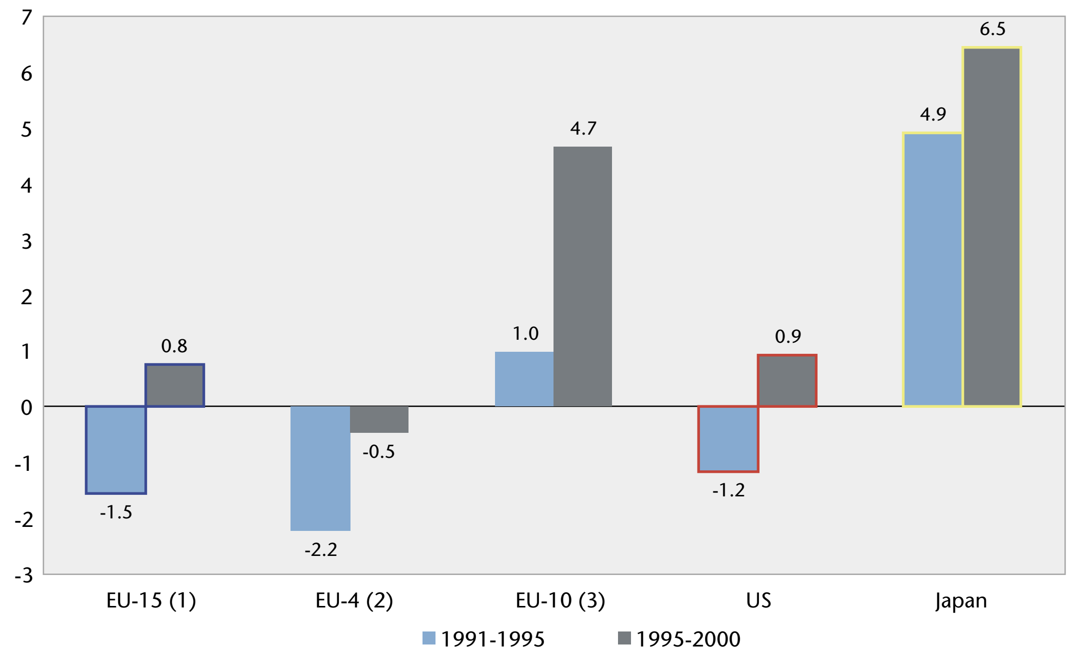
The relatively slow development of budget-based R&D funding in the EU in the 1990s was due mainly to the near-zero or even negative growth rates in the largest EU economies. Throughout the 1990s, the rates of growth for EU-10 were positive, and higher than the rates of the US.

Considering the latest trends in budget-based R&D funding, there are large differences within the EU area. This indicates that the EU governments have had different strategies and budgetary emphases in respect of their commitment to investing in new knowledge and to budgeting funds for R&D activities.

Since the mid-1990s, government budgetary funding of R&D activities has increased most in small EU economies and in EU countries with low R&D intensity. The average annual real growth of government R&D budgets has been the highest in Spain (11% per year), Portugal (11%) and Ireland (9%) (figure D1.1.4). These three countries stand out in the EU group, being the only EU countries scoring better than Japan. Comparatively high growth rates of GBAORD were also recorded for Greece (averaging 5% per year), Finland and Belgium. The growth rates in other EU countries were all below 4%.

High growth rates raise the question of the reasons for, and factors involved in, the favourable development of government R&D financing. In general, one may argue that science and technology policies have been put high on the political agenda in the countries concerned. Apparently, this has facilitated the favourable increase in R&D budgets. However, a more detailed investigation shows that the growth factors differ significantly among those EU countries that have recorded high GBAORD growth rates (see box on "Definitions and general information" and the next section on socio-economic objectives). For instance, in Spain, the increase in defence-related R&D accounted for almost half of the growth of GBAORD in 1995–2000[2]. All the other categories of socio-economic objectives of government R&D investments increased as well, although to a lesser extent. In Portugal, the major source of growth in GBAORD was investment in

Figure D1.1.3 Government budget appropriations for R&D – average annual real growth (%) (1991-1995 and 1995-2000)



Source: DG Research
Data: Eurostat (NewCronos), OECD, DG Research provisional estimates
Notes: (1) L data are not included in EU-15 average. (2) EU-4 comprises the largest EU economies, i.e. D, F, I and UK. (3) EU-10 comprises the EU countries excluding EU-4 and L.

Third European Report on S&T Indicators, 2003

[2] *In Spain, because of an exceptional contribution by the Ministry for Industry and Energy, the defence objective in government R&D budget almost doubled in 1997 (OECD 2001a).*

'Research financed from General University Funds' (GUF). This category accounted for over 28% of the total increase in government budget investments in R&D.

'Research financed from General University Funds' is the largest of the R&D budget items, accounting for over 31% of total GBAORD in 2000. It has also been a major factor in GBAORD growth in the EU in 1995–2000. GUF accounted for almost a third of the total growth of government-financed research. In the Netherlands, Denmark, Portugal, Finland, and Greece, GUF was clearly the major source of growth in GBAORD. In the Netherlands, university funds accounted for 61% of the total increase in government R&D funding in the period 1995–2000. In Italy and Belgium, government funding increased particularly in the area of 'Technological objectives', or more specifically, in the NABS category of 'Industrial production and technology'. In Italy and Belgium, this category accounted for 59% and 48%, respectively, of total GBAORD growth (see the next section for more on the impact of different socio-economic objectives on GBAORD).

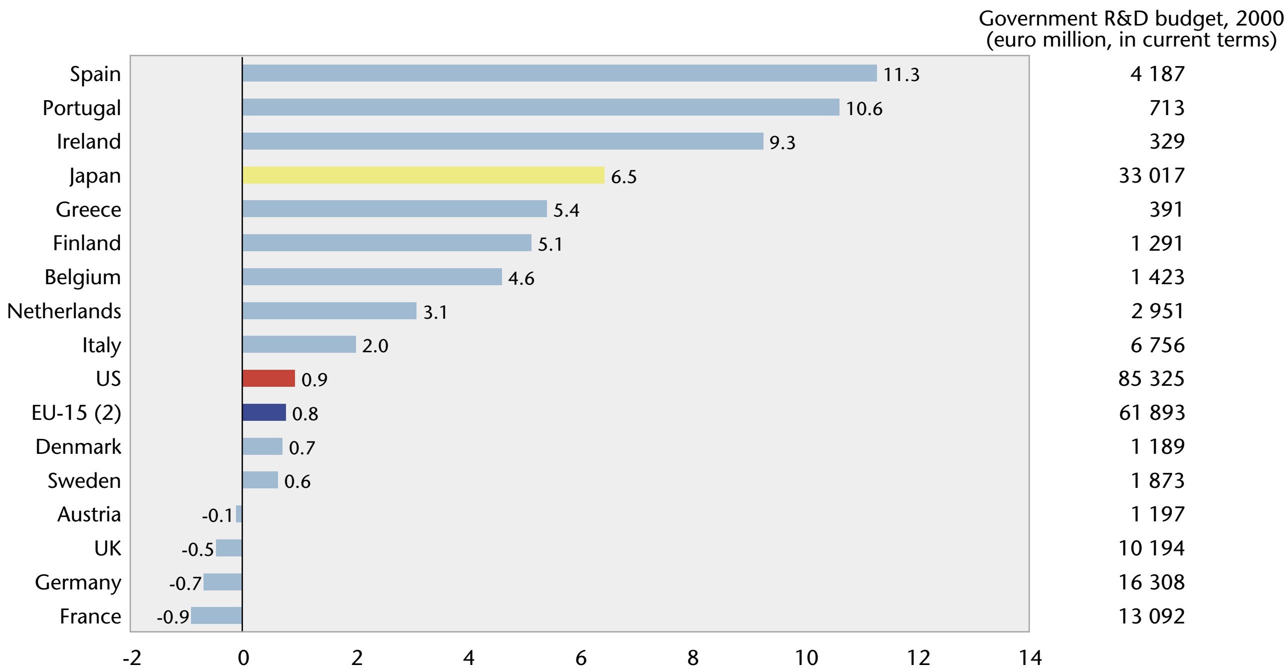
Compared to US growth over the 1995–2000 period, the relative growth of R&D support in government budgets was slower in three of the four major EU economies (D, F, UK) (figure D1.1.4). Of the major EU economies, only Italy (2%) managed to maintain a faster growth rate than the US, and to record a higher rate than the EU average. Through these efforts, Italy has compensated – at least partially – for large cutbacks in its R&D budget earlier in the decade.

In spite of this positive development, Italy remains part of the group of five countries, comprising the four main EU economies and Sweden, in which the absolute volume of GBAORD in real terms in 2000 was at a lower level than it was in 1991. In this group, the combined volume of government resources devoted to R&D activities fell by more than 11% between 1991 and 2000. Even excluding defence-related R&D – the budget item responsible for most cutbacks in government investments – only the UK is currently earmarking more resources for R&D than in the early 1990s.

Figure D1.1.5 shows the ratio between the average annual real growth of GDP and GBAORD in the EU countries, the US and Japan in 1995–2000. In most of the EU countries, the average annual real growth of GDP was between 2% and 4%, while the average growth of GBAORD had a wider range from –1% to +6%.

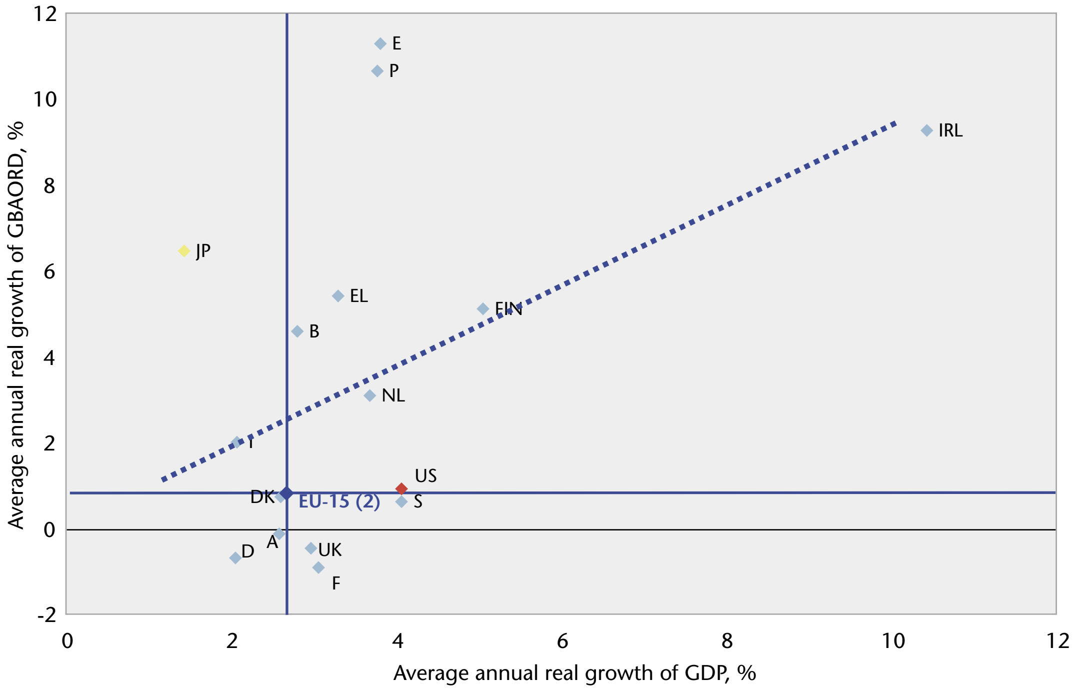
Figure D1.1.5 also suggests that Spain, Portugal, Greece, Belgium and Japan increased resources going to GBAORD more than might have been expected on the basis of growth of GDP and a comparison with other countries. In other words, in these five countries, GBAORD grew at a higher rate than GDP. The situation is the reverse in the UK, Austria, Germany and France, where in spite of the favourable real growth in GDP (2–3% per year), the rate of growth in GBAORD in real terms was negative in the late 1990s. In general terms, an examination of the ratio of the growth rates of the variables shows substantial differences between individual countries. It

Figure D1.1.4 Government budget appropriations for R&D – average annual real growth (%), 1995-2000 (1)



Source: DG Research
Data: Eurostat (NewCronos), OECD, DG Research provisional estimates
Notes: (1) D, F, IRL, IT: 1996-2000; DK: 1997-2000; S: 1998-2000. (2) L data are not included in EU-15 average.
Third European Report on S&T Indicators, 2003

Figure D1.1.5 Average annual real growth rates of GDP and GBAORD, 1995-2000 (1)



Source: DG Research
Data: Eurostat (NewCronos), OECD, DG Research provisional estimates
Notes: (1) D, F, IRL, IT: 1996-2000; DK: 1997-2000; S: 1998-2000. (2) L data are not included in EU-15 average.
Third European Report on S&T Indicators, 2003

is also apparent that the relationship between the two variables is comparatively weak.

In 2000, Finland (0.98%) and France (0.92%) were the countries with the highest volume of government investment in R&D activities relative to GDP (figure D1.1.6). In Germany, Sweden and the Netherlands, the ratio was also above the EU average. Only Finland, France and Germany recorded higher GDP shares of government R&D funding than the US (0.8%).

At the opposite end of the scale among the EU countries, Ireland and Greece represented the lowest volume of government budget appropriations, allocating only around 0.3% of their GDP to R&D activities. At the same time, as far as growth rates are concerned, it needs to be emphasised that GBAORD and GDP grew faster in both Ireland and Greece than the EU average (figure D1.1.5). The figures recorded for Belgium, Italy, Austria and Portugal were also comparatively modest at around 0.6%, and below the relative investment volume recorded for Japan.

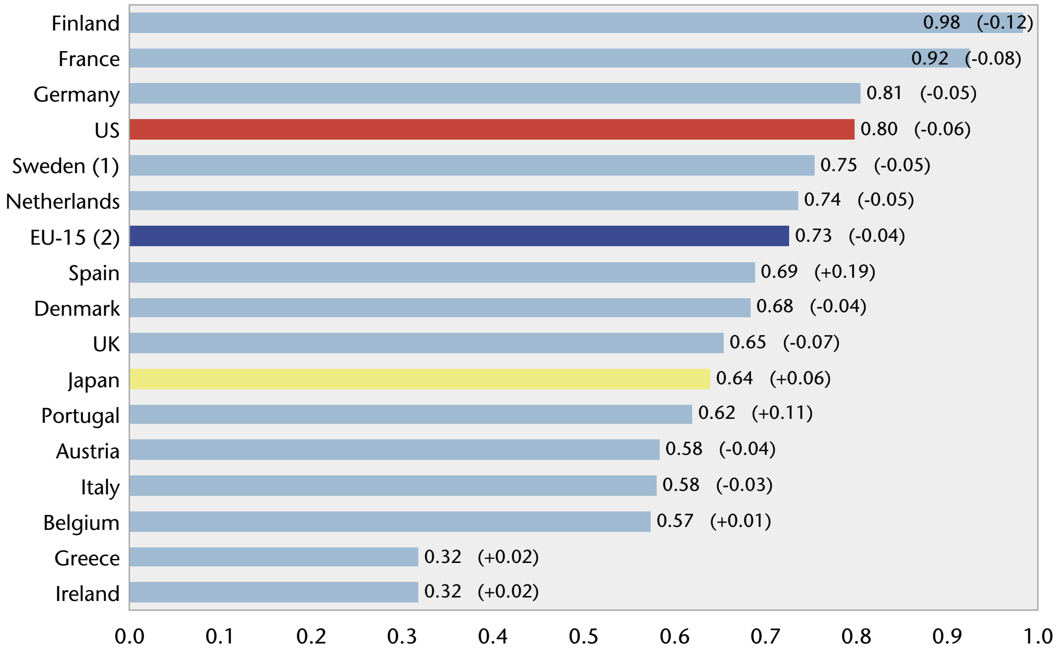
During the latter half of the 1990s, government investment in R&D relative to GDP declined steadily in most individual EU countries, the EU as a whole and in the US (figure D1.1.6). The pattern is most apparent in Finland (–0.12 percentage points in 1997–2000), France (–0.08), the UK (–0.07), and Sweden (–0.05[3] in 1998–2000). Finland and France were still the biggest public R&D investors in relative terms. On the other hand, GBAORD relative to GDP increased in five EU countries since 1997. The highest growth of the GBAORD/GDP ratio was experienced in Spain (+0.19 percentage points) and Portugal (+0.11 percentage points), i.e. in the same countries that have recorded highest average annual real growth of GBAORD since the mid-1990s.

In terms of development over the whole of the 1990s period, government R&D budget relative to GDP has shown the most notable downward trend in France and Sweden. In 1991, these two countries recorded exceptional GBAORD/GDP ratios of 1.35% and 1.23%, respectively, which were almost 0.5 percentage points higher than the corresponding figures in 2000.

In France, Sweden and the UK, a relative decrease in the government R&D budget is generally due to cutbacks in defence-related spending. The same three countries, together with Germany, Austria and Denmark, form the group of EU Member States where the volume of GBAORD in real terms has either only increased very modestly or has actually decreased since 1995 (figure D1.1.4).

[3] *The figure for Sweden in 1997–2000 was –0.21 percentage points. However, a break in series in 1998 reduces the reliability of the figure and prevents a reliable comparison over the entire period.*

Figure D1.1.6 Government budget appropriations for R&D as % of GDP, 2000
Growth of the share from 1997 to 2000 in brackets (percentage points)



Source: DG Research
Data: Eurostat (NewCronos), OECD, DG Research provisional estimates
Notes: (1) S: 1998-2000 instead of 1997-2000. (2) L data are not included in EU-15 average.
Third European Report on S&T Indicators, 2003

Section II Government R&D budget by socio-economic objectives

Major objectives in total R&D budget: defence research makes a difference

Table D1.2.1 illustrates the total government budgets for R&D by socio-economic objectives in the EU, the US and Japan. As discussed earlier in this dossier, the total volume of government R&D budget in the US in 2000 was about PPS 13 billion higher than in the EU (EU: PPS 54 billion, 62 billion euro in current terms; US: PPS 67 billion, 85 billion euro). Defence R&D has a strong influence on the volume of GBAORD in the EU, and especially in the US. In 2000, the volume of defence R&D in the US was five times bigger than that of the EU. In addition, defence R&D has increased recently in the US, which is the reverse of the trend in the EU. Because of this development in the defence R&D sector, the US has managed to maintain its advantage over the EU in terms of GBAORD-related investment at the level of PPS 12–15 billion in the 1990s and in 2000.

In some EU countries, defence R&D still plays a major role. This situation is most discernible in the UK, France and Spain, where defence R&D was the most important single socio-economic category. Likewise, the defence-related R&D investment share of total GBAORD in these three countries was the highest in the EU group in 2000, accounting for 23–33% of total government-financed R&D spending. In addition, defence-related research in Spain accounted for almost half of the growth in total R&D financing by the government in 1995–2000 (for more on defence R&D, see the box on “Defence R&D budget”, below).

Table D1.2.1 displays differences in the volume and structure of GBAORD across the EU area and between the EU, the US and Japan. In the EU, ‘Research financed from General University Funds’ (GUF) was the leading socio-economic objective, with an absolute volume of 19.2 billion euro in 2000. The next largest budget items were ‘Non-oriented research’ (9.5 billion euro) and ‘Defence’ (9.2 billion euro). Together these three objectives accounted for over 61% of total GBAORD at the EU level. In Japan, the three objectives accounting for most of the budgetary R&D spending, with a combined share of almost 68% of total GBAORD, were ‘Research financed from General University Funds’ (11.7 billion euro), ‘Protection, distribution and rational utilisation of energy’ (6.0 billion euro) and ‘Non-oriented research’ (4.6 billion euro).

In the US, over half of total GBAORD in 2000 was allocated to 'Defence' (table D1.2.1). The next categories in terms of absolute volume and share of total GBAORD were 'Protection and improvement of human health' (20.0 billion euro) and 'Exploration and exploitation of space' (9.2 billion euro). In the US, all three categories accounted for significantly higher volumes and larger shares of total GBAORD than in the EU or Japan. Of the 11 socio-economic objectives available in the US, the above-mentioned three accounted for over 85% of the total government R&D budget. No data are available for the categories of 'Research financed from GUF' and 'Other civil research'. Hence, the structure of the US government R&D budget differs substantially from that of the EU and Japan.

R&D budget for civil purposes: large differences in government funding priorities

Table D1.2.2 shows government R&D budgets for civil R&D – i.e. GBAORD excluding the category of defence-related research – in the EU, the US and Japan in 2000. An important aspect is that when only the volume of budgetary appropriations for civil R&D is included, a very different picture of the EU and the US emerges. In 2000, the EU group spent a total of PPS 46 billion (53 billion euro) on civil R&D; this was 25% above the corresponding investment figure in the US in current terms (42 billion euro).

On the one hand, if defence R&D is excluded, Europe is in a better situation, with the EU governments' R&D spending exceeding that of the US. On the other hand, although defence R&D includes research carried out primarily for defence-related purposes, the content of investigations may also have significant long-term effects and multiplier impacts on the economy and civil R&D and applications. Hence, for an overall picture of the total impact of R&D on the economy, the role of defence R&D should not neither be underrated nor ignored. Civil and defence R&D should not be considered as isolated spheres of research. Moreover, civil and defence R&D cannot simply be separated without ignoring their interplay within the entire R&D system and the special role these spheres of research have in that system (see also the box "Defence R&D budget").

When investigating civil R&D by socio-economic objectives in the EU, it becomes apparent that two socio-economic objectives – 'Research financed from General University Funds' and 'Technological objectives' – are responsible for over 60% of the civil R&D budget at the EU level. One or the other of these two objectives was the most important R&D budget item in all EU countries (also in Japan), except in Ireland and the UK. 'Research financed from General University Funds' was the most important category of investment by

Table D1.2.1 Government budget for R&D – by socio-economic objectives (NABS) (€ million, in current terms, 2000) (1)(2)

Socio-economic objectives	B	DK	D	EL	E	F	IRL	I	NL	A	P	FIN	S	UK	EU	US	JP
Exploration and exploitation of the earth	14	15	297	15	83	76	1	110	24	29	12	20	31	145	872	1 116	556
Infrastructure and general planning of land-use	16	22	269	20	27	96	3	18	87	24	54	28	76	187	927	1 753	1 237
Control and care of the environment	51	33	560	13	112	239	5	168	114	25	31	29	26	260	1 666	582	264
Protection and improvement of human health	23	24	558	23	202	735	13	457	108	30	47	88	25	1545	3 877	19 977	1 282
Production, distribution and rational utilization of energy	39	24	570	6	152	664	:	302	89	5	6	68	108	51	2 085	1 206	5 965
Agricultural production and technology	42	148	410	27	176	321	47	142	90	40	93	70	35	420	2 060	1 893	1 144
Industrial production, and technology	321	76	1999	54	662	838	70	1045	386	76	93	367	102	62	6 151	405	2 231
Social structures and relationships	63	133	592	16	24	98	23	238	79	26	24	70	106	373	1 866	787	301
Exploration and exploitation of space	169	33	741	4	231	1437	.	587	90	1	4	27	63	255	3 641	9 163	1 836
Research financed from general university funds (GUF)	273	463	6274	179	895	2345	63	2875	1358	763	258	346	953	2148	19 193	:	11 702
Non-oriented research	340	212	2712	31	307	2942	104	755	315	177	58	159	:	1370	9 481	5 299	4 621
Other civil research	66	:	17	1	52	343	:	:	135	0.3	24	:	215	40	894	:	510
Defence	5	7	1308	3	1264	2960	:	59	76	0.3	8	17	133	3340	9 180	45 389	1 368
Total appropriations	1 423	1 189	16 308	391	4 187	13 092	329	6 756	2 951	1 197	713	1 291	1 873	10 194	61 893	87 569	33 017

Source: DG Research
Data: EUROSTAT (NEWCRONOS), OECD
Notes: (1) L data are not included in EU-15 average. (2) The US GBAORD data broken down by socio-economic objectives are derived from an earlier version of the US data for 2000 and not consistent with the latest available data used elsewhere in this dossier (cf. US data in figures D1.1.4 and D1.2.2). : Data not available.

Third European Report on S&T Indicators, 2003

far, with a 36% share of the total civil GBAORD in 2000 (table D1.2.2). The group of 'Technological objectives' accounted for 24% of civil GBAORD.

A closer look at government priorities in individual EU countries reveals that GUF was the main priority in eight EU countries, of which Austria, Sweden, the Netherlands, Greece and Italy recorded the highest shares (64–43% of the total).

The group of 'Technological objectives' was the most important NABS class in four countries, with Spain, Belgium and Finland (38–39%) being the leading ones. The share of 'Technological objectives' of civil GBAORD was around 30% in France and Italy.

The next socio-economic objectives in order of importance were 'Non-oriented research' (18%), and 'Human and social objectives' (16%). In France, 'Non-oriented research' accounted for nearly as high a share of civil GBAORD as the most important group ('Technological objectives'). In the UK, 'Human and social objectives' was the largest group of civil research (35% of total civil R&D).

The share of 'Human and social objectives' of total civil GBAORD across the EU countries ranged mainly from 11% to 19%. The share of 'Agricultural production and technology' was very low at 2–7%, except in Ireland with a share of 14%, and in Portugal and Denmark.

As 'Research financed from General University Funds' has traditionally been the most important R&D budget item in the EU, it warrants a closer look at the development of this area of government investment. As shown in figure D1.2.1, over the period 1995–2000 the average annual real growth of university funds has been highest in Portugal (8% per year), Finland (6%), Greece (5%), the Netherlands (5%) and Denmark (4%).

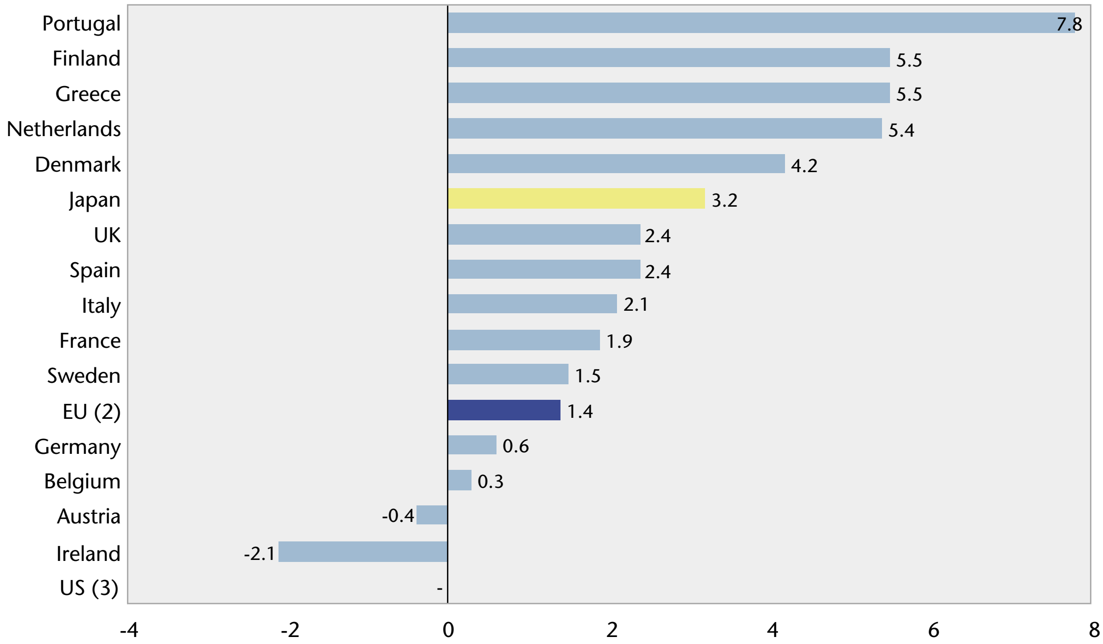
Table D1.2.2 Government civil R&D budget by socio-economic objective (NABS) share (%) of each NABS chapter in total civil GBAORD, 2000 (1) (2)

	GBAORD for civil purposes: euro million, in current terms, 2000	Agricultural production and technology %	Human and social objectives (3) %	Technological objectives (4) %	Research financed from General University Funds (GUF) %	Non-oriented research %	Other civil research %	Total %
B	1 418	3.0	10.8	38.3	19.3	24.0	4.7	100
DK	1 182	12.5	17.9	12.5	39.2	17.9	:	100
D	15 000	2.7	13.2	24.0	41.8	18.1	0.1	100
EL	388	7.0	18.4	20.2	46.1	8.0	0.3	100
E	2 923	6.0	12.5	**38.6**	30.6	10.5	1.8	100
F	10 132	3.2	11.5	29.8	23.1	29.0	3.4	100
IRL	329	**14.4**	13.3	21.5	19.2	**31.5**	:	100
I	6 697	2.1	13.2	30.5	42.9	11.3	:	100
NL	2 875	3.1	13.5	20.5	47.2	11.0	4.7	100
A	1 197	3.3	8.8	9.3	**63.7**	14.8	0.03	100
P	705	13.2	22.2	16.3	36.6	8.2	3.4	100
FIN	1 274	5.5	16.9	37.8	27.2	12.5	:	100
S	1 740	2.0	13.4	17.5	54.8	:	**12.4**	100
UK	6 854	6.1	**34.5**	7.5	31.3	20.0	0.6	100
EU (5)	52 712	3.9	15.8	24.2	**36.4**	18.0	1.7	100
US	42 180	4.5	**54.8**	28.2	:	12.6	:	100
JP	31 649	3.6	9.7	33.5	37.0	14.6	1.6	100

Source: DG Research
Data: EUROSTAT (NEWCRONOS)
Notes: (1) The figures in bold represent the highest value of each NABS chapter. The underlined figures denote the highest value in each country.
(2) Government investment in R&D is relatively most specialised in countries with the highest figures, both by NABS chapter and as compared to other countries (figures in bold and underlined).
(3) Human and social objectives include the following NABS chapters: 'Infrastructure and general planning of land-use'; 'Control and care of the environment'; 'Protection and improvement of human health'; 'Social structures and relationships'.
(4) Technological objectives include the following NABS chapters: 'Exploration and exploitation of the Earth'; 'Production, distribution and rational utilisation of energy'; 'Industrial production, and technology'; 'Exploration and exploitation of space'.
(5) L data are not included in EU-15 average.
: Data not available

Third European Report on S&T Indicators, 2003

Figure D1.2.1 General University Funds (GUF) in government R&D budget – average annual rate of growth (%), in real terms (PPS, at 1995 prices), 1995-2000 (1)



Source: DG Research
Data: Eurostat (NewCronos), OECD, DG Research provisional estimates
Notes: (1) D, F, IRL, I: 1996-2000; S: 1998-2000. (2) L data are not included in EU-15 average. (3) No data available for the US.
Third European Report on S&T Indicators, 2003

The development of GUF reflects the importance of universities in the national innovation systems. It implies that the governments of Portugal, Finland, Greece, the Netherlands and Denmark have found it necessary to guarantee the favourable development of the university system, and to support its advancement by awarding more resources to universities. These five countries not only stand out in the EU group, they have also scored higher growth rates than Japan (3%). On the other hand, since the mid-1990s, the rate of growth of GUF in Japan has been more than double the EU growth rate.

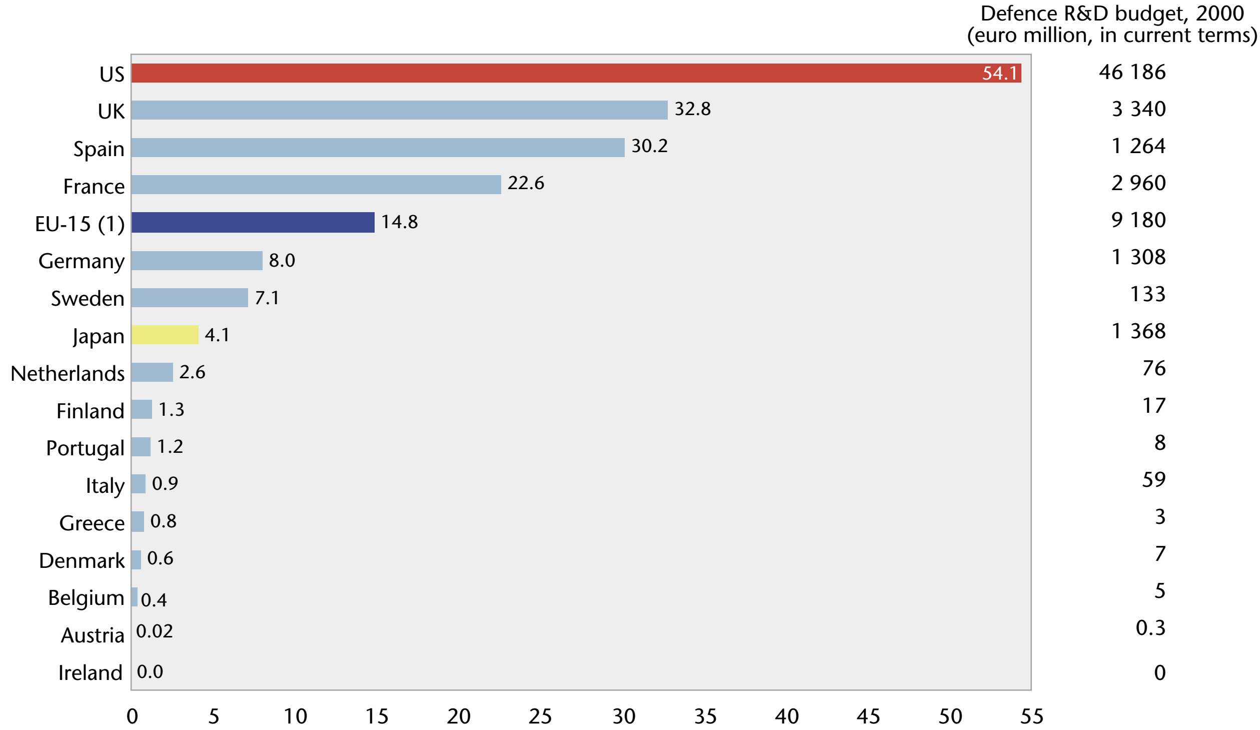
Among the larger EU economies, the GUF growth rates recorded for the UK, France and Italy have been comparatively high, at 1.9–2.4%. In light of the negative growth of total GBAORD in the UK and France since the mid-1990s (figure D1.1.4), the growth rates of budgetary funding for university research in these countries can be considered favourable. In Germany, which alone accounts for almost 33% of total GUF in the EU, the average annual growth rate of university funds was only 0.6%. Once again, taking into account the negative growth of total GBAORD recorded for Germany (–0.7% per year in 1996–2000), the real growth rate of GUF can at least be regarded as fair. Austria and Ireland have been the only EU countries to experience, in real terms, a negative GUF growth rate in the period 1995–2000.

EU defence R&D budgets* in decline

The proportion of defence-sector R&D in government budgetary financing has steadily diminished in the EU since the late 1980s. Defence-related R&D reductions are mostly due to the end of the Cold War era at the start of the 1990s, which led to an overall decrease in military expenditure. In addition, the economic recession and general budgetary constraints in the EU in the early part of the 1990s compelled governments to reassess their investment priorities (e.g. NSF, 2002).

As a result, the volume of government R&D investment in real terms started to decline and the ratio between civil and defence research changed. Since the early 1990s, non-defence R&D has generally outpaced the growth of funding of defence-related research in government budgets. Figures such as the real volume of defence R&D, the defence R&D share of total GBAORD, and the defence R&D as a percentage of GDP in the EU have all decreased during the 1990s, and again in 2000. In 1991, the share of

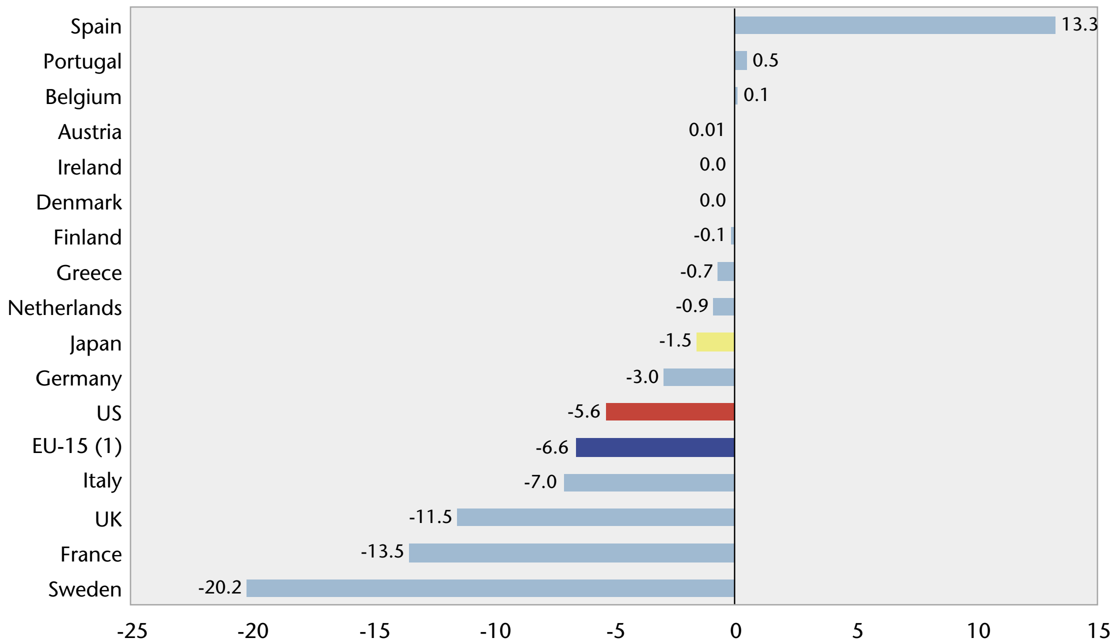
Figure D1.2.2 Government R&D budget – defence R&D as % of total GBAORD, 2000



Source: DG Research
Data: Eurostat (NewCronos), OECD
Note: (1) L data are not included in EU-15 average.

Third European Report on S&T Indicators, 2003

Figure D1.2.3 Defence R&D budget – change in the share (percentage points) of total GBAORD, (1991-2000)



Source: DG Research
Data: Eurostat (NewCronos), OECD
Note: (1) L data are not included in EU-15 average.

Third European Report on S&T Indicators, 2003

defence R&D in relation to total government budget appropriations for R&D in the EU area amounted to approximately 21%. The figure for 2000 was below 15%. At the same time, change in the share of defence of total government R&D investment in the US was even more significant. In 1991, defence R&D accounted for almost 60% of total GBAORD. Currently, more than half the US government R&D budget still goes to defence (54% in 2000) (figures D1.2.2 and D1.2.3).

In 2000 four countries, the UK, France, Germany and Spain, accounted for almost 97% (8.9 billion euro, in current terms) of total EU-area defence R&D budgets. The highest shares for defence R&D as a percentage of GBAORD were recorded in the UK (33%), Spain (30%), and France (23%). The figure for Germany is already below the EU average and close to Sweden's figure. With the exception of Spain, the defence share of government R&D budgets has either remained largely unchanged or declined considerably in all EU economies – as in the US and Japan (Figure D1.2.3). In Spain, the recent increase in the defence R&D budget has contradicted trends in other EU countries.

France made the most significant cutbacks in the absolute volume of defence R&D investments in the 1990s. In 2000, France's defence R&D budget was some PPS 2.6 billion (3.0 billion euro), the second biggest in the EU and immediately behind the UK. In 1991, France's budget was the highest in the EU, at PPS 5.1 billion (4.8 billion euro). Thus, defence spending was cut by 49% in real terms in France over the decade. In the UK, spending on defence R&D was reduced by more than 27% over the same period.

The US can be distinguished from the EU in terms of the defence sector's high volume and large share of total government R&D budget. In 2000, the volume of defence R&D in the US was nearly five times the EU volume and equivalent to 75% of the total GBAORD for the EU.

As in the EU, the real volume of defence R&D in the US in 2000 was lower than in 1991. However, while defence R&D investments in the EU have decreased steadily since the early 1990s, developments in terms of defence R&D budgeting in the US have been twofold. In 1991–1996, the budget decreased in real terms by some 3% per year. Since 1996, funding of defence-related R&D activities in the US has increased again by more than 1% per year. Thus, in terms of investment volume, recent trends in the US and the EU seem to be moving in opposite directions.

(*) *According to the OECD (1993), the NABS category of 'defence' "includes all R&D programmes undertaken primarily for defence reasons regardless of their content or whether they have secondary civil applications. It includes nuclear and space R&D undertaken for defence purposes. It does not include civil R&D financed by ministries of defence, for instance, on meteorology or telecommunications."*

Conclusions

The key findings with regard to government R&D budgets in 1991–2000 are as follows:

- Measured in terms of the government budget appropriations for R&D, investments in the EU in 2000 were PPS 54 billion (at 1995 prices) or 62 billion euro (in current terms). The corresponding figures for the US and Japan were PPS 67 billion (85 billion euro) and PPS 18 billion (33 billion euro), respectively.
- The picture is different when budgetary funding for defence-related R&D is excluded. The EU spent a total of PPS 46 billion (53 billion euro) on civil R&D in 2000, which was 25% more than the corresponding investment in the US.
- In 2000, the volume of defence R&D in the US was five times higher than in the EU, and the funding of defence R&D in the US has since shown further increases. Thus, recent trends in the US have been quite the reverse of the EU trend. Consequently, the US had managed to maintain the R&D investment gap between itself and the EU by the turn of the millennium.
- Since the early 1990s, total R&D financing by EU governments has decreased substantially. By 2000, government R&D budgetary provisions at EU level were still PPS 1.3 billion lower than in 1991.
- The moderate growth of R&D financing by the business enterprise sector in the EU is the major reason, although not the only one, for the widening investment gap between the EU and the US. Another factor in this unfavourable EU development relates to government R&D investment. In terms of both absolute volume (amount of investment) and relative volume (e.g. funding in relation to GDP), EU governments invest less in R&D activities than the US.
- Individual EU countries display markedly different trends in respect of R&D funding. Smaller EU economies and countries catching up from a low level of investment have recorded the highest growth rates in government-financed research. Since 1995, average annual real growth of government R&D budgets was the highest in Spain and Portugal (above 10% per year). At the opposite end of the spectrum, in France, the UK, Germany and Austria, the real growth rate of government R&D financing was negative. In France, the UK and Germany, the unfavourable trend was mainly due to cutbacks in defence R&D funding.
- In spite of the moderate real growth of EU-level total GBAORD since the mid-1990s, most of the Member States have considered funding of university research as an important function of government. Consequently, compared to development in other single categories in 1995–2000, the growth of GUF has been quite favourable in all EU countries except Belgium, Ireland and Austria.
- While the development of government R&D budget has been modest in the EU, the role and functions of government in R&D have been changing, placing more demands on the public sector's role in the innovation system and in the economy as a whole. Governments are increasingly seen as facilitators, creating a favourable regulatory framework and environment in which the various players in the innovation system can conduct research and collaborate with each other. One of the key issues is stimulating public-private partnerships, both in financing and in research and development. Governments need to pay more attention to the catalysing effect of public funding on the national innovation systems as a whole.

Selected Bibliography

Eurostat (1994) *NABS: Nomenclature for the Analysis and Comparison of Scientific Programmes and Budgets*, Luxembourg.

Eurostat (2000) *Statistics on Science and Technology in Europe, Data 1985–1999*, Luxembourg.

Eurostat (2001) *Research and Development: Annual Statistics, Data 1990–2000*, Luxembourg.

NSF *National Science Board* (2002) *Science and Engineering Indicators 2002*, National Science Foundation, Arlington VA (NSB-02-1).

OECD (1993) *Frascati Manual: Proposed Standard Practise for Surveys of Research and Experimental Development*, Paris.

OECD (2000) *OECD Science, Technology and Industry Outlook 2000*, Paris.

OECD (2001a) *Main Science and Technology Indicators* 2001-2, Paris.

OECD (2001b) *OECD Science, Technology and Industry Outlook 2001. Drivers of Growth: Information Technology, Innovation and Entrepreneurship*, Paris.

OECD (2002a) *Benchmarking Industry-Science Relationships*, Paris.

OECD (2002b) *Dynamising National Innovation Systems*, Paris.

Prest et al. (2002) *Assessing the Socio-economic Impacts of the Framework Programme*, The University of Manchester/PREST, Manchester.

CHAPTER 3
Private sector investment in scientific and technological knowledge

Introduction: Business sector R&D at the core of the interactive innovation process

This chapter focuses on the levels and dynamics of business sector investment in knowledge, i.e. business sector R&D activities that stand at the very core of the interactive model of innovations. Innovations are the key output of business sector knowledge production and they are considered as new combinations of existing and/or new knowledge. However, in the process of generating innovations firms not only engage in the production of new technological knowledge but also perform scientific, developmental, organisational, financial and commercial activities.

Current understanding about the process of innovations – the part on knowledge creation and absorption – in a knowledge-based economy is based on the interactive model of innovation that underlines the importance of various types of knowledge and their interactions for innovations. In particular, the interactive model of innovations stresses the interactions and diffusion of knowledge flows (continuous interactions and feedbacks, linkages between upstream and down stream research, external feedbacks between science, technology and process phases of development (cf. Petersen and Sharp, 1998).

In effect, the core idea of the modern innovation theory – on the knowledge creation part of it – is that there is no single source for scientific and technological knowledge but strong interdependencies and interactions between the knowledge producing institutions (Smith, 1995; Edquist, 1997; Metcalfe, 1995). Yet, fundamentally it is the level and dynamics of business sector R&D activities that reflect the firms' knowledge production, utilisation and absorption of knowledge from other sectors for the profit-oriented innovations. Therefore, business sector R&D activities essentially reflect business sector investment in knowledge creation and in knowledge absorption from other firms and institutions. Ultimately, the resulting innovations create the competitiveness, employment and economic dynamics of a knowledge-based economy.

Consequently, Europe's efforts in transition towards a competitive knowledge-based economy – as first demanded by the Lisbon Council 2000 – depend strongly on the level and dynamics of the business sector conducting and financing of R&D activities, i.e. investment in scientific and technological knowledge production and absorption to create innovations.

Through this chapter a comparison of the level, dynamics and industrial structure of business sector R&D is taking place between the EU, the US and Japan as well as between the Member States. The first section analyses the structure and development of the financing of R&D activities. The analysis starts with financing of Gross Domestic Expenditure on R&D (GERD) and shows the different roles of the profit-oriented business sector and the government following political goals in knowledge production and absorption. It is followed by an analysis of the financing of Business Enterprise Expenditure on R&D (BERD). The role of the business sector in financing public sector R&D and the role of foreign financial sources are also analysed.

Section 2 analyses the business sector as a performer of R&D by looking at the level and dynamics of business sector R&D investment at the aggregate country level. In particular, the existence and development of the business sector R&D gap between the EU and the US is apparent.

In section 3 the level and dynamics of business sector R&D activities (BERD and R&D intensities) in manufacturing and services across countries are investigated. Business sector investment in R&D by industry is analysed by focusing on the differing R&D intensities across industries between countries. This analysis informs us about the very different distribution of scientific and technological knowledge production in the manufacturing sector across the Member States, the US and Japan as well as according to the classification by high-tech, medium-high-tech and medium-low-tech and low-tech industries. Finally, a closer look is given to the R&D activities in the very heterogeneous service sector – in particular, the knowledge intensive services which are closely linked to the emerging knowledge-based industry.

Section 3 describes three predominant phenomena in the R&D strategies of firms that are connected with globalisation. They are illustrated by the R&D expenditures of foreign firms, cross-country mergers and acquisitions and their relationship to intra-firm R&D activities and finally, international research joint ventures for co-operative activity in the field of R&D between two (or more) independent firms.

Finally, in section 4 the level and dynamics of business sector R&D activities according to the size of the firms are analysed in order to discover whether the business sector knowledge investment and governments' support are concentrated more in large or in small firms. The analysis investigates in depth the R&D investment of European top international R&D performers in comparison to that of the US and in selected sectors. In comparison to the very large firms the SMEs are a very heterogeneous group that needs to be taken into account when targeting policies.

Section 5 analyses the development of the venture capital investment (in seed, start-up and expansion phases) across the countries and across stages. In particular, the investment by stages in the high-tech and non-high-tech sectors is seen as an indication for venture capital's role in creating R&D performers and new business sector R&D investment in the emerging knowledge-based economy.

Finally, this chapter closes with a dossier about the results of a case study concerning the creation of science-based spin-offs which are an important mechanism for commercialisation of the research results and which obviously require a coherent financing and knowledge support system.

SECTION I FINANCING OF R&D ACTIVITIES: THE ROLE OF THE BUSINESS SECTOR

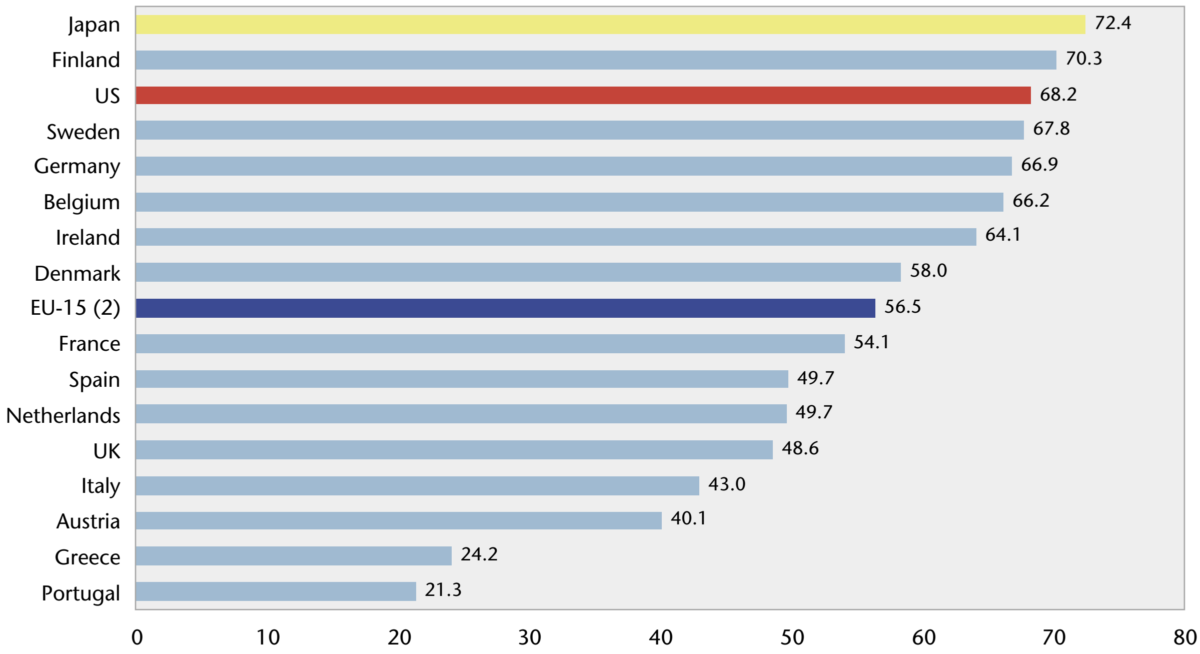
1. R&D activities financed by the business sector

Business sector R&D financing of Gross Domestic Expenditure on R&D (GERD)

The objective of research activities financed by business enterprise is to increase future profitability and competitiveness. These activities do not have to be conducted within the business sector alone, but can be carried out in the government sector, higher education sector or in other sectors as well. Such research executed outside the business sector probably includes research activities that are not normally conducted in the business sector, such as basic research, or that which is complementary to the sector's own research and development (R&D) efforts.

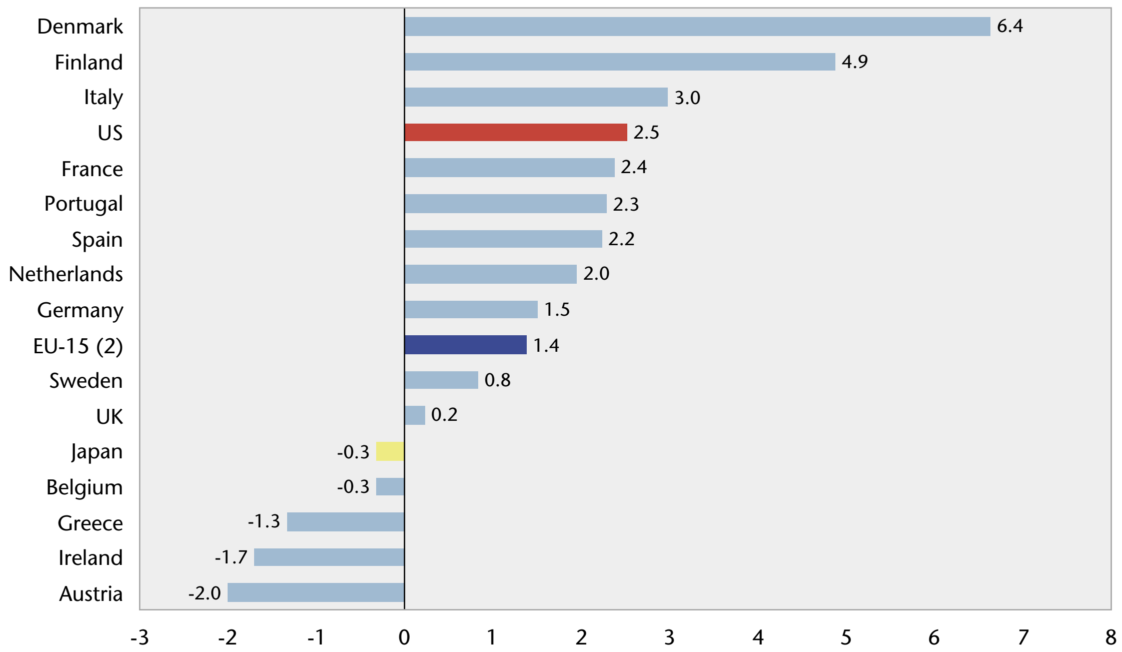
In the EU, the business sector is the major source of financing for total R&D (GERD) in the late 1990s. In this period, however, its share amounted to 56.5%, which ranks con-

Figure 3.1.1 Share of Gross Domestic Expenditure on R&D (GERD) financed by industry (%), 1999 or latest available year (1)



Source: DG Research
Data: OECD
Notes: (1) I: 1996; E, FIN, US, JP: 2000; D, A: 2001. (2) EU-15 calculated by DG Research; L not included.
Third European Report on S&T Indicators, 2003

Figure 3.1.2 Share of Gross Domestic Expenditure on R&D (GERD) financed by industry – average annual growth (%), 1995 to latest available year (1)



Source: DG Research
Data: OECD / Eurostat
Notes: (1) I: 1995-1996; JP: 1996-2000; F: 1997-1999; FIN: 1998-2000; E, US: 1995-2000; D, A: 1995-2001; all other countries and EU-15: 1995-1999. (2) EU-15 calculated by DG Research; L not included.

Third European Report on S&T Indicators, 2003

siderably behind the US (68.2%) and Japan (72.4%). There are considerable differences in the business sector financing of GERD across the Member States, indicating structural differences in financing the system of knowledge production. In particular, in Belgium, Ireland, Finland, Sweden, Germany and Denmark the shares are comparable with those of the US and Japan. In contrast, in Portugal and Greece the share is extremely low at just above 20% (figure 3.1.1).

In the US, the relative importance of the business sector in financing GERD is not only considerably higher in 2000 but has also increased by 2.5% more than in the EU. In the second part of the 1990s this share has grown only slightly in the EU, implying that there are no radical changes of the knowledge production system in this respect. In Japan it has, contrary to the situation in the EU and the US, declined, although the Japanese share is still slightly higher than in the US.

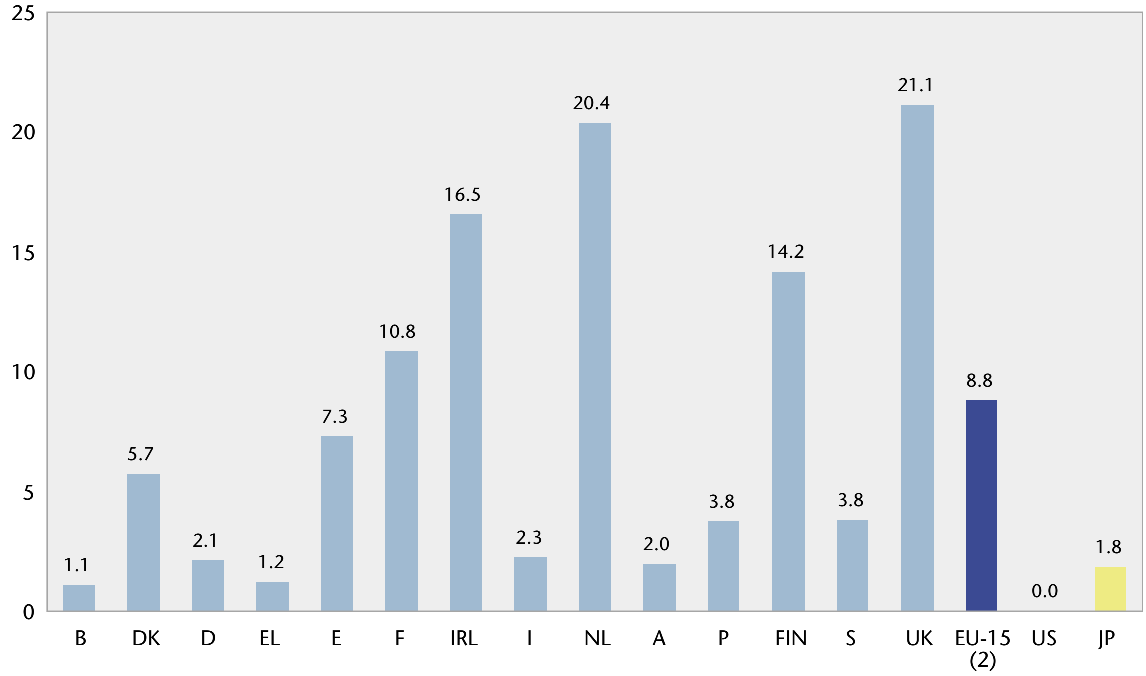
In particular, the dynamics of GERD financed by industry differ strongly across the Member States. Portugal, Spain and France are catching up with relatively high growth rates from initially low levels. In contrast, Austria and Greece are falling further back as they have negative dynamics at a low level of GERD financed by industry. Other countries - Ireland, Belgium and Japan - also have negative growth rates but are starting from a high initial level. Finland and also Denmark show strong positive dynamics at a high initial share of GERD financed by industry while in Sweden and the UK the trend is increasing only slightly (figure 3.1.2).

R&D activities of other sectors financed by industry: utilisation of other sectors' knowledge pool

The business sector's financing of research activities in other sectors reflects industry's strategy to utilise the knowledge pool and competencies outside of the business sector, such as in the public sector and higher education. The existence of such a pool provides a strategic benefit for the firms, provided that the business sector has appropriate absorptive capacities for the utilisation of the research results.

The share of government expenditure on R&D financed by industry reflects the links and co-operation between science and industry. In some Member States, for example the UK (21.1%) and the Netherlands (20.4%), such co-operative efforts are very intensive. In comparison to the EU average (8.8%) this is also the case, although to a lesser extent, in Ireland (16.5%), Finland (14.2%) and France (10.8%) (figure 3.1.3).

Figure 3.1.3 Share of Government Intramural Expenditure on R&D (GOVERD) financed by industry (%), 1999 (1)



Source: DG Research
Data: OECD
Notes: (1) A: 1993; D, IRL, US: 2000. (2) EU-15 calculated by DG Research; L not included.
Third European Report on S&T Indicators, 2003

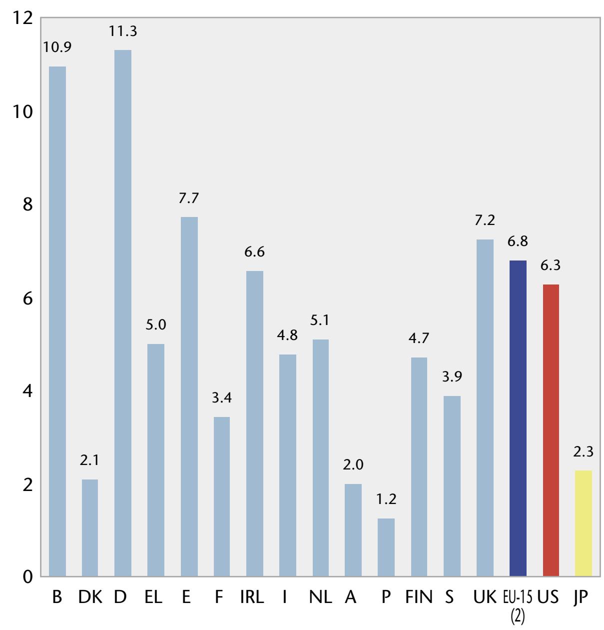
Share of higher education expenditure (HERD) financed by industry

Another important knowledge producing sector is higher education. It provides a potential target (pool of knowledge) for the knowledge investment of the business sector. The share of higher education expenditure on R&D financed by industry reflects the links and co-operation between science and industry.

Figure 3.1.4 shows that in the EU (6.8%) such co-operation is slightly higher than in the US (6.3%) and much higher than in Japan (2.3%). In Germany (11.3%), Belgium (10.9%), Spain (7.7%) and the UK (7.2%), business sector investment in the knowledge production of the higher education sector plays an important role, in contrast to Portugal, Austria and Denmark, which have very low shares of business sector investment.

The efforts of the business sector in investing in knowledge and exploiting the other sectors' knowledge pool, depends on the institutional framework of the knowledge production system, and on the capability of the business sector to absorb the research results from other sectors.

Figure 3.1.4 Share of Higher Education Expenditure on R&D (HERD) financed by industry (%), 1999 (1)



Source: DG Research
Data: OECD
Notes: (1) A: 1993; IRL: 1998; D, US: 2000.
(2) EU-15 calculated by DG Research; L not included.
Third European Report on S&T Indicators, 2003

2. Financing of business sector R&D (BERD)

Business sector knowledge creation and absorption, i.e. R&D activities executed in the business sector, can, however, be financed by other sectors than the business sector alone. Such alternative sources of business sector R&D financing include government, other national sources (non-profit private funds) and foreign sources. The magnitude of these sources is an important issue in research and innovation policy. This is the case, in particular, for government and foreign financing of business sector R&D activities, whereas other national sources are normally not a variable of the innovation policy. Also quantitatively they play a small role, normally remaining below one per cent of the total financing.

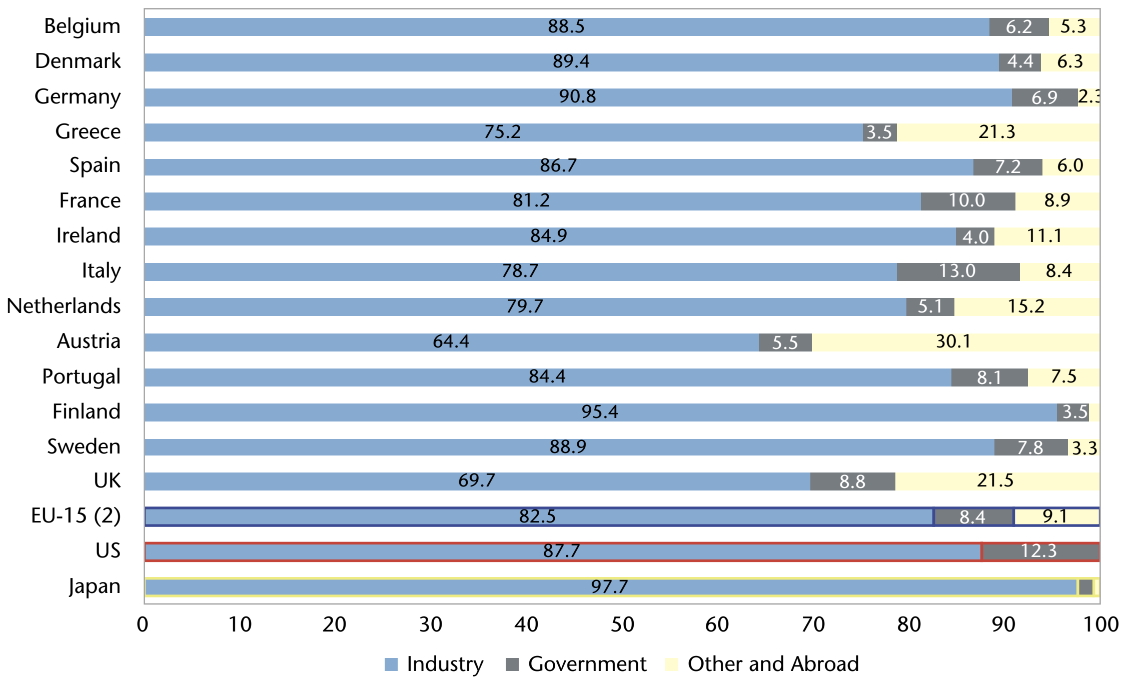
Business sector R&D financed by external sources

A government's role in financing business sector R&D informs us about the relative importance of government's support for industrial research activities. Government financed BERD governs research grants, contracts for defence, national space and a small part of S&T infrastructure (Young, A. 1998)[1]. With regard to the various sources of market failure in business sector knowledge investment, such as weak appropriateness, uncertainty, and high fixed costs, government's support for business sector knowledge investment is essential for the dynamics of the innovation processes.

The business sector itself is the largest financial source of industrial R&D activities in the EU (82.5%), the US (87.7%) and quite distinctively in Japan (with 97.7% in 2000) (figure 3.1.5). However, in the US, there has been a major restructuring towards business sector funding (BERD) since the beginning of the 1990s, with a very high share of government financed BERD (22.5%), i.e. BERD was relatively low – compared to that of 1999 (figure 3.1.6). However, this trend may be affected by rising defence expenditure in the present period.

However, the information with regard to 'others', which normally includes foreign sources, is not available for the US. This complicates a comparison of the business and government sector. US data for foreign funding of R&D is also not available, but the National Science Foundation (NSB, 2000) estimates that the share of foreign funding of R&D performance amounts to 8%.

Figure 3.1.5 Business Enterprise Expenditure on R&D (BERD) financed by sector (%), 1999 or latest available year (1)



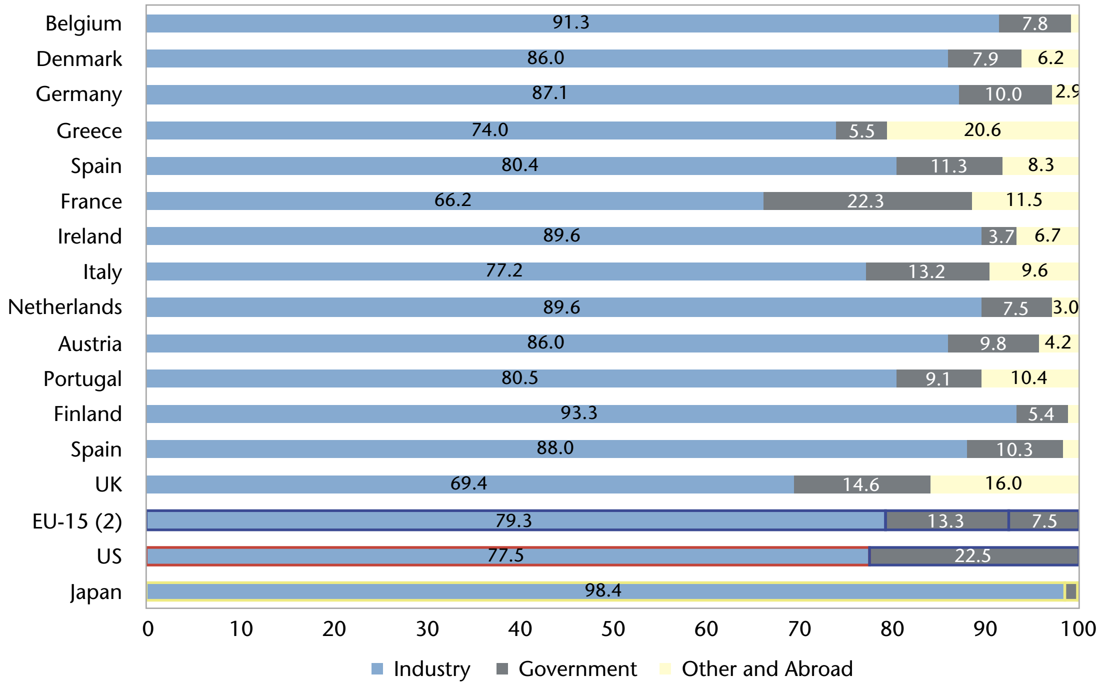
Source: DG Research
Data: OECD
Notes: (1) B, E, FIN, UK, JP: 2000; D: 2001; A: 1998. (2) EU-15 calculated by DG Research; L not included.
Third European Report on S&T Indicators, 2003

[1] *Other indicators such as funding of industrial technology and GBAORD contain other elements.*

The importance of the business sector in the financing of BERD varies considerably between the Member States. Finland has the highest share, followed by Denmark, Sweden and Belgium. At the end of the 1990s, the UK, Greece, Italy and the Netherlands had the lowest shares of business sector financed BERD (less than 80%), i.e. below the EU average. However, in the UK, Greece and Italy the role of business sector financing of BERD has been increasing since 1990 even if in 1999 it was still at a low level (figures 3.1.5 and 3.1.6). In spite of these differences in the importance of business sector financing, the general development is towards higher involvement of the business sector across most of the countries.

The reasons for the trends in the different countries are hard to pinpoint. In one country it might be caused by a high share of defence R&D contracting (for example in the UK, although here there is a downward trend) or by a high level of state aid for industry in the form of direct measures (this has traditionally been the case in the Netherlands).

Figure 3.1.6 Business Enterprise Expenditure on R&D (BERD) financed by sector (%), 1991 (1)



Source: DG Research
Data: OECD
Notes: (1) P: 1997; A: 1993. (2) EU-15 calculated by DG Research; L not included.

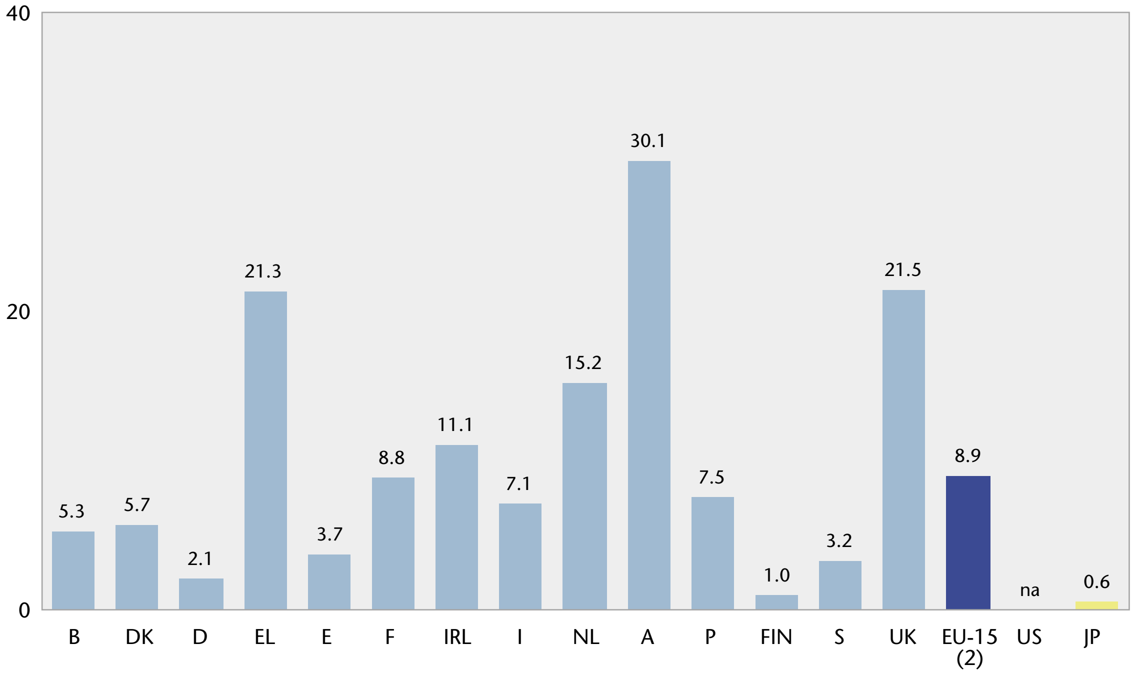
Third European Report on S&T Indicators, 2003

Business sector R&D financed by foreign sources

Internationalisation of R&D is linked to strategic issues in the development of a dynamic system of knowledge production and absorption. Globalisation is reflected in the relative importance of foreign sources in the financing of business sector R&D. It comprises the R&D expenditure of foreign firms (multinationals) and financing by the Framework Programme (Frascati Manual). The Framework Programme finances research activities both of large firms and of SMEs. Crucially, countries can try to attract foreign financing of R&D through their attractiveness as locations of (high-tech) FDIs with sophisticated R&D activities that potentially create international knowledge spillovers. At the same time, governments can try to support participation in international co-operation within the frame of the European Framework Programmes, as it provides opportunities to transfer additional financial resources to domestic business sector R&D activities.

Differences in economic and institutional structures and, in particular, in the openness of the innovation system, influence the structure of financial sources for business sector knowledge investment. Consequently, in some countries business R&D financed by foreign sources is significant, whereas in others its role is of lesser importance. In Austria, the UK, Greece, and the Netherlands, in particular, financing of BERD from abroad comprises, respectively, 30.1%, 21.5%, 21.3% and 15.2% of total BERD in 1999 (or latest available

Figure 3.1.7 Business Enterprise Expenditure on R&D (BERD) financed by abroad as % of total BERD, 1999 or latest available year (1)



Source: DG Research
Data: OECD
Notes: (1) A: 1998; B, E, FIN, UK, JP: 2000; D, I: 2001. (2) EU-15 calculated by DG Research; L not included.
Third European Report on S&T Indicators, 2003

year), which reflects the importance of the foreign business sector and of the European Framework Programme. In contrast, in Finland, Japan and Germany foreign sources do not play a material role (figure 3.1.7).

However, the aggregate figures do not allow us to analyse the relative importance of foreign financing of R&D by foreign firms or by the Framework Programme. The foreign funding of US R&D is recorded as zero, although this is the result of a data collection problem. As mentioned above, the National Science Foundation (NSB, 2000) estimates the share of foreign funding of R&D performance at 8%, which represents a considerable increase from the 3% share in 1980.

Section II Business sector as performer of R&D

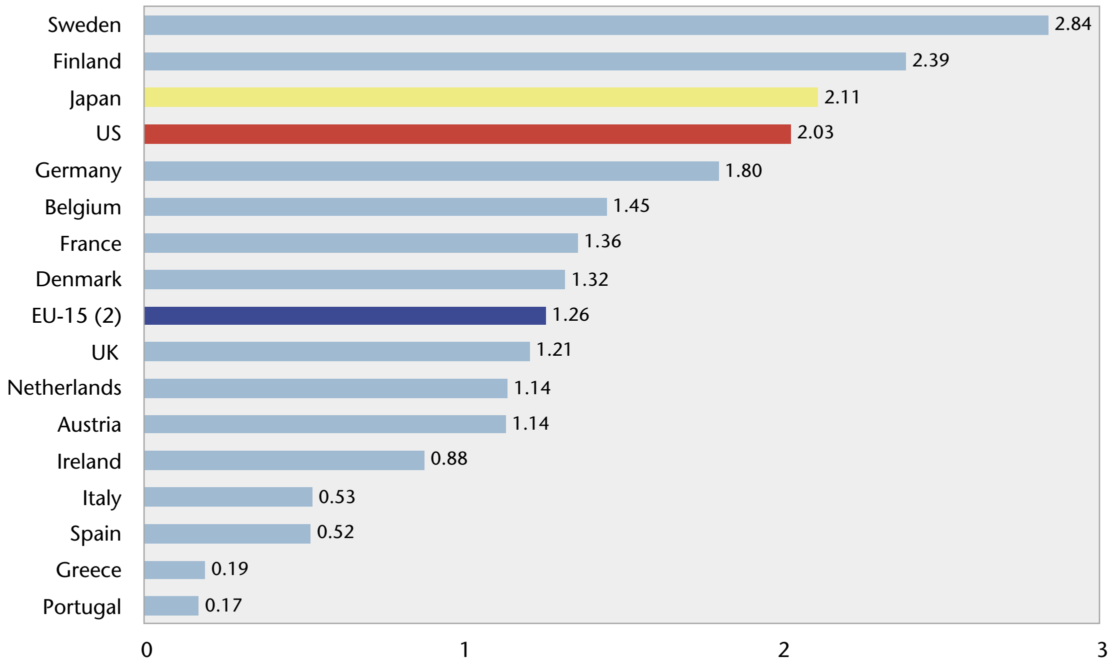
1. Importance and dynamics of business sector investment in knowledge

Importance of business sector R&D expenditure

Independently of the source of financing, the R&D activities executed in the business sector are essential for the innovative output and competitive dynamics of a country although – of course – all other types of R&D activities (public, international) are needed in the innovation process. The fundamental characteristic of business sector R&D activities is that they are ultimately innovative and profit-oriented for the purpose of increasing the competitiveness of the firms. This does not exclude the possibility that some R&D activities in the business sector are similar to basic research activities (Rosenberg, 1990). This is not surprising as, according to the interactive model of innovation, firms need to develop absorptive capacities in order to be able to utilise the knowledge created through basic research in the public sector.

The relative importance of business sector R&D efforts, which reflect profit-oriented creation, application and absorption of knowledge, is indicated by the level of expenditure on BERD as a share of gross domestic product (GDP). The relative importance of R&D expenditure in total economic activity in the EU (1.26%) lags considerably behind that of the US (2.03%). However, some of the EU countries – Sweden (2.84%) and Finland (2.39%) – allocate even more of their resources to business sector R&D activities than the US (figure 3.2.1). Consequently, there are significant differences in the levels and dynamics of business sector R&D expenditure. In particular, the levels of BERD expenditure differ considerably between the EU Member States, which is due partially to their different sizes and, in particular, to the specialisation of their economies.

Figure 3.2.1 Business Enterprise Expenditure on R&D (BERD) as % of GDP, 2000 or latest available year (1)



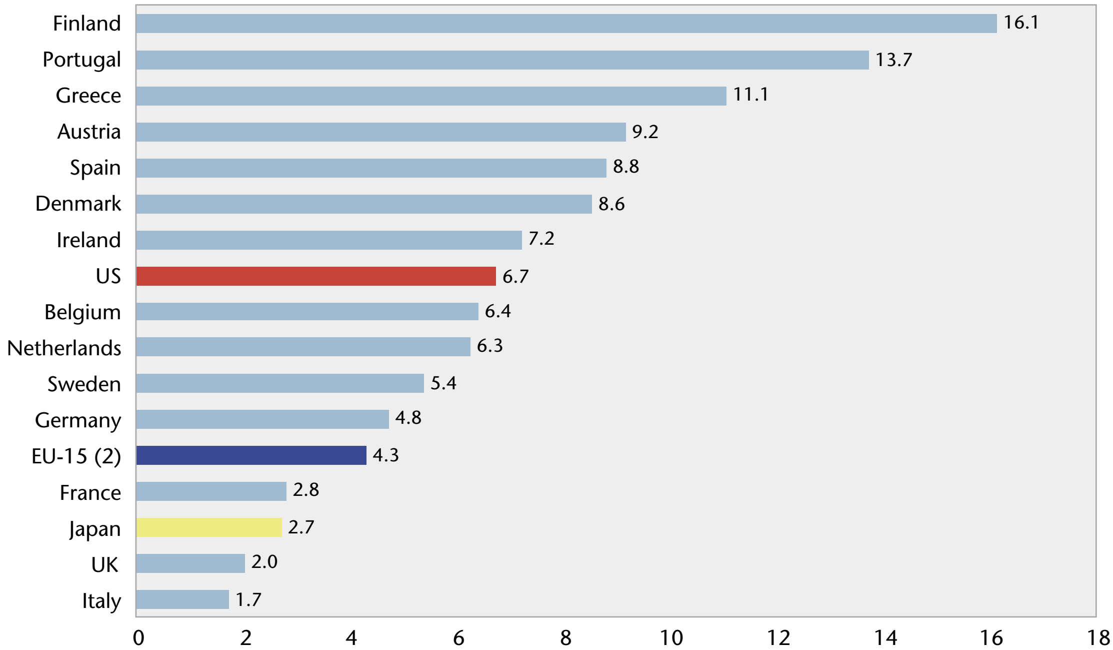
Source: DG Research
Data: Eurostat / OECD
Notes: (1) A: 1998; DK, EL, IRL, NL, P, S: 1999; D, E, I: 2001. (2) EU-15 calculated by DG Research; L not included.

Third European Report on S&T Indicators, 2003

Yet, not only the relative importance but the dynamics of BERD is an important indicator about business enterprise knowledge creation and absorption. From 1995 to 2000, the relatively slower growth of business sector R&D expenditure in the EU (4.3%) compared to the US (6.7%), is obvious. Even so, several EU Member States exceed the US growth rate. Countries with lower BERD levels, such as Portugal, Ireland, Greece and Spain, are catching up, while Finland starting at a high level of BERD, continues its dynamic business sector R&D activities. However, as the BERD expenditure concentrates on the three larger countries France, Germany and the UK – and makes up 68.6% of the EU total, the growth dynamics of the EU remains low in spite of some very dynamic – but small – countries.

As we have already seen in chapter 2, the intensity of R&D varies considerably, not only between countries, but also and more significantly between regions within and across individual countries. The following two lists in the box illustrate this phenomenon for BERD as a % of GDP. The first list gives an overview of the best performing regions – at NUTS 2 level – in 1999. The second list shows thoses regions where enterprises invested least in research and technological development in 1999. The results are striking.

Figure 3.2.2 Business Enterprise Expenditure on R&D (BERD) – average annual real growth (%), 1995 to latest available year (1)



Source: DG Research
Data: Eurostat / OECD
Notes: (1) A: 1993-1998; DK, EL IRL, NL, P, S: 1995-1999; B, FIN, UK, US, EU: 1995-2000; D, E, I: 1995-2001; JP: 1996-2000; F: 1997-2000. (2) EU-15 calculated by DG Research; L not included.

Third European Report on S&T Indicators, 2003

Best Performing Regions in the EU in terms of BERD as a % of GDP (1999) (NUTS 2)

1. Braunschweig, Germany (4.60%)
2. Stuttgart, Germany (4.38%)
3. Västsverige, Sweden (4.22%)
4. Stockholm, Sweden (4.10%)
5. Oberbayern, Germany (3.75%)
6. Tübingen, Germany (3.48%)
7. Pohjois-Suomi, Finland (3.14%)
8. Sydsverige, Sweden (3.02%)
9. Eastern, United Kingdom (3.01%)
10. Rheinhessen-Pfalz, Germany (2.76%)
11. Darmstadt, Germany (2.74%)
12. Uusimaa, Finland (2.66%)
13. Île-de-France, France (2.46%)
14. Östra Mellansverige, Sweden (2.42%)
15. Noord-Brabant, Netherlands (2.38%)

EU average: 1.25% (EUROSTAT estimate for 1999)
Data: EUROSTAT; No data available for Austria

Besides large metropolitan areas such as Greater Stockholm, Greater London, Greater Helsinki and Greater Paris, one can see smaller regions with strong innovative business presence such as Noord-Brabant (Philips), Braunschweig (Volkswagen), Stuttgart (Mercedes, BMW) and even peripheral regions such as Pohjois-Suomi around Oulu (famous science-based Technical University).

Least[(1)] Performing Regions in the EU in terms of BERD as a % of GDP (1999) (NUTS 2)

1. Ionia Nisia, Greece; Açores, Portugal (0.00%)
2. Dytiki Makedonia and Voreio Aigaio, Greece; Calabria, Italy (0.01%)
3. Ipeiros and Notio Aigaio, Greece (0.02%)
4. Nisia Aigaiou, Greece (0.03%)
5. Crete, Greece; Baleares, Spain; Alentejo, Portugal (0.04%)
6. Thessalia, Greece; Sardegna, Italy; Madeira, Portugal; Äland, Finland (0.06%)
7. Canary Islands, Spain; Algarve, Portugal (0.07%)
8. Extremadura, Spain (0.08%)
9. Voreia Ellada, Greece
10. Dytiki Ellada, Greece (0.10%).

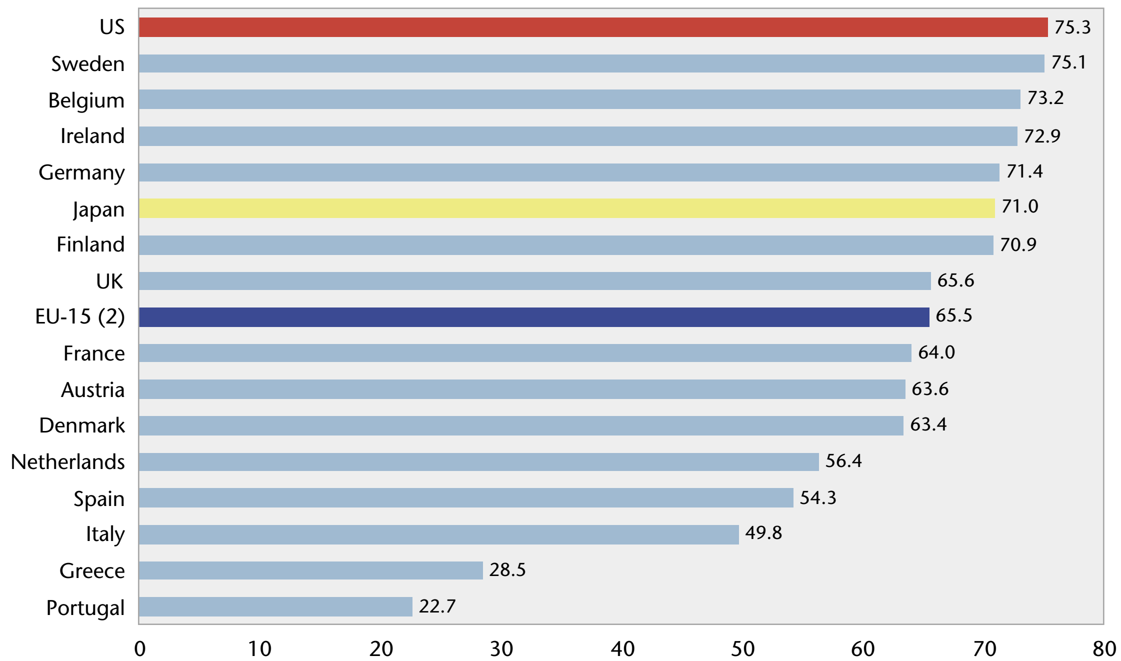
(1) Defined as equal/less than 0.10% of GDP
EU average: 1.25% (EUROSTAT estimate for 1999)
Data: EUROSTAT; No data available for Austria

It is striking to see that low business expenditure for R&D is strongly biased towards the southern regions of the EU with the Finnish Åland islands being the only exception in geographical terms. Many less favoured regions in Europe show consistently low levels of R&D investment coming from the business sector. This low level of business R&D activity results in sub-optimal absorptive capacities that could otherwise enable firms to take advantage of research activities undertaken elsewhere due to knowledge spillovers.

Relative importance of the business sector in overall R&D activity

In particular, the efforts of the business sector in R&D activities in relation to the overall R&D activities informs us about the relative importance of profit-oriented knowledge creation and absorption. In 2000, business sector activities make up the bulk of total GERD in the EU (65.5%), in the US (75.3%), with a rising trend since 1990, and in Japan (71%), with a declining trend. However, in some of the Member States – Portugal and Greece – the shares only reach 22.7% and 28.5% reflecting relatively weak business sector knowledge investment in comparison to the public and higher education sectors' knowledge investment.

Figure 3.2.3 Business Enterprise Expenditure on R&D (BERD) as % of Gross Domestic Expenditure on R&D (GERD), 2000 or latest available year (1)

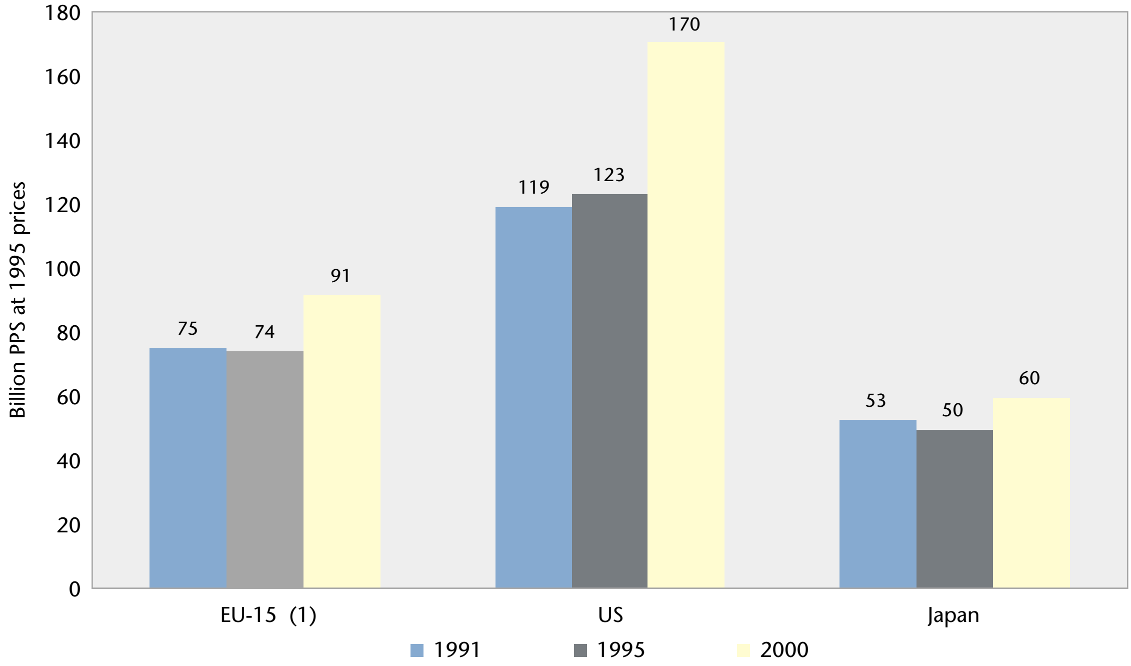


Source: DG Research
Data: OECD
Notes: (1) A: 1998; DK, EL IRL, NL, P, S: 1999; D, E: 2001. (2) EU-15 calculated by DG Research; L not included.
Third European Report on S&T Indicators, 2003

Weaker dynamics of European business sector R&D vis-à-vis the US

An analysis of the levels and dynamics of business sector R&D expenditure brings to light a huge difference in knowledge creation and absorption between the EU and the US. In 2000, the EU (91 billion PPS at 1995 prices) spent far less than the US (170 billion PPS at 1995 prices) but more than Japan (60 billion PPS at 1995 prices) (figure 3.2.4). In addition to this, the evolution of BERD between 1991 and 2000 shows that the EU is not catching up with the US which is starting at a higher level and increasing its business sector R&D expenditure much faster than the EU.

Figure 3.2.4 Evolution of Business Enterprise Expenditure on R&D (BERD) for EU-15, the US and Japan (1991-2000)



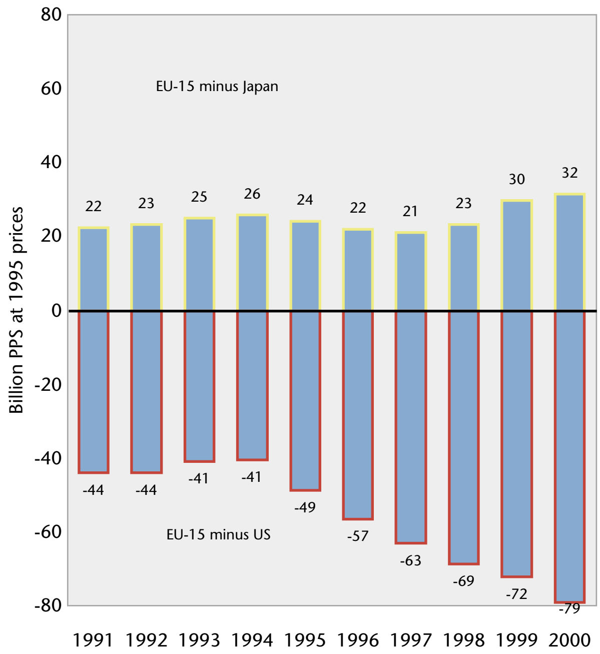
Source: DG Research
Data: OECD
Note: (1) EU-15 calculated by DG Research; L not included.

Third European Report on S&T Indicators, 2003

In the 1990s, the initially lower level of the European investment in knowledge creation and absorption is connected with a permanently lower growth rate of this investment, in comparison to the US business enterprise R&D activities. This situation over several years has created a large and increasing investment gap between the EU and US (figure 3.2.5). The investment gap between Europe and the US has increased from 44 billion PPS at 1995 prices in 1991 to 79 billion PPS at 1995 prices in 2000, an increase of 79% during the 1990s. It reflects an alarming situation of the European business sector constantly investing far less in knowledge creation and absorption than the US business sector. Clearly, this deficit has serious consequences for the competitiveness and dynamics of the European economy (Muldur, 2001).

Undoubtedly, a comparison of the levels of BERD makes sense only between the US and the EU as a whole which have comparable sizes and economic levels. However, – even if the comparison with individual countries is problematic – the comparison of the development of the business sector R&D investment gap between the US and individual Member States provides striking information about the regional sources of the gap. In order to take into account the size of the countries, the comparison is carried out on the basis of the BERD investment per capita (in PPS at 1995 prices).

Figure 3.2.5 Business Enterprise on R&D (BERD)-Gap between EU, the US, and Japan (1991-2000)



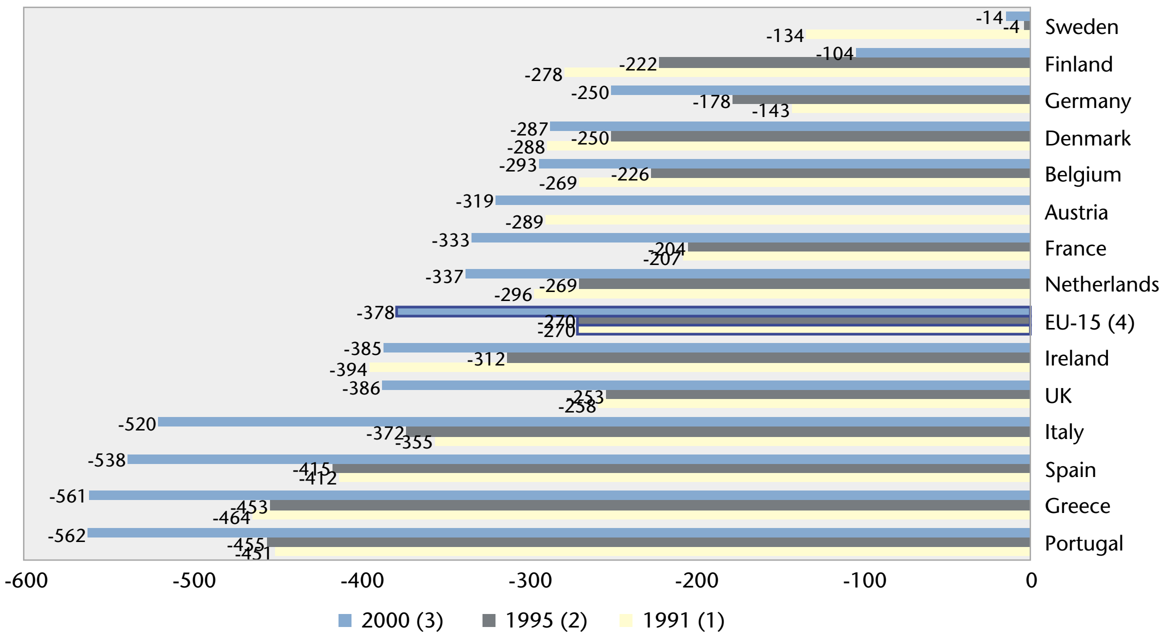
Source: DG Research
Data: Eurostat / DG Research estimates
Note: L not included in EU-15.

Third European Report on S&T Indicators, 2003

It is normal that countries at a lower economic level than the US - such as Portugal, Greece and Spain for example - also invest less in business enterprise R&D in relation to their population. However, from the emerging knowledge-based economy point of view, it is a worrying factor that the gap in business sector R&D expenditure per capita between the US most EU Member States is increasing consistently.

Yet, the comparison in figure 3.2.6 reveals that the increases in the gaps have not been uniform. In particular, the per capita gap of large Member States such as Germany and France, which have a smaller gap in business sector R&D expenditure per capita than the EU average, has been increasing significantly vis-à-vis the US since the beginning of the 1990s. Unfortunately this is also the case for many countries - such as the UK, Italy, Greece and Portugal that have a larger gap than the EU average. In contrast, Sweden and Finland have closed the investment gap (per capita) towards the US since 1991 (figure 3.2.6).

Figure 3.2.6 Business Enterprise Expenditure on R&D (BERD) per capita in PPS at 1995 prices – Gap between each Member State and the US



Source: DG Research
Data: OECD / Eurostat
Notes: (1) A: 1993; P: 1992. (2) A: Data not available for 1995. (3) A: 1998; DK, EL, IRL, NL, P, S: 1999
(4) EU-15 calculated by DG Research; L not included.

Third European Report on S&T Indicators, 2003

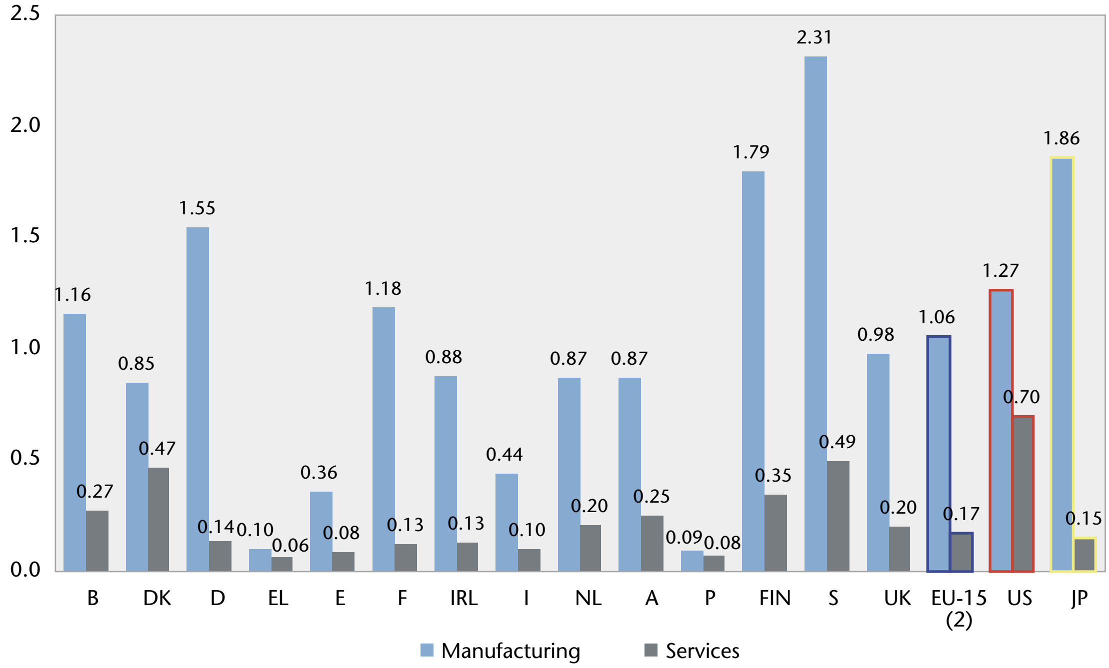
2. Business sector R&D by industry

Relative importance of services and manufacturing in research: changing patterns

Industrialised countries are experiencing deep structural changes towards the service sector. Today, the share of the service sector amounts to around 50 - 70% of the total value added (GDP) and to 70 - 80% of total employment. However, in contrast to the quantitative importance of the service sector in the economy, its efforts in research and development are considered traditionally to be rather low. Indeed, R&D intensity in the service sector (R&D expenditure as a percentage of GDP) is very low (0.17% at the European level, varying from 0.06% in Greece to 0.49% in Sweden) in comparison with the manufacturing sector (1.06%, European average). In the US, the R&D intensity of the service sector (0.70%) is also relatively low compared to the manufacturing sector (1.27%), but much higher than the EU as a whole (0.17%), as shown in figure 3.2.7.

The relatively low R&D intensity of the service sector is reflected in figure 3.2.8, which shows that the share of services in total business R&D activities (BERD) is quite low in all countries. Quantitatively, most industrial knowledge creation and absorption activities take place in the manufacturing sector. However, there is considerable variation in this share among individual countries. In the US, knowledge

Figure 3.2.7 Business Enterprise Expenditure on R&D (BERD): Manufacturing and Services as % of GDP, 1999 (1)



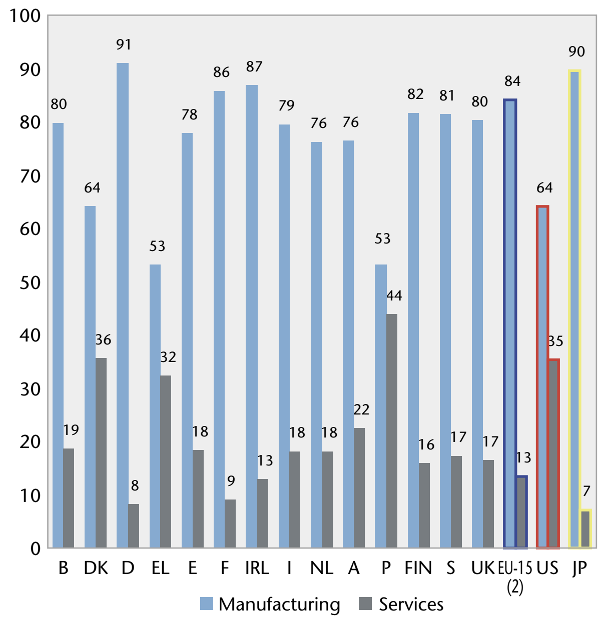
Source: DG Research
Data: OECD / Eurostat
Notes: (1) IRL: 1997; A: 1998; B, I, UK: 2000. (2) L data are not included in EU-15 average.
Third European Report on S&T Indicators, 2003

investment in the service sector (35%) far exceeds that of EU-15 (13%). Only two of the Member States allocate relatively more resources than the US to service sector BERD – Portugal with 44% and Denmark with 36%. The lowest shares are found in Germany, with 8%, and France, with 9%.

Recently, however, it has been recognised that at least some parts of the service sector are both very innovative and also play a critical role in the emerging knowledge-based economy. The low research intensities may be due in part to the methodology used for the measurement of service sector R&D (cf. OECD 2001, NESTI paper on revision of the Frascati Manual). These issues are discussed further in this section under the title ‘Business sector R&D in the service sector: the role of knowledge intensive services’.

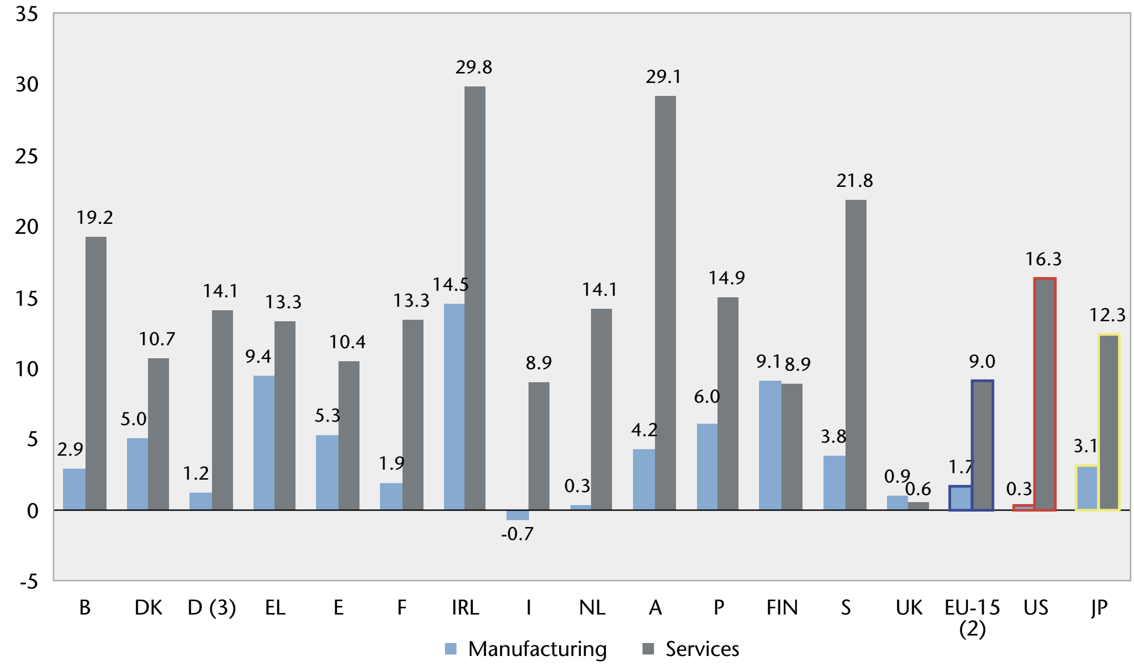
Therefore, to look only at the relatively low share of BERD in the service sector would underestimate its role in the emerging knowledge-based economy. Almost in all Member States (with exceptions of Finland and UK) and the US and Japan the investment in knowledge (BERD) in the service sector has grown in the 1990s much faster than in industry (figure 3.2.9). For Germany and France, with a present low share of service sector BERD but positive growth rates in the 1990s, the initial share of the service sector in industrial knowledge production has been extremely low.

Figure 3.2.8 Share (%) of Manufacturing and Services in Business Enterprise Expenditure on R&D (BERD), 1999 (1)



Source: DG Research
Data: OECD / Eurostat
Notes: (1) IRL: 1997; A: 1998; B, I, UK: 2000.
(2) L data are not included in EU-15 average.
Third European Report on S&T Indicators, 2003

Figure 3.2.9 Business Enterprise Expenditure on R&D (BERD) for Manufacturing and Services – Long-term Real Growth Rates (%), 1987-1999 (1)



Source: DG Research
Data: OECD / Eurostat
Notes: (1) IRL: 1987-97; A: 1989-98; EL, P: 1988-99; B, I, UK: 1987-2000. (2) L data are not included in EU-15 average.
(3) The data for 1987 refer to the former West Germany.

Third European Report on S&T Indicators, 2003

Therefore, knowledge production and application is increasing in the service sector as business sector R&D expenditure has been directed more strongly towards the service sector. This results from both the expansion of the service sector and structural changes to emerging, knowledge intensive segments in the service sector. Such segments provide knowledge-intensive services to the manufacturing and other services.

In EU-15, the growth of service sector BERD (9%) has been lower since the beginning of the 1980s than in the US where the service sector (with 16.3%) is growing relatively more strongly than BERD in the manufacturing sector (0.3%). Therefore, the restructuring of R&D efforts between manufacturing and services in the US has been taking place since the 1980s, i.e. it is a long-term phenomenon (figure 3.2.9).

Distribution and dynamics of industrial knowledge production

1. Differences in knowledge investment efforts between industries: R&D intensities

Industries differ typically in their relative efforts to produce and absorb knowledge that can be measured by R&D intensity, i.e. by share of R&D expenditure in value added. Usually, the R&D efforts of an industry depend on the types of products and the (related) characteristics of the production techniques. Technically sophisticated and knowledge-intensive products are expected to have R&D-intensive production methods with high R&D expenditure and human-capital efforts.

Table 3.2.1 presents R&D intensity in total manufacturing as well as specific R&D intensities across industries in Member States, the EU, the US and Japan. Although the data are lacking in respect of some Member States, it is still obvious that industries differ considerably in their relative efforts to invest and absorb knowledge.

In 1999, R&D intensity in the total manufacturing sector in the US (7.8%) was considerably higher than in EU-7 (5.7%), reflecting greater relative efforts in knowledge production and absorption. Also within the EU, R&D intensity in manufacturing differs considerably between the Member States, ranking from 11.3% in Sweden (1997) – well above the US R&D intensity – to 2.1% in Spain (1999).

In particular, R&D intensity in the same industries differs from country to country, implying that efforts in production and absorption of the scientific and technological knowledge of a particular industry also differ from country to country. R&D intensity in an industry can vary considerably. In the Computer and Office Machinery industry, for example, Sweden (39.5%) invests most in knowledge production and

Table 3.2.1 R&D Intensities across industries: Member State, EU, the US, Japan – Business entreprise expenditure on R&D as % of value added

	B	DK	D	E	F	I	A	FIN	S	UK	EU-7 (1)	US	Japan
	1999	1999	1999	1999	1999	1999	1998	1999	1997	1998	1999	1999 (2)	1998 (3)
TOTAL MANUFACTURING	6.4	5.7	7.5	2.1	7.0	2.2	4.6	8.3	11.3	5.4	5.7	7.8	8.4
Food, Beverages and Tobacco	1.6	1.4	0.6	0.5	1.0	0.4	na	2.8	1.0	1.2	0.8	na	1.9
Textiles, apparel and leather	2.0	0.8	2.1	0.6	0.9	0.1	na	2.2	1.2	0.4	0.7	0.6	2.1
Paper and printing	0.9	na	0.3	0.4	0.3	0.1	0.5	1.3	na	na	0.4	na	na
Pharmaceuticals	25.0	40.0	na	10.1	27.6	na	15.1	na	46.5	48.0	na	23.3	19.0
Non-electrical machinery	6.6	6.6	5.8	2.9	4.6	1.4	4.4	9.0	11.2	4.8	4.6	4.7	5.7
Computers, Office Machinery	12.3	18.0	17.0	7.5	13.3	7.0	3.7	na	39.5	3.5	14.1	22.0	na
Electrical Machinery	7.6	8.0	3.4	3.3	7.7	na	5.7	na	18.2	7.8	4.5	12.0	17.6
Electronic Equipment	32.7	13.5	36.9	19.1	34.1	na	28.5	28.1	38.6	12.1	32.7	na	23.6
Instruments	11.3	15.3	11.9	3.7	16.9	2.2	6.8	22.5	18.5	7.3	11.5	32.6	23.8
Motor Vehicles	4.0	na	18.3	2.6	13.1	10.4	10.1	3.6	28.9	9.2	14.3	16.0	13.2
Aerospace	6.5	na	na	25.0	40.1	na	na	na	na	24.3	na	30.9	0.6

Source: DG Research
Data: OECD
Notes: (1) (a) EU-7: B,DK,D,E,F,I and FIN (b) Electrical Machinery does not include data for I and FIN (c) Electronic Equipment does not include data for Italy (d) Paper and Printing and Aerospace do not include data for Denmark. (2) US: The following sectors refer to 1998: Pharmaceuticals, Computers, Office Machinery, Electrical Machinery. (3) JP: The following sectors refer to 1997: Pharmaceuticals, Electrical Machinery, Electronic Equipment, Motor Vehicles, Aerospace.

Third European Report on S&T Indicators, 2003

absorption, whereas in Austria (3.7%) it is of minor importance. Such strong variations in R&D intensity can be observed across all industries. They are likely to result from differences in product quality and specialisation in different quality segments within industries. One expects that higher R&D intensity in a particular industry indicates higher technological and qualitative sophistication of the manufactured products and related production methods.

The R&D intensity of the total manufacturing sector in each country results both from specialisation across high, medium and low-tech industries – a classification based on the relative importance of R&D expenditure – and general levels of R&D investment across all industries. Whether the relatively low R&D intensity in European manufacturing is a result of specialisation across high, medium and low technology industries or of a generally lower level of R&D expenditure, has important implications for policy formulation.

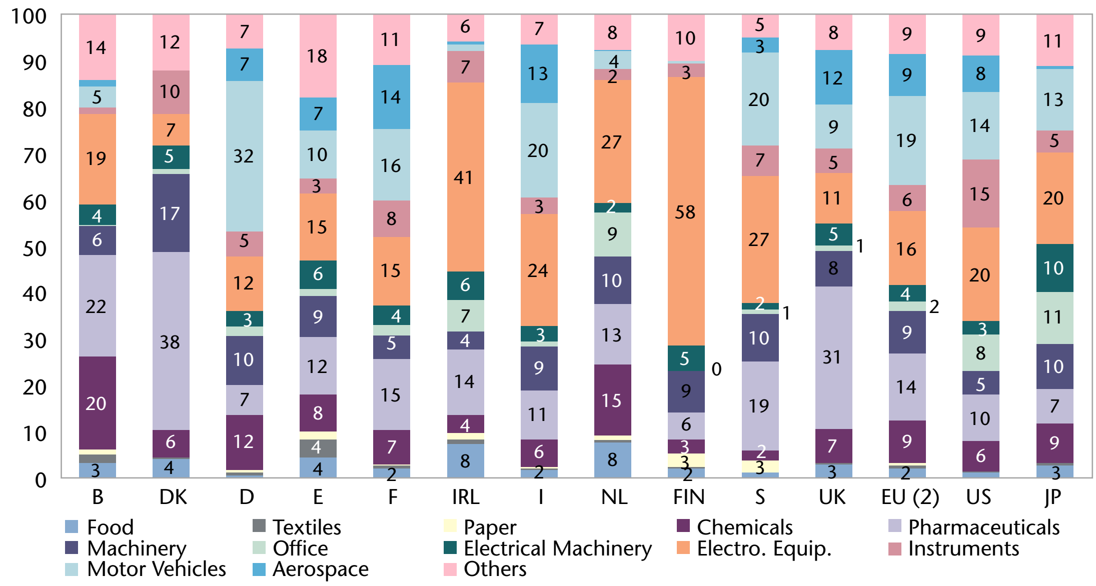
The relative roles of structural specialisation and levels of R&D expenditure in the manufacturing sector can be analysed by breaking down the total R&D intensity into structure and level components. On the one hand, countries may have a high R&D intensity because they are specialised in industries that typically possess a high R&D intensity (such as high-tech industries). On the other hand, the reason for the high R&D intensity in the manufacturing sector can be a result of a higher level of R&D investment in all industries (Sandven & Smith, 1998). The first component illustrates what the R&D intensity in manufacturing would have been if, given the country's actual structure, each industry had been equal to the typical R&D intensity. The second component, by holding the R&D intensity in each industry constant, measures the effect of industrial structure on the R&D intensity in manufacturing.

2. Knowledge investment by industry: allocation of BERD

Distribution patterns of BERD across industries show that countries are indeed allocating their BERD very differently across industries, i.e. knowledge creation and absorption is located in very different industries. In particular, in the US the 'Office, Accounting & Computing Machinery', 'Electronic Equipment (Radio, TV & Communication)' and 'Instruments' industries play a more important role in the production of scientific and technological knowledge (total BERD) than in the EU, where 'Pharmaceutical', 'Motor Vehicle', 'Machinery' and 'Chemical' industries are more important (figure 3.2.10).

Within some EU countries the BERD is very much concentrated – such as Finland, where electrical machinery (mainly the high-tech ICT industry) accounts for 58% of total BERD, and Ireland (41%) and the Netherlands (27%). On the other hand, in Germany (32%) and Italy (20% apart from an ICT of 24%), the motor-vehicle industry produces and absorbs the bulk of industrial knowledge, while in Denmark, the pharmaceutical industry is dominant with a share of 38%.

Figure 3.2.10 Allocation of Business Enterprise Expenditure on R&D (BERD) by industry, 2000, %



Source: DG Research
Data: OECD, ANBERD database
Notes: (1) Latest year available: I: 2001; B, D, ES, FIN, UK, US, JP: 2000; All other countries: 1999.
(2) EL, L, A, P data are not included in EU-15 average.
Food: Food, Beverages & Tobacco; Textiles: Textiles, Fur & Leather; Paper: Paper; Chemicals: Chemicals (less Pharmaceuticals); Pharmaceuticals: Pharmaceuticals; Machinery: Machinery; Office: Office, Account. & Computing Machinery; Electrical Machinery: Electrical Machinery; Electro. Equip.: Electro. Equip. (Radio, TV & Commun.); Instruments: Instruments, Watches & Clocks; Motor Vehicles: Motor Vehicles; Aerospace: Aerospace; Others.

Third European Report on S&T Indicators, 2003

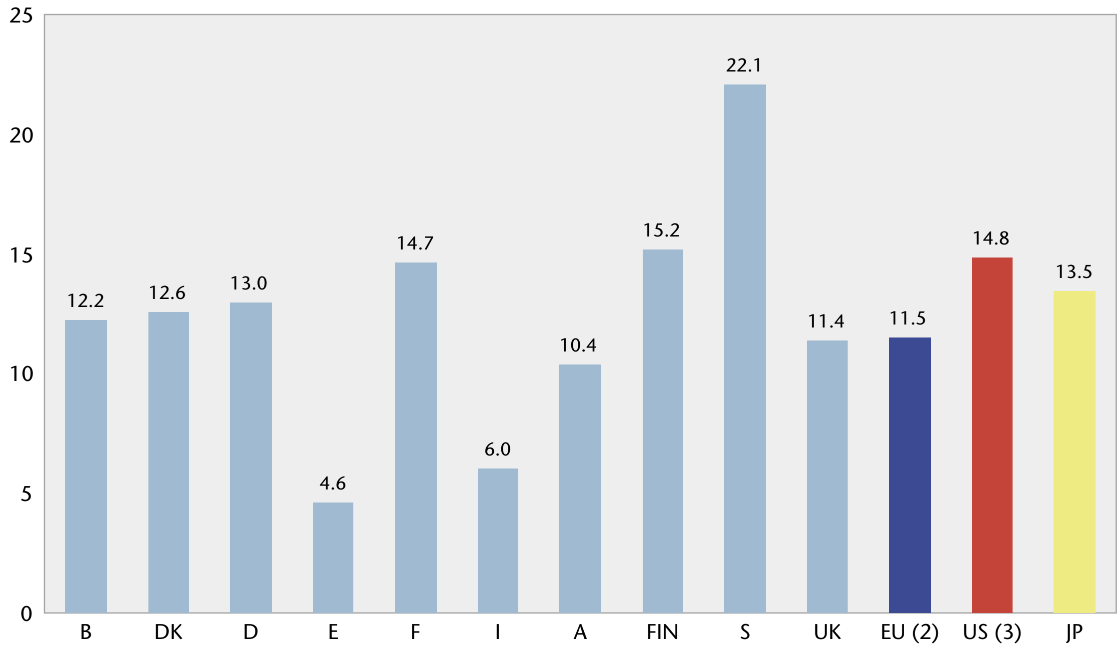
Analysis of knowledge investment according to high-tech classification

1. R&D intensities of high-tech industries differ across countries

Industries can also be classified in terms of typical R&D intensity in high-tech, medium-tech and low-tech industries. Knowledge investment efforts in the US high-tech and medium high-tech industries (14.8%) are higher than in EU-10 (11.5%) (the typically low-R&D-intensive countries are missing). However, there are significant differences between the Member States, as Sweden and Finland rank much higher than the US (figure 3.2.11).

However, the R&D intensity does not inform us about the absolute efforts in industrial knowledge as it is measured in relation to value added. Yet the absolute level of knowledge investment determines the amount of knowledge produced. The absolute level and dynamics of BERD depend also on industrial specialisation in high, medium and low-tech industries. Consequently, the dynamics of BERD investment and the total R&D intensity of manufacturing are related to structural changes in high-tech industries.

Figure 3.2.11 High-tech and Medium High-tech Industries – Business Enterprise Expenditure on R&D (BERD) as % of Value Added, 1999 (1)



Source: DG Research
Data: OECD
Notes: (1) A, FIN, UK, EU-10: 1998; S, JP: 1997. (2) EU-10: Calculated by DG Research does not include EL, IRL, L, NL and P
(3) US: Extrapolated by DG Research.

Third European Report on S&T Indicators, 2003

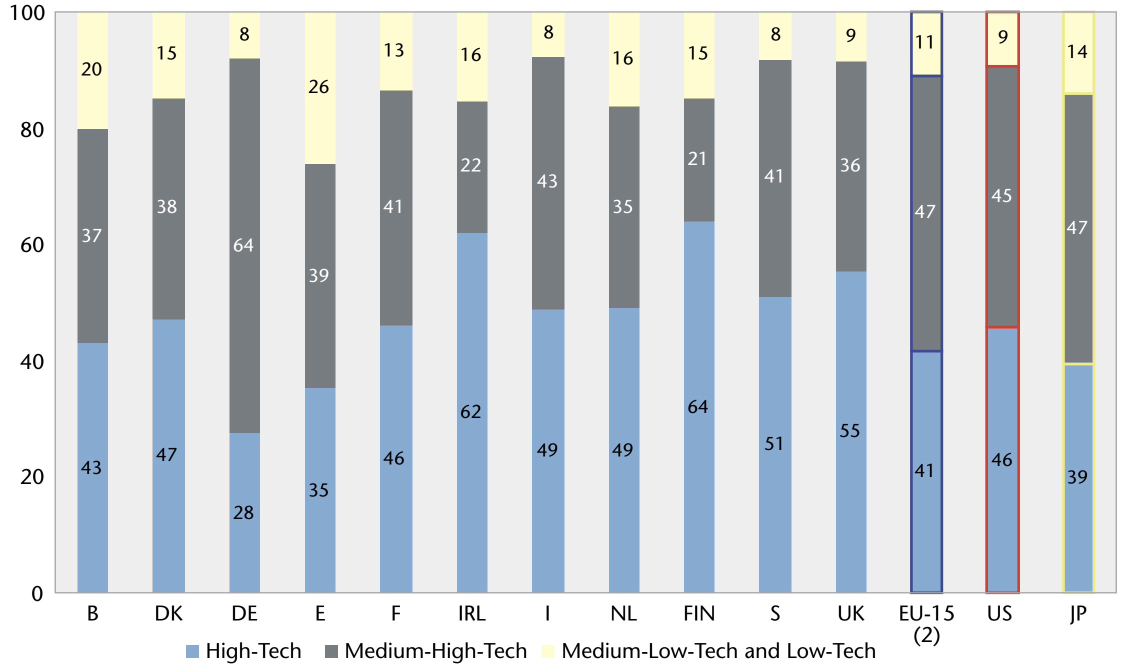
2. Allocation of Business Expenditure on R&D according to classification of technology intensity

The emerging knowledge-based economy implies a structural change towards high-tech industries whose competitiveness is based on intensive knowledge production and utilisation. However, knowledge-based economies are also expected to be characterised by a more intensive use of knowledge in all industries. Therefore, the absolute level of industrial R&D expenditure should increase due to the greater specialisation in high-tech industries, as well as to overall higher investment in and utilisation of knowledge.

The share of high-tech industries in knowledge investment of the business sector is noticeably higher in the US with 45.8% than in the EU-11 with 41.5% (Greece, Luxembourg, Austria and Portugal are missing but this probably does not reduce the EU average for high-tech industries) while Japan ranks even lower (39.3%). However, the EU share of medium-high-tech industries (47.6%) exceeds that of the US (44.7%) indicating a relatively stronger specialisation in scientific and technological knowledge production in medium high-tech industries in Europe. The share of medium-low-tech and low-tech industries is slightly higher in Europe (11.0%) than in the US (9.4%) whereas the share in Japan is considerably higher (14.1%) (figure 3.2.12).

The structure of total BERD across the high-tech, medium high-tech and low-tech industries differs noticeably between the Member States implying important differences in industrial knowledge investment. Again some of the Member States – Ireland (62.1%) and Finland (64.0%) – exceed the US share of high-tech industries strongly. While in Germany the high-tech industry and the low-medium-tech industry shares are relatively low, the share of the medium-high-tech sector in BERD investment is very significant with 64.3% which exceeds the EU average (47.5%) and the US (44.7%). The share of medium-low-tech and low-tech industry is the highest in Spain followed by Ireland for which countries the share of high-tech in BERD is also important.

Figure 3.2.12 Share (%) of Business Enterprise Expenditure on R&D (BERD) in the Manufacturing sector by technology intensity, 2000



Source: DG Research
Data: OECD
Notes: (1) DK, F, IRL, NL, S, EU: 1999; All other countries: 2000.
(2) EL, L, A and P are not included in EU-15.

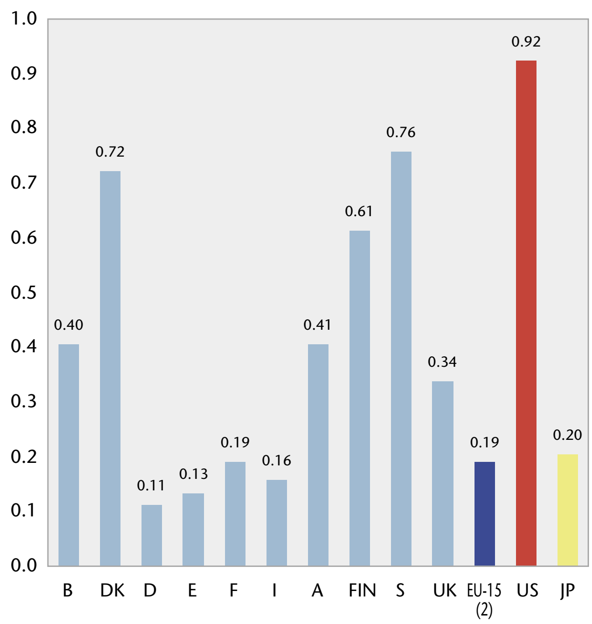
Third European Report on S&T Indicators, 2003

3. Business sector R&D in the service sector: the role of knowledge intensive services

The heterogeneity of services - some have very low technology, low-skill and repetitive activities while others involve sophisticated technological, informative and knowledge efforts – complicates the understanding and analysis of research and innovation activities in the service sector. In spite of its heterogeneity, the service sector differs typically from the manufacturing sector, as service products are intangible, the final products are simultaneously the process of creating them and, interactions between the client and producer are intensive. Furthermore, most service firms are small – with exceptions in the financial and public sector. There has been a recent upsurge in literature dealing with services and innovations (Green et al., 2001; Tether and Metcalfe, 2001; Djellal and Gallouj, 2001).

R&D intensity of the service sector – indicating the relative efforts of the scientific and technological knowledge investment in the service sector – is, however, very low. Nevertheless, the US R&D intensity (0.92%) is significantly higher than that of the EU (0.19%), while some of the Member States (Sweden and especially Denmark) show a very high R&D intensity, as seen in figure 3.2.13.

Figure 3.2.13 Business Enterprise Expenditure on R&D (BERD) in the Service Sector as % of Value Added of the Service Sector, 1999 (1)



Source: DG Research
Data: OECD
Notes: (1) B, I: 2000; A, JP: 1998;S: 1997.
(2) EU-15 does not include EL, IRL, L, NL, A, P and S.

Third European Report on S&T Indicators, 2003

The result of low levels of knowledge creation and absorption in the service sector – when measured by R&D investment alone – has created considerable doubts about measuring innovative activity in the service sector in the same way as in the manufacturing sector. Consequently, there is considerable debate on how the characteristics of services may influence the nature and measurement of innovations in the service sector (cf. box).

How to measure innovation activities in the service sector

Considerable debate is taking place about the nature and measurement of innovations in the service sector. In particular, it is argued that the technological focus in innovations – as applied to the manufacturing sector – is not adequate for measuring innovations in the service sector. Rather, in the service sector, innovations are more knowledge intensive (human capital intensive) than technology (R&D) intensive. Innovations in the service sector comprise also other types of innovation than technological innovations, such as organisational innovations. Furthermore, service-sector activities rely heavily on the use of new technologies, especially ICT. A specific problem is the distinction between product and process innovations in the manufacturing sector. This distinction makes little sense in the service sector, where it is impossible to separate final products from their production processes (Nice Conference, Section Services; Miles, A. Leiponen, Miles, Galloj, etc.). Consequently, R&D expenditure captures only a minor part of innovation investments in the service sector. The present discussion is playing an important part in the design of the CIS3, which will deal with the service sector more intensively (Nice).

Significant qualitative and structural changes in the service sector have, in particular, raised some doubts about prevailing opinions of services as being labour-intensive, low productivity and low R&D intensive activities. A more differentiated view of the characteristics of service-sector products indicates that certain new service activities with high knowledge and R&D intensity are emerging that are at the core of a knowledge-based economy. In a knowledge-based economy, in particular, the role of knowledge-intensive services as complementary activities and intermediates for the manufacturing sector and for other services is critically important for innovation activities and the productivity growth of the economy as a whole.

Recently, certain types of service activities – knowledge-intensive business services (KIBs) and research-service providers – are emerging that are characterised not directly as research intensive, but as knowledge and development intensive. They are an integral part of the emerging knowledge-based economy, as they fulfil important functions in society's knowledge production, absorption and dissemination. The critical function of intensive business services (KIBs) is linked to the increasing importance of dissemination of knowledge, outsourcing activities and networking. It is therefore not surprising that such service activities make intensive use of ICT technologies, with the result that the total services sector is the largest user of ICT investment (83%) in the US. Obviously, business and communication services are central in facilitating knowledge and information flows in the economy (Leiponen, A. 2000). The following knowledge-intensive activities are defined as knowledge-intensive business services (table 3.2.2).

Table 3.2.2 Knowledge-Intensive Business Services (KIBs industries)

Accounting & bookkeeping	Management consulting
Technical engineering	R&D services, consulting
Design	Environmental
Computer & IT-related	Legal
Marketing & Advertising	Real estate
Training	Specific financial
Temporary labour recruitment	Press and news agencies (content)

Source: Leiponen, A. 2000
Data: Leiponen, A. 2000 (information from Miles, I. 1995)
Third European Report on S&T Indicators, 2003

From the point of view of knowledge production, knowledge services can focus more on those activities that serve knowledge creation and absorption processes directly. Although they play a vital role in determining the productivity of knowledge production, their role depends on the institutional structure of the knowledge system. Such services comprise telecommunication services, computer services and R&D services (Eurostat, Statistics in Focus 2001).

It is expected that these knowledge intensive sectors will play an increasing role in the emerging knowledge-based economy. This role is reflected in a high share of these activities in the service sector's R&D activities and in a high level of R&D intensity in comparison to other services. Knowledge-intensive services are measured by following the OECD definition while a broader Eurostat definition also exists[2]. How-

[2] *Post and telecommunications, Computer and related activities, Research and development, Water transport, Air and space transport, Financial intermediation, Real estate, renting and business activities, Education, Health and social work and Recreational, cultural and sporting activities (i.e. NACE Rev.1 codes 61, 62, 64-67, 70-74, 80, 85, 92).*

ever, serious comparability problems arise as only few countries provide data across the same sub-sectors of the knowledge-intensive services. The only information to be derived from the available data is that in the US, the Netherlands and in Italy, the shares of knowledge-intensive sectors in service-sector R&D expenditure amount to 57.7%, 21.6% and 71.0% respectively. Calculations about R&D intensity are impossible because the corresponding value-added data are missing at this disaggregated level.

Section III Strategies and dynamics of international R&D performance

Fundamental changes have emerged in the global economy that are affecting the basis of competitive advantage at company level. The decreased cost of information flow, increases in the number of markets, the liberalisation of product and labour markets in many parts of the world, and the deregulation of financial flows is stripping away many traditional sources of competitive differentiation and exposing a new fundamental core as the basis for wealth creation (Teece, 2000). Due to this 'globalisation' of previously-protected economies, there has been an increase in 'internationalisation' of the business sector. During the 1990s, the structure of industry worldwide has undergone a significant re-shaping, increasing firm dynamics which led businesses to restructure their activities on an international scale in order to remain efficient, flexible and competitive. During the last ten years in particular, companies have moved towards more innovative global strategies for restructuring their operations into research and development (R&D), production, marketing and sales activities. Concerning the internationalisation of R&D, three predominant forms have emerged:

- *Foreign Direct Investment* (FDI) whereby foreign firms contribute to the domestic investment in knowledge;
- *Mergers and Acquisitions* (M&A), which firms use in order to gain access to R&D resources and skills of the other firms;
- *International Research Joint Ventures* (RJV) which enable co-operating firms to join forces on the R&D front, but to remain independent in other business areas.

Within the context of *Foreign Direct Investment*, the OECD distinguishes several forms of R&D internationalisation, namely (OECD 2001a:27):

- location (or re location) of R&D laboratories;
- acquisition of R&D laboratories abroad;
- international sub-contracting of R&D;
- R&D as a business service.

Countries such as Ireland have shown what success such a national strategy can entail for the country's economic development.

The second form of R&D internationalisation, *Mergers and Acquisitions*, is one of the most visible forms of industrial restructuring. Some of the factors that have prompted this trend include deregulation, privatisation, technological requirements, new financing instruments and the need to rationalise activities in a climate of enhanced global competition. During the 1990s, intra-EU mergers have risen sharply, reflecting the on-going Europeanisation of industry.

International *Research Joint Ventures* are a co-operative activity in the field of R&D between two (or more) independent firms. The co-operation between EU and US companies in the area of research and development activities is of particular interest. These two regions are at the forefront of developments across high-technology industries, and their companies compete frequently in similar product markets. International RJVs have proved popular because they provide a useful strategic option to firms, and offer more flexibility than mergers and acquisitions.

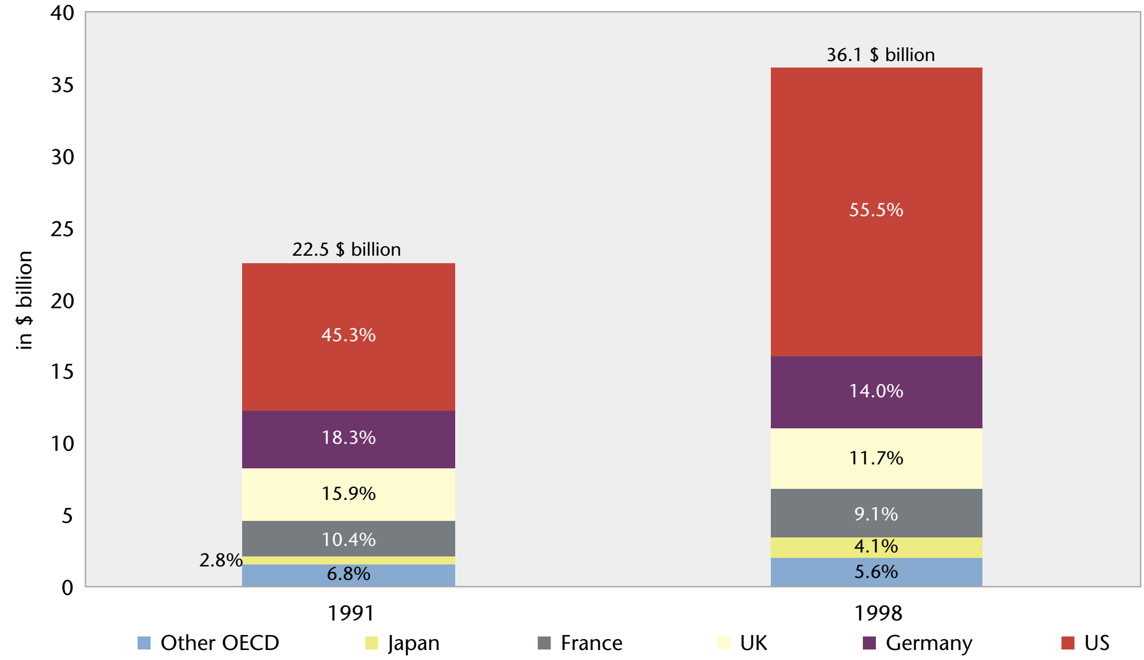
1. R&D and Foreign Direct Investment

The internationalisation of business-sector R&D activities reflects the globalisation of a knowledge-based economy connected to the increased role of foreign actors in knowledge creation, and with the potential of international knowledge spillovers. All countries would hope to attract as many as possible high-tech FDIs with sophisticated R&D activities.

The effects of globalisation on research is evident from the data on R&D expenditure by affiliates of foreign multinationals. Between 1991 and 1998, R&D expenditure of affiliates based in the OECD area rose from $22.5 billion to $36.1 billion, as shown in figure 3.3.1. The US continues to attract the largest share of foreign R&D investment (55.5% of the OECD total, compared with 45.3% in 1991). Of the $20 billion spent on research by US-based foreign affiliates in 1998, three-quarters could be attributed to European companies located in US territory. Conversely, around 70% of R&D by overseas affiliates of US parent companies took place in the European Union (NSB, 2002).

A first indication of the degree of foreign contribution to the domestic investment in knowledge is foreign R&D expenditure in a country. The internationalisation of industrial R&D activities varies considerably across EU countries. It is very high in Ireland (64.8% in 1997), reflecting the country's overall development strategy, which is based on the attraction of FDI. The UK, which traditionally attracts FDI, also has a relatively high percentage (31.5%). The very low share of foreign R&D activities in Japanese manufacturing R&D implies a closeness of the innovation system, with low international knowledge spillovers (figure 3.3.2). Unfortunately, restricted availability of data prevents a detailed analysis of the degree of internationalisation in R&D.

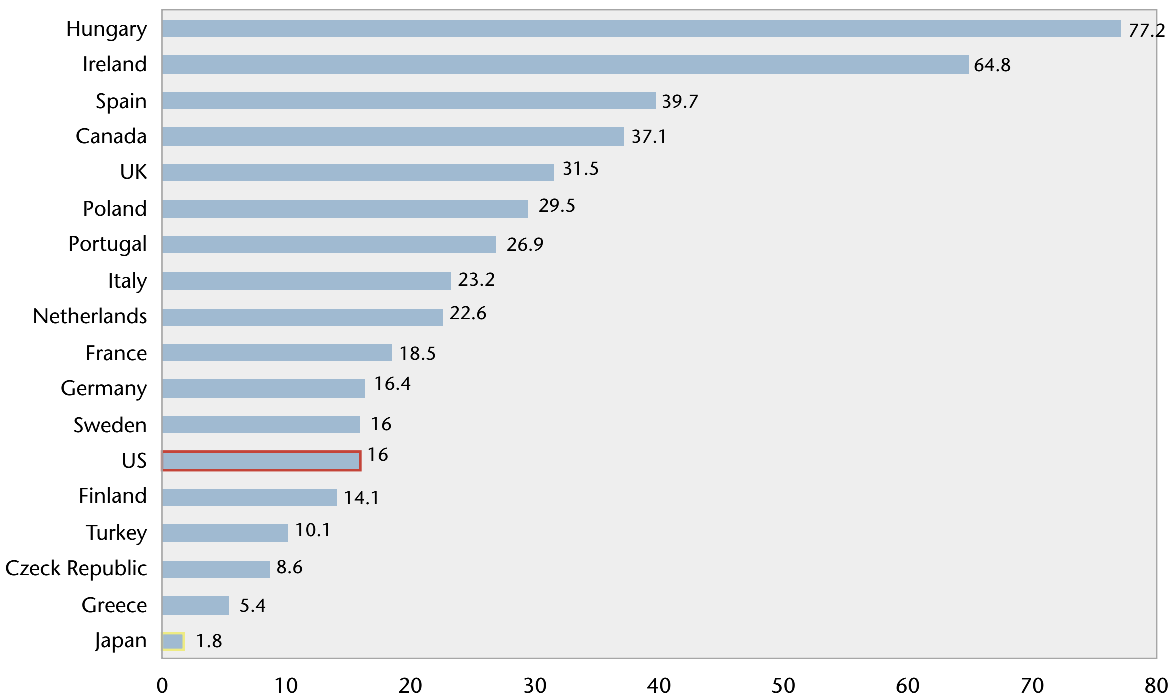
Figure 3.3.1 Trend in the share of R&D expenditure under foreign control in the manufacturing industry in selected OECD countries



Source: DG Research
Data: OECD, Activities of Foreign Affiliates Database

Third European Report on S&T Indicators, 2003

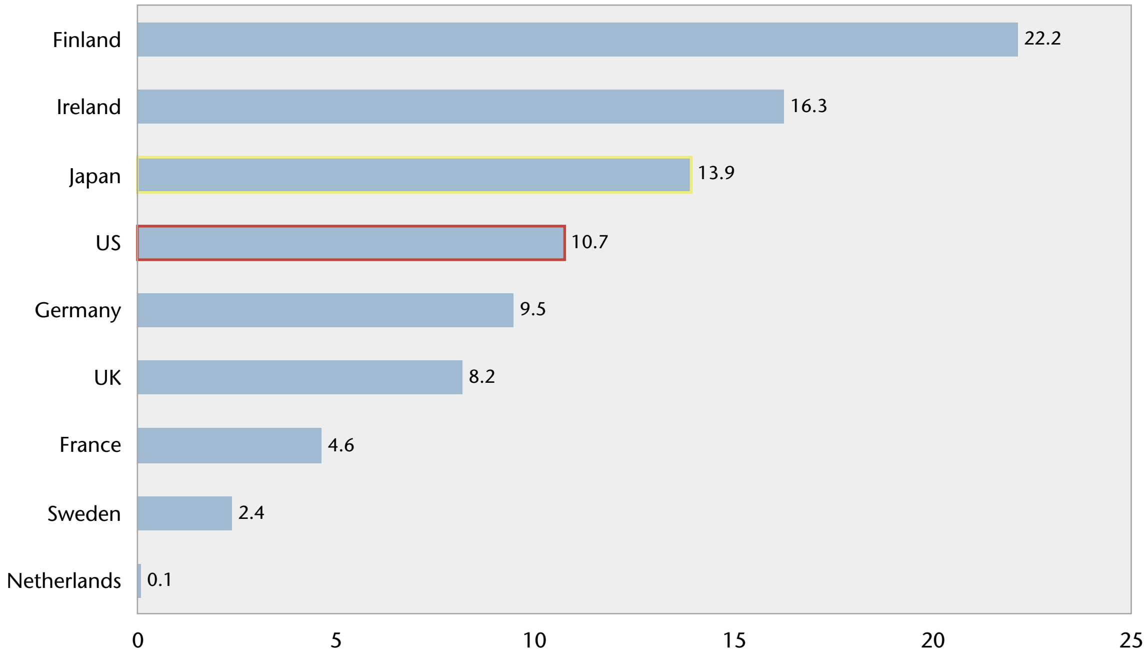
Figure 3.3.2 Share of foreign affiliates in manufacturing R&D, %, 1998 or latest available year (1)



Source: DG Research
Data: OECD, Activities of Foreign Affiliates Database
Note: (1) S, UK, PL, P, FIN: 1999; HU, IRL, EL: 1997; D: 1995, I: 1992.

Third European Report on S&T Indicators, 2003

Figure 3.3.3 Growth of BERD by foreign affiliates in the manufacturing sector, latest available year (1)



Source: DG Research
Data: OECD
Note: (1) D, IRL: 1995-1997; JP, S, US, F: 1995-1998; FIN: 1995-1999; UK: 1996-1999; NL: 1997-1998.
Third European Report on S&T Indicators, 2003

Figure 3.3.3 shows the dynamics of international R&D activities and reveals that Japan and Finland, which have a low level of internationalisation of R&D activities, are improving. Their growth rates of R&D expenditure by foreign affiliates are quite high (respectively 13.9% and 22.2%). Ireland, which already has a high degree of international R&D activity, has also had a high growth rate (16.3%).

Besides the direct input, the effective contribution to the knowledge production of the host country also depends on knowledge spillover effects, which cannot be measured directly. The extent of these spillovers from a foreign affiliate's R&D activities depends on its links to domestic research activities, as well as on the absorptive capacities of those involved in domestic knowledge production. The factual outcome cannot be measured with simple indicators and requires a complex analysis.

Although it may appear that research conducted abroad by domestic firms is a loss for domestic knowledge production, this research can be an important channel for exploiting the international knowledge pool. It may also induce knowledge spillovers which play a vital role in domestic knowledge accumulation. The extent of knowledge spillovers from a company's R&D activities that take place abroad depend on the capability of the parent firm to absorb this knowledge, as well as its external links with the domestic R&D activities (cf. box).

A country's national effort in industrial R&D: a country-based concept for knowledge creation

These issues raise the question of what is ultimately the relevant indicator for measuring a country's total investment in knowledge, i.e. effective R&D for creation of technological potential. A new concept of technological potential being developed is one that is based on the nationality of firms. Consequently, a country's national effort in industrial R&D includes research conducted on its territory by domestic firms and by affiliates of those firms abroad. If the objective of the research activity is the local market, the research of foreign affiliates in a country is added to the host country's total R&D effort. On the other hand, if the research is world-market oriented, only the spillover effects should be counted (OECD, 2001b).

A country's investment in its technological potential therefore cannot be limited to what is produced within its territory. This investment, on the one hand, consists of the creation of knowledge within a country's borders. On the other hand, it comprises (technological) knowledge from foreign sources, including knowledge transfer from R&D affiliates, from affiliates of national firms abroad, R&D subcontracted abroad and acquisition of R&D laboratories abroad, among others (OECD, 2001b).

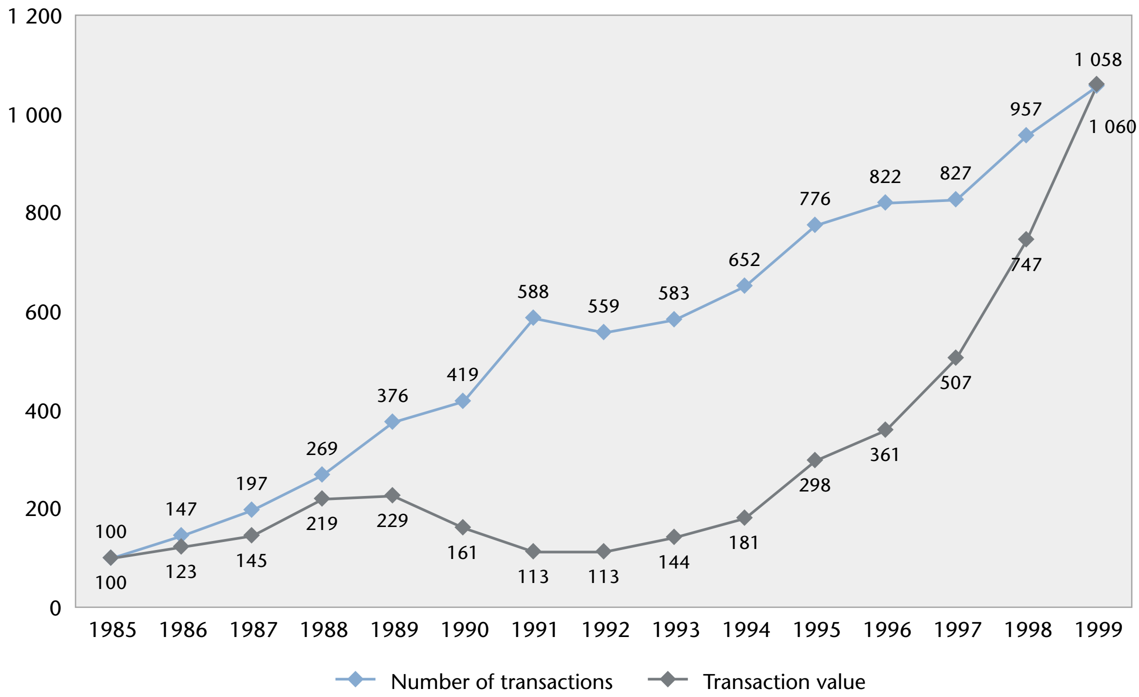
2. R&D Performance of Mergers and Acquisitions

Mergers and Acquisitions (M&As) are driven by deregulation, economic globalisation, technological requirements, new financing instruments and more pressure on companies to focus on their core business. Through different alliances, companies feel better able to meet the needs of international consumers. This trend is stronger in respect of high-tech products, which show continuously shortening life cycles. Furthermore, high-tech industries are characterised by shorter time-to-market periods. The need to amortise the higher costs of R&D across a wider geographical area, and the opening of new markets to competition, have accelerated the pace of M&As within the overall process of foreign and domestic investment. M&As, alongside strategic alliances, seem to offer a solution in terms of acquiring the necessary know-how and market-entry facilities.

M&As have received increasing attention in the last 15 years (1985-1999), during the so-called Fifth Merger Wave (Black, 2000), for two reasons:

- the sheer increase in number of M&As, which has almost doubled since 1985;
- the enormous increase in the value of these transactions, where this value in 1999 was more than seven times higher than the corresponding value in 1993. These points are illustrated in figure 3.3.4.

Figure 3.3.4 Transaction Value and Number of Worldwide M&As, index (1985=100)



Source: Black (2000)

Third European Report on S&T Indicators, 2003

Acquisitions involving at least one European partner have increased from 15% in 1985 to 43% of the total world-wide number in 1999. The share of M&As involving at least one US partner shrunk from 86% to 40% over the same period. Although US and European takeovers are still dominating the world totals, Asian companies have become more active over the same period and now represent about 14% of total worldwide acquisitions.

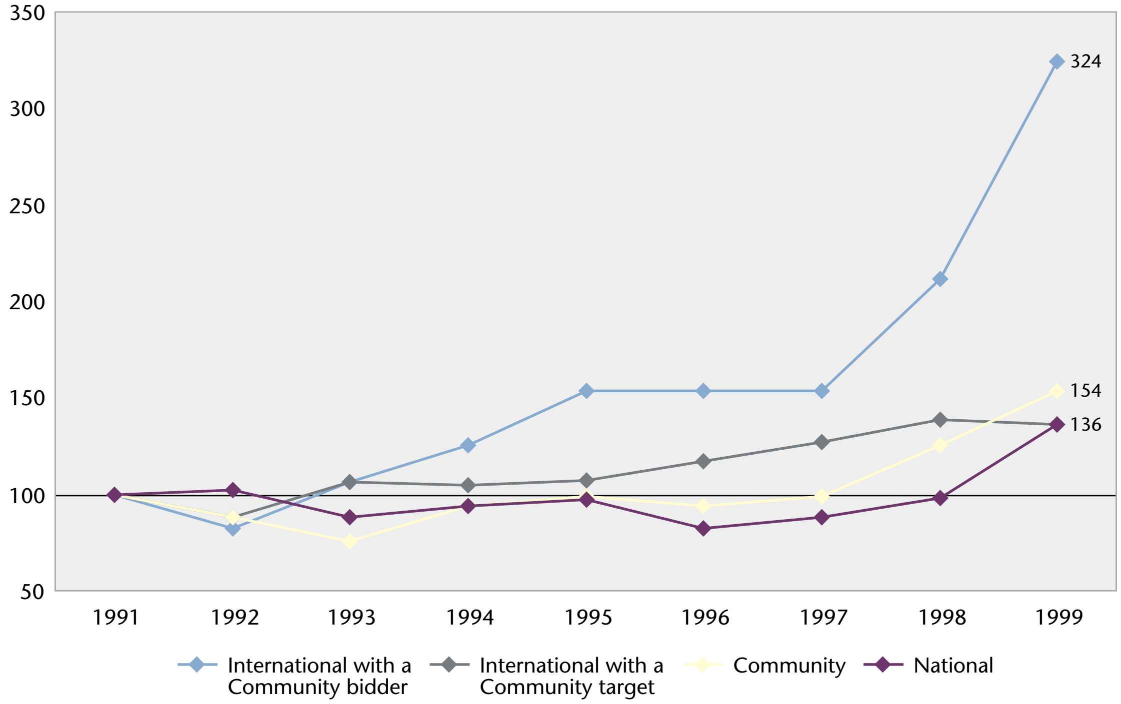
The increasing attractiveness of Europe's industries for EU and non-EU investors

In 1999, about 56% of all M&As in the EU involved companies located in the same Member State. As can be seen in figure 3.3.5, although this still represents more than half of all operations, it indicates a downward trend, as national transactions in 1992 comprised 68% of all operations involving EU companies. The increase in the number of Community cross-border mergers reflects the on-going Europeanisation of industries as a result of market integration.

Between 1991 and 1999, the number of international operations with an EU target has risen by 36%. Throughout the 1990s, EU enterprises remained consistently attractive to non-European investors. Even more striking is the strong growth (231%) of international acquisitions by European companies over the same period.

Among the ten most-targeted sectors (1998-1999 data), the business-services sector, including the activities of holding companies, ranked first. It shows a sharp rise compared to the 1996-1997 data. 'Distribution' ranks second, although its share has declined. The merger-intensive industries in manufacturing are mainly industrial machinery, food and chemical industries.

Figure 3.3.5 Number of National, Community and international M&As, index (1991=100)



Source: European Commission, DG Economics and Financial Affairs
Data: based on SDC-M&A

Third European Report on S&T Indicators, 2003

Motives for M&As

Observations based on public statements about the rationale behind M&As, as collected by the European Commission and published annually up to 1992, reflect the changing sectoral structure and the widening geographical scope of such transactions. These are given in table 3.3.1.

The strengthening of market position as a motive for M&As, at the expense of the rationalisation and synergy motives favoured in the period up to 1988, has become increasingly important. The desire to expand operations has also become a major motive behind M&As in Europe. Diversification plays a subordinate role in mergers, which contrasts with the merger wave in the 1960s and early 1970s.

Few M&As appear to be motivated solely with R&D as a goal. Merger activities form part of adjustment strategies with respect to the European Single Market. More recent evidence, albeit of a less systematic nature, suggests that this trend has continued into the late 1990s. Mergers are used increasingly as a means to re-focus on core business activities and to occupy leading positions in industries (OECD, 2001a).

Figure 3.3.6 shows the relationship between the intensity of M&As and the intensity of R&D per sector for the period 1996-1998[3].

The figure does not show a clear linear relationship between the R&D intensity and M&A intensity of a sector, which confirms that motives for merging differ from industry to industry and from company to company. Confining the impact of technological change on M&As to a simple relationship

[3] *R&D intensity is based on the relationship between the amount of R&D in each sector and the weight of that sector in the economy. M&A intensity is calculated in a similar way.*

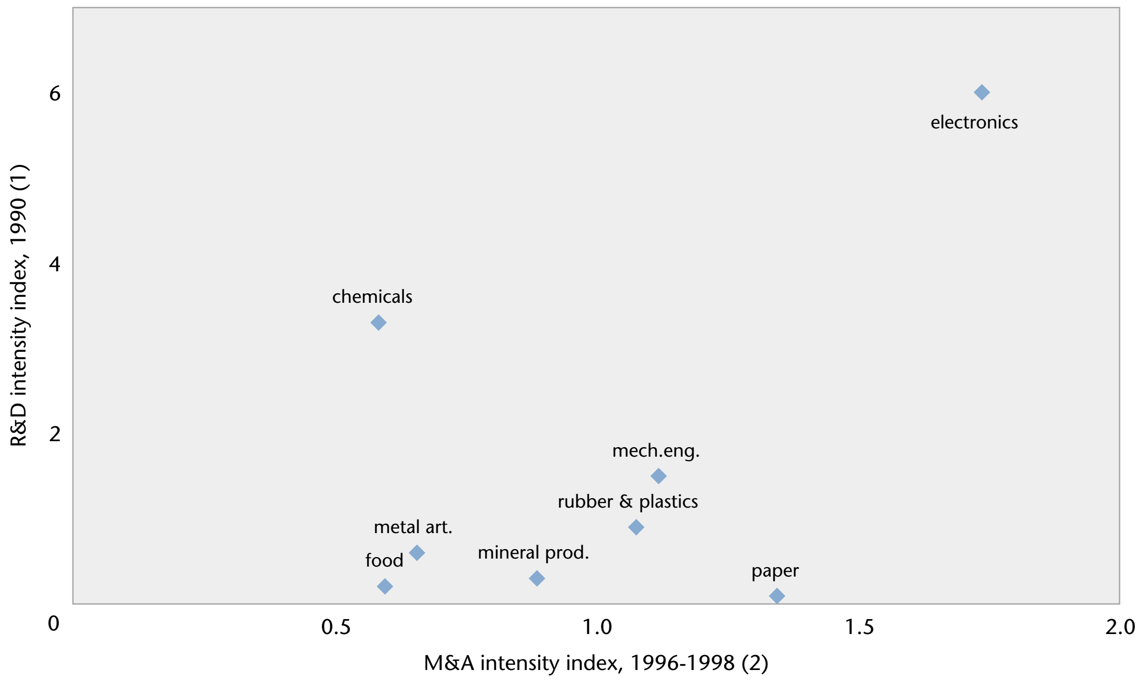
Table 3.3.1 Company Motives for Mergers and Acquisitions – as % of all motives

	1985-1986	1986-1987	1987-1988	1988-1989	1989-1990	1990-1991	1991-1992
Expansion	17.1	22.1	19.6	31.3	26.9	27.7	32.4
Diversification	17.6	5.8	8.3	7.1	3	2.8	2.1
Strengthening market position	10.6	11.5	25.4	42.2	45.3	48.2	44.4
Rationalisation and synergy	46.5	42	34.4	14.4	17.7	13.3	16.2
R&D	2.4	5.3	0.7	0	0.6	0	0
Other	5.9	13.3	11.6	4.9	6.4	8	5
All	100	100	100	100	100	100	100

Source: Colombo & Garonne, 2002

Third European Report on S&T Indicators, 2003

Figure 3.3.6 M&As vs R&D intensity by sector in Europe



Source: Colombo & Garonne, 2002
Notes: (1) European Commission : DG Research (First European Report on S&T Indicators, 1994).
(2) DG Economics and Financial Affairs (1999).

Third European Report on S&T Indicators, 2003

between the intensities of R&D and M&As would be grossly misleading in analysing technological factors related to M&As. Technological change stimulates M&As in different ways, as illustrated by the following examples:

- New and superior technologies may provide the necessary competitive advantage to expand abroad and compete successfully with established local enterprises (Dunning, 1992). In sectors characterised by economies of scale and excess capacity, companies prefer foreign acquisitions rather than greenfield investments;
- Information and communication technologies (ICT) help companies to acquire dominant market positions through acquisitions beyond national borders, while maintaining efficiency and flexibility in their management and supply systems;
- More generally, the rapid pace in new technological developments tends to shorten product life cycles continuously and promote new entrants that have innovative technology. As a result, competition has become much more dynamic, with rapidly changing market structures.

Table 3.3.2 Impact of M&As on R&D effort and performance by typologies: a synthesis

	Typologies								
	Same business	Same product lines	Direct competitors	Same techno-logical fields	Comple-mentary technolo-gical fields	Cross-border	Prior relations	Private acquisi-tion	Leveraged transaction
Change of R&D physical equipment		-	---	---				++	--
Change of R&D personnel		-	--	--	+	+		++	-
Change of R&D performances	--	--	---	--					--

Source: Colombo & Garonne, 2002
Note: +: in this M&A typology, changes are significantly more positive or less negative than in the remaining M&As.
-: in this M&A typology, changes are significantly less positive or more negative than in the remaining M&As.
+++/—-: confidence level > 99%; ++/—: confidence level > 95%; +/-: confidence level > 90%.

Third European Report on S&T Indicators, 2003

Table 3.3.3 Impact of M&As on R&D activity by typologies: a synthesis of the results of the principal component analysis

	Typologies								
	Same business	Same product lines	Direct competitors	Same techno-logical fields	Comple-mentary technolo-gical fields	Cross-border	Prior relations	Private acquisi-tion	Leveraged transaction
R&D: input									
Increase in R&D effort		--	--			++		++	-
Decrease in R&D effort	+++		++	++	-	++		---	+
R&D rationalisation				+++	--	--		---	
New R&D fields and sources			--			-		+	
Critical mass in R&D		-	--						
R&D: output									
Increase in R&D output			--		+++		++	+++	
Better exploitation of technological competencies	--						+++		
Less technological competition		++	+	+++	--				++
R&D: productivity									
Increase in R&D productivity	---		---		-		++		-
Decrease in R&D productivity		++		+++					
Organisation and management of R&D									
R&D specialisation and knowledge transfer							+		+++
R&D restructuring							++		
R&D resource redeployment						---			
R&D: mission									
Broadening of R&D mission	-		--				++		-
Focusing of R&D mission				+++	-				

Source: Colombo & Garrone, 2002
Note: +: in this M&A typology, the effect is significantly stronger / more frequent.
-: in M&A cases other than this typology, the effect is significantly stronger / more frequent.
+++/—-: confidence level > 99%; ++/—: confidence level > 95%; +/-: confidence level > 90%

Third European Report on S&T Indicators, 2003

Table 3.3.2 and table 3.3.3 synthesise the results of an empirical analysis[4] of the impact of M&As upon the R&D activity of merging companies according to the type of transaction. Table 3.3.2 documents the impact of M&As on R&D effort and R&D performance, whereas table 3.3.3 synthesises the results of the principal component analysis.

Where M&As have been driven by R&D-related motivations, an increase of R&D effort is usually registered after the deal as regards both physical equipment and personnel. The opposite phenomenon occurs in the other category, as seen in table 3.3.4. However, no significant difference emerges when looking at the impact of M&As on R&D returns and productivity. The main benefit of R&D-related transactions appears to be the achievement of critical mass in R&D, whereas non-R&D-related ones exhibit a larger extent of R&D restructuring.

Table 3.3.4 The impact of M&As on R&D input and performance: R&D related vs. non-R&D related motivations

	R&D related motivations		
	Yes (a)	No (a)	Confidence level (b)
Changes in physical R&D facilities (c)	0.7 (1 520)	–0.5 (1 595)	***
Changes in R&D personnel (c)	0.6 (1 531)	–1.0 (1 596)	***
Changes in R&D performance (d)	1.3 (1 768)	1.9 (1 799)	

Source: Colombo & Garrone, 2002
Note: (a) Standard errors in parentheses
(b) T-test of the different between mean values: *** = confidence level > 99%, ** = confidence level > 95%, * = confidence level > 90%
(c) Answers codified through a ten-degree scale, ranging from –5 (100% decrease) to +4 (increase greater than 100%) and 0 meaning no change.
(d) Answers codified through a nine-degree scale, ranging from –4 (substantial decrease) to +4 (substantial increase) and 0 meaning no change.

Third European Report on S&T Indicators, 2003

3. R&D in international joint ventures

In addition to the growth in international M&As, one of the important developments in firm dynamics during the 1990s has been a marked increase in international technological alliances between enterprises. This has not only been part of the general trend towards globalisation, but also reflects a strategic shift towards co-operation in research as an important complement to competition. Such alliances have proved popular because they provide a useful strategic option to companies. They offer more flexibility than M&As, are less costly to reverse, and enable companies to respond rapidly to new market conditions. In some cases, they provide an easier way of obtaining access to markets than through M&As.

The formation of research joint ventures is said to enable companies to pool resources and risk, exploit research synergies and reduce research duplication. It ensures continuity for long-term research, and creates otherwise unattainable investment 'options' in emerging technology fields (Contractor and Lorange, 1988; Coombs et al., 1996; Dodgson, 1993; Hagedoorn et al., 2000 and Vonortas, 1997).

In an era of strong globalising forces and increased international interdependence and competition, policy-makers need to understand more about the co-operative RTD activities being established in other parts of the world by their own companies, universities, and research institutes. For Europe in particular, understanding the involvement of European organisations in co-operative RTD ventures set up in the US is vital. The two regions are arguably at the forefront of developments across high-technology industries. They compete head-to-head in similar products around the globe, and their companies frequently meet across product and geographical markets.

Main trends in EU-US research joint ventures

Almost 45% of research joint ventures (RJVs) registered in the US between 1985 and 1999 have involved at least one partner from the EU. Annual registrations have followed a

[4] *This empirical analysis is part of a larger empirical study on "Mergers and Acquisitions and Science and Technology Policy" that was commissioned by the European Commission in the framework of the Common Basis for Science, Technology and Innovation Indicators (CBSTII) part of the Improving Human Potential specific programme and performed during the period 2000-2002 by a consortium consisting of: IDEA Consult: Dr. G. Steurs (Contractor); Catholic University of Leuven: Prof. Dr. R. Veugelers; Universitat Pompeu Fabre: Prof. Dr. B. Cassiman; Politecnico di Milano: Prof. Dr. M. Colombo; University of Reading: Prof. Dr. J. Cantwell.*

skewed, bell-shaped distribution pattern. They increased on average during the first 10 years and reached a peak in 1995, before dropping again. The drop in registrations was, however, stemmed during the last available data year and the 1990s ended with more or less the same level of RJV registrations as at the beginning of the decade (figure 3.3.7).

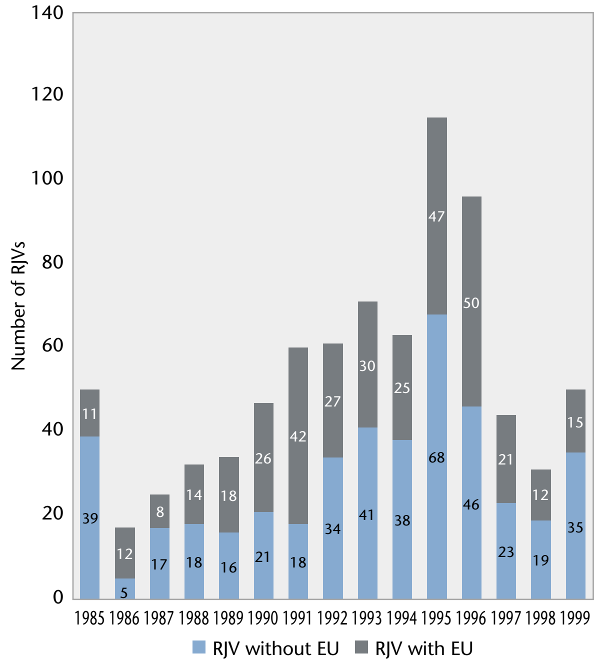
A survey of the primary-technology focus areas of research joint ventures for the period 1985-1999, illustrated in figure 3.3.8, showed that:

- EU participation has been fairly widespread across technology areas;
- four technology areas account for more than half of the RJVs with EU partners, i.e. environmental, energy, transportation and telecommunications.

The other technology areas comprising the highest number of EU-partner RJVs are, in descending order, computer software, chemicals, advanced materials, sub-assemblies and components (including semi-conductor devices), factory automation, test and measurement, and manufacturing equipment. Many of these fields – the first four in particular – are areas of strength in the European industry.

Apart from the US itself, UK and Japanese participation in US RJVs is the highest, followed by Germany, Canada and France (figure 3.3.9). As a whole, the EU has a far larger number of participants than any other region or country outside North America.

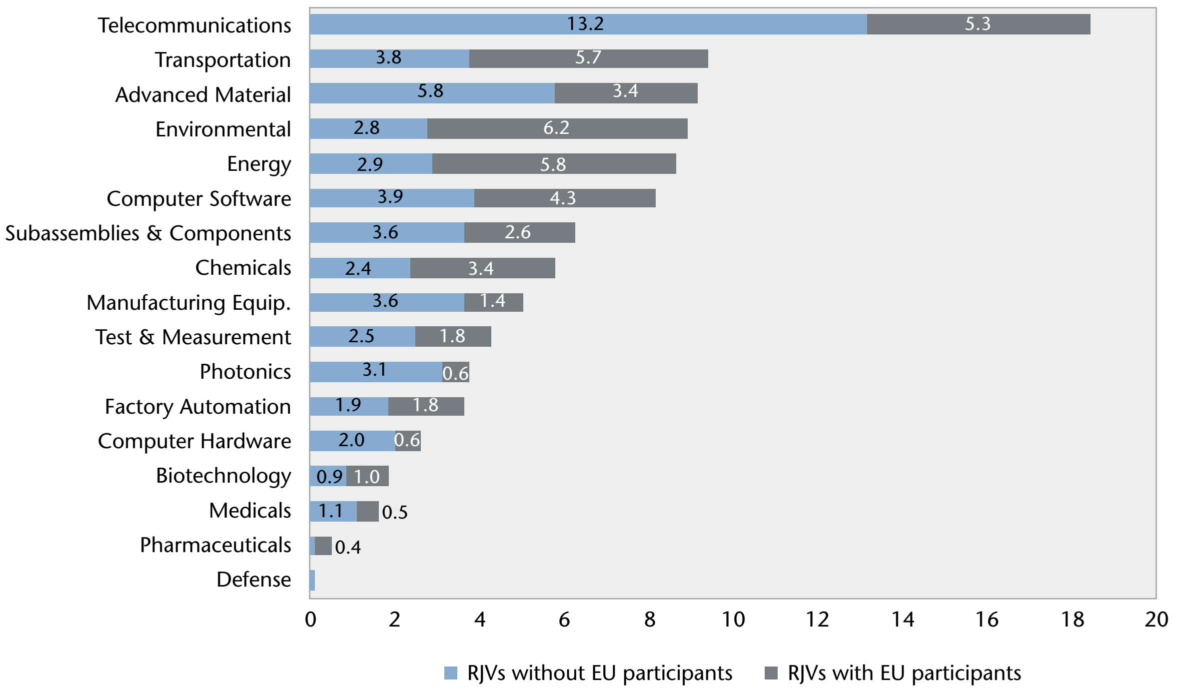
Figure 3.3.7 Creation of new Research Joint Ventures (RJVs) in the US, 1985-1999



Source: N. Vonortas (2000)
Data: NCRA-RJV database, George Washington University CISTP

Third European Report on S&T Indicators, 2003

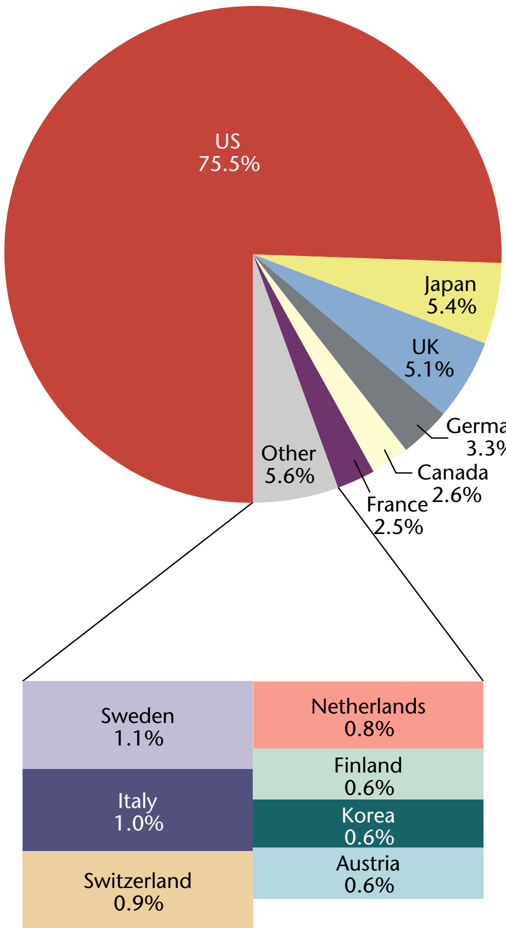
Figure 3.3.8 US Research Joint Ventures (RJVs) by technical area - as % of total RJVs, 1985-1999



Source: DG Research based on figures from N. Vonortas (2000)
Data: NCRA-RJV database, George Washington University CISTP

Third European Report on S&T Indicators, 2003

Figure 3.3.9 Membership of US Research Joint Ventures (RJVs) by participating country, 1985-1999



Source: DG Research based on figures from N. Vonortas (2000)
Data: NCRA-RJV database, George Washington University CISTP
Third European Report on S&T Indicators, 2003

Table 3.3.5 Top 20 most active foreign companies in US research joint ventures (1985-1999)

Rank	Entity	Country	Memberships
1	BP Amoco	UK	164
2	DaimlerChrysler	Germany	56
3	Siemens	Germany	55
4	Nortel	Canada	51
5	Fujitsu	Japan	48
6	Thomson-CSF	France	34
7	NEC	Japan	33
8	Philips Electronics	Netherlands	33
9	NTT	Japan	32
10	Hitachi	Japan	31
11	Toshiba	Japan	31
12	Ericsson	Sweden	28
13	Alcatel	France	25
14	Groupe Bull	France	23
15	BT	UK	22
16	Bayer	Germany	21
17	Marconi plc	UK	20
18	Mitsubishi	Japan	20
19	Nokia	Finland	20
20	Sony	Japan	20

Source: Vonortas, 2000
Data: NCRA-RJV database, George Washington University CISTP.
Third European Report on S&T Indicators, 2003

Table 3.3.6 Top 20 most active EU companies in the US Research Joint Ventures, 1985-1999

Rank	Entity	Country	Memberships
1	BP Amoco PLC	UK	164
2	DaimlerChrysler AG	Germany	56
3	Siemens AG	Germany	55
4	Thomson-CSF	France	34
5	Philips Electronics N.V.	Netherlands	33
6	L.M. Ericsson AB	Sweden	28
7	Alcatel	France	25
8	Groupe Bull	France	23
9	British Telecom PLC	UK	22
10	Bayer AG	Germany	21
11	Nokia Corp.	Finland	20
12	Marconi plc	UK	20
13	Fiat S.p.A.	Italy	17
14	Racal Electronics, PLC	UK	17
15	Hoechst AG	Germany	16
16	AstraZeneca PLC	UK	15
17	Deutsche Bundespost Telekom	Germany	14
18	France Telecom	France	14
19	Volvo AB	Sweden	13
20	Societe Nationale Elf Aquitaine	France	13

Source: Vonortas, 2000
Data: NCRA-RJV database, George Washington University CISTP
Third European Report on S&T Indicators, 2003

The involvement of EU companies

Only two EU companies appear in the list of top 20 companies overall (UK, Germany). However, as is shown in table 3.3.5, if non-US participants are considered separately as a group, EU companies account for 12 of the top 20 positions, the remainder being predominantly Japanese. Similarly, table 3.3.6 shows that the most active EU companies are also large multi-national corporations, as are almost all RJV players. The energy, telecommunications and electronics sectors dominate the list of European companies.

As these tables suggest, participation in RJVs is highly centred around a small number of large players. Entities that have participated in at least six RJVs each amount to approximately 7% of all entities. The same entities, mostly companies, account for just under half of the total number of identified RJV memberships.

The participation of EU universities in research joint ventures

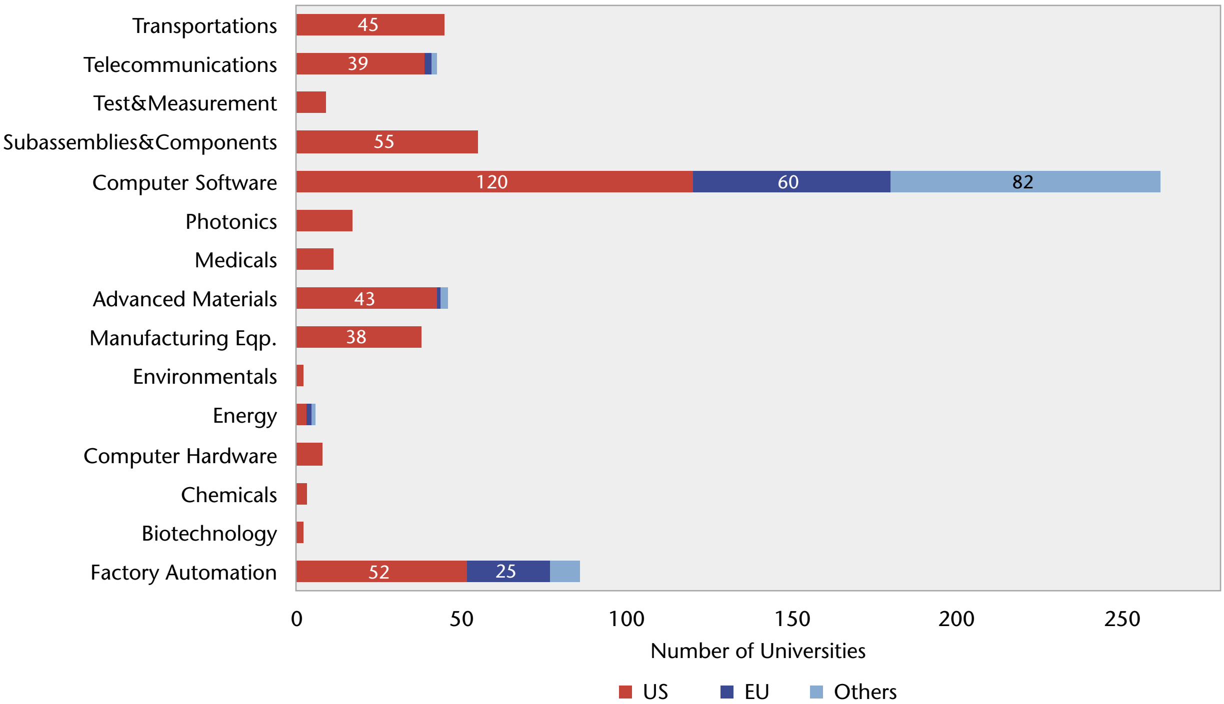
Figure 3.3.10 demonstrates that two technical areas dominate university involvement in US RJVs:

- computer software (which accounts for 40% of all university participation);
- factory automation (a further 14%).

Participation by European universities has been clustered in these two key areas. Two-thirds of all EU academic participation is in software, and just over a quarter in factory automation. Much of this co-operative activity can be attributed to a small number of very large RJVs, formed during the late 1980s and early 1990s, and associated with developing standards for open software.

The number of participating EU universities declined in the second half of the 1990s, as new RJV registrations decreased significantly. However, this drop was not necessarily the result of the overall decline in RJVs, as it started in 1995-1996, which was the peak period for new RJV registrations as a whole.

Figure 3.3.10 University participation in US Research Joint Ventures (RJVs) by technical area, 1985-1999



Source: N. Vonortas (2000)
Data: NCRA-RJV database, George Washington University CISTP

Third European Report on S&T Indicators, 2003

Participation of non-US universities in RJVs too has been heavily concentrated in computer software and factory automation. Moreover, neither of these two areas experienced steep declines in new RJV registrations.

The difference between EU and US universities is striking, as US universities have a much broader pattern of participation in RJVs. In addition to software and factory automation, six other areas have accommodated significant numbers of US universities (figure 3.3.10):

- sub-assemblies and components (including semi-conductors),
- factory automation,
- transportation,
- advanced materials,
- telecommunications,
- manufacturing equipment.

The most active Member States

EU Member States differ substantially in terms of business and university involvement in the RJVs under review and it is evident that the most active European countries have been the larger and more industrialised ones (figure 3.3.11).

Taking into account the role of language, it is not surprising that the United Kingdom, with its more general international business orientation, heads the list, followed by Germany, France, Italy, Sweden, and the Netherlands.[5] The likely implication is that companies and universities engage in RJVs from a position of strength, not weakness. Those entities (mainly companies) that are perceived to have the requisite capabilities and resources, and to be comfortable with working in international environments, engage in RJVs more frequently than others.

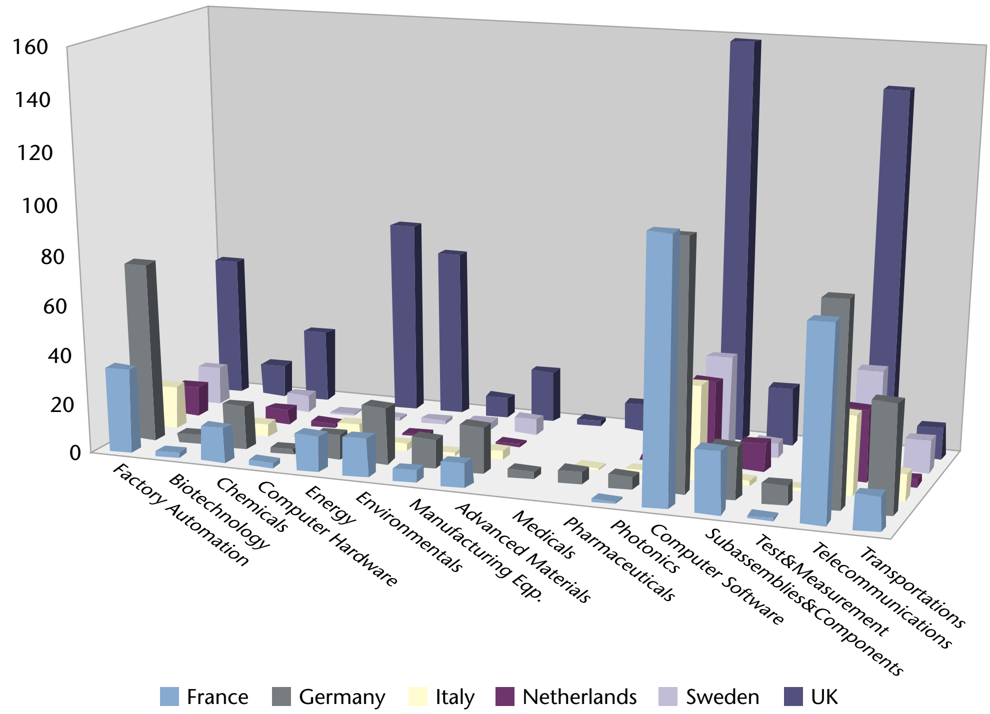
It is also evident that Europe tends as a whole to participate in RJVs in its areas of strength. These are notably the environmental, energy, transportation, and telecommunications areas. To a lesser extent, strong areas also comprise computer software, chemicals, advanced materials, sub-assemblies and components (including semi-conductor devices), factory automation, test and measurement, and manufacturing equipment.

When considering the pattern of participation by technology area in the six most-active EU states, two areas – computer software and telecommunications – emerge as dominant. In these areas, there are several large RJVs with many partners aiming to establish universal technology standards, e.g. open computing systems, and mobile telephones. Figure 3.3.11 illustrates that the interest of European companies in these RJVs, as well as universities in the case of software, is not surprising. In both computer software and telecommunications, UK entities participate much more frequently than the rest, followed by entities in Germany and France, and, some distance behind, by entities in Sweden.

A third area with a significant concentration of EU memberships is factory automation. In this area, figure 3.3.11 shows that even though they are ranked much lower than the other two in terms of RJV numbers, Germany and the UK are the leaders, with France a distant third.

In the areas of energy and the environment, RJVs are mainly present in the UK and comprise large petrochemical companies.

Figure 3.3.11 The six most active EU countries by technical areas of RJVs (1985-1999)



Source: N. Vonortas (2000)
Data: NCRA-RJV database, George Washington University CISTP

Third European Report on S&T Indicators, 2003

[5] *The position of Italy and Sweden interchanges if memberships, rather than entities, are counted.*

Section IV Business firms as R&D performers

1. Diversity of business firms and knowledge investment

Research or knowledge investment activities of the business sector are found in firms that are very diverse in nature. The diversity of firms and their relationships are an important factor in determining the success and evolution of knowledge-production and innovation systems. Every type of firm plays a different role which is complementary to that of other types of firms. Sectors, on the other hand, are usually dominated by sector specific types of firms and relationships between them. Therefore, total investment in knowledge (for which BERD is used as a proxy) is determined by the characteristics of the different categories of firms.

The level of knowledge investment and the manner in which R&D activities are performed, is expected traditionally to be influenced by the size of the firm involved in R&D. Initially, Schumpeter (Mark I) claimed that entrepreneurship, which entails the establishment of new business ventures, is the key element in introducing innovations into the economy. Schumpeter, however, later developed the hypothesis (Mark II) that the bulk of research is carried out by large firms, as small ones do not have the resources and the scale to do so.

However, the old understanding about the relationship between the size of firms and the R&D investment is not really questioned but it is necessary to consider also the role and behaviour of dynamic new technology based firms (NTBFs) that are highly R&D intensive and innovative. This has especially been the case in the emerging high-tech sectors such as biotech and ICT. Obviously, the (typical) behaviour of R&D – or knowledge – investment differs across the types of firms by size, stage of life cycle and sector (high-tech and knowledge intensive sectors). Consequently, also the structure of the firm population in a sector or economy influences the level of business sector R&D expenditure. This recognition, together with the phenomenon of limited access to finance, particularly in the case of small firms in high-tech sectors with strategically important intangible assets, has been the basis for the innovation policy that supports R&D activities in small and medium-sized firms.

One of the main contributions of the innovation systems approach is its emphasis on the 'system', including the interrelations between the different innovation actors, rather than on the actors alone. It offers a theoretical motivation to implement a modern R&D policy going far beyond the mere financing of R&D activities in the public or private sector. It motivates policy actions aimed at improving the interaction between different actors within the same sector, e.g. small and medium-sized enterprises (SMEs) and large enterprises, or different sectors, e.g. co-operation between science and industry. The innovation systems approach is aimed at a much broader policy than one merely focused at correcting the inefficient working of the market.

In practice, the innovation-systems approach stimulates policy actions in SMEs in order to enhance technology diffusion between actors, and to increase the absorptive capacity of these companies. It also encourages mobility of researchers to improve transfer of knowledge, and calls for a policy which facilitates flexible arrangements between universities and industry. It should be noted that the European Commission's Framework Programme is aimed more and more at encouraging the participation of SMEs.

A complete new set of innovation policy actions is appearing: public involvement in the financing and nurturing of innovative ventures (with growth potential). The reasoning is straightforward: in the founding or early growth period of these ventures, uncertainty about the potential success is so high and information about the technological potential is so asymmetrically in the hands of the entrepreneurs that no private agent would invest in them, or give them advice. As a result, public initiatives oriented towards the seed or even pre-seed financing of these ventures and their incubation have blossomed in different European countries.

2. Knowledge investment and size of firms: distribution of Business Expenditure on R&D

Business R&D by size class

The relative importance of large and small firms in investing in scientific and technological knowledge production and absorption is analysed in the table 3.4.1. The data for R&D expenditure by size of firm have been collected through a mini-questionnaire launched for the first time in 1997 by OECD. The data were originally divided into classes for firms with fewer than 100 employees and secondly, for firms with between 100 and 500 employees. The class of firms with 500 and more employees is calculated as a residual from total 100%. However, this classification has a problem in the smallest size class because the lowest size of the firms included in the questionnaire may vary from country to country.

The available data indicate clearly that the importance of large and small firms in knowledge investment is different between the EU (7.6%) and the US (10.4%). In the US, R&D expenditure is more concentrated in the size classes with less than 100 employees and with 500 employees upwards than in the EU. In the US, obviously, the role of very small (less than 100 employees) and very large firms (500 and more) in knowledge investment (10.4% and 81.4% respectively) is more intense than in Europe (7.6% and 77.9% respectively).

Definition of SMEs according to European Commission Recommendation (1996)

Small and medium size enterprises (SMEs) are defined as enterprises which:

- have fewer than 250 employees;
- either have an annual turnover not exceeding 40 million euro, or an annual balance sheet total not exceeding 27 million euro;
- conform to the criterion of independence as defined in paragraph 3 in 96/280/EC: Commission Recommendation of 3 April 1996.

Often, the data from various countries on SMEs do not always comply with the above Commission definition. The definitions of SMEs used, vary considerably from country to country. In some cases, variations in the definition have a considerable effect on the data (Santos, R. 2001).

The intensity of business-sector R&D activities, i.e. investment in knowledge in large and small firms, varies significantly across the Member States. In large countries such as Germany, France, Italy and the UK, and also in Sweden too, the share of firms with fewer than 100 employees is much lower than the EU average. In Germany, Sweden and France in particular, knowledge investment is concentrated mainly in large firms with 500 and more employees. In Italy and the UK, medium-sized firms with 100 to 500 employees are also quite important, ranking above the EU average.

In other European Union Member States – mainly small countries, the role of small firms in knowledge investment is relatively more important and the small firms have the highest share in Portugal with 25.6% followed by Belgium (19.0%). Portugal has also the highest share in the class of 100 to 500 employees implying that the bulk of knowledge investment (66.8% of BERD) is conducted in firms with less than 500 employees. The same is – to a lesser extent – valid for Spain (43.4%) and, correspondingly, the role of very large firms is rather low in knowledge investment. In other countries, the importance of firms with less than 500 employees amounts to roughly 30-40% while the role of very large firms is not very high. Therefore, assuming that the smaller countries have a firms' population concentrated in SMEs and the larger countries in larger companies, the dynamics of BERD may differ a lot between big and small countries: the importance of 'R&D Champions' in larger countries and networking, technology diffusion, spin-offs in the small countries.

Table 3.4.1 Share of business R&D by size of firms, 1999, %

	Firms with fewer than 100 employees	Firms with 100 to 500 employees	Firms with fewer than 500 employees (1)	Difference: Firms with 500 and more employees (2)
Germany (1997)	5.8	9.3	:	85.0
Sweden	3.7	13.2	:	83.1
France (1998)	6.8	14.3	:	78.9
Italy (1998)	5.4	18.9	:	75.7
UK	7.2	17.2	:	75.6
Netherlands (1998)	10.6	18.2	:	71.2
Finland	14.0	14.2	:	71.8
Belgium (1995)	19.0	17.2	:	63.8
Denmark (1998)	16.1	23.4	:	60.6
Spain	17.2	26.2	:	56.6
Portugal	25.6	41.2	:	33.2
EU-15	7.6	14.5	:	77.9
US	10.4	8.3	:	81.4
Japan	:	:	7.2	92.8

Source: DG Research
Data: OECD, STI/EAS Division, May 2001
Notes: (1) Calculated by adding columns 1 and 2. (2) For calculating the difference: the value for firms with 500 and more employees is influenced by the differences in the lower limit for the size of the firms in the class fewer than 100

Third European Report on S&T Indicators, 2003

The relationship between firm size and policy

In parallel with the development of the theoretical approach towards the national systems of innovation, practitioners were pointing to the SME problem. Whilst the large enterprises seemed to benefit from the large public support programmes for R&D, the SMEs – generally considered as Europe's engine for economic growth – did not participate at all. Therefore, SMEs have become an important policy objective of innovation and technology policy. In particular, while dynamic SMEs have a strong potential to create new ideas, innovations and employment they are constrained by weak access to knowledge resources and to finance, through relatively high fixed costs as well as through relatively high information costs and administrative costs if they participate in research programmes (cf. Bessant, 1999). However, even though the SMEs (firms with less than 500 employees) arount to more than 90% of the firms population only a very small part 'high-tech start-ups or techno-starters' and eventually potentially innovative SMEs are interesting targets for innovation policy (cf. further in this section under the title 'Modern industrial R&D policy – large enterprises, SMEs and techno-starters').

Public funding of R&D gives governments an instrument for directing resources to their research priorities and/or to certain types of performers. In spite of such innovative potential in the SMEs, the share of government financed BERD in the EU average does not indicate a strong political focus in supporting knowledge investment in smaller firms (less than 500 employees) because the relative shares of BERD by size class (table 3.4.1) and government financed BERD are similar. In the US, the share of government financed BERD is even lower than the corresponding share in BERD reflecting at the first sight a low political priority. Yet, the range of instruments in supporting scientific and technological investment may differ significantly between countries depending on the institutional set-up of the innovation system. Therefore, government financed BERD in the class of SMEs does not necessarily give the entire picture about the support for SMEs.

The differences in allocation of government financing across the size classes of firms are striking as they probably reflect not only the relative sizes of the size classes, but also differing policy priorities and support systems. The large European countries such as Germany, France, the UK and Italy allocate more than 80% of government financing in BERD towards firms with 500 or more employees while the respective share of this size class is more or less similar at around 80%.

It is rather the smaller countries that allocate more government financed BERD to firms with fewer than 500 employees than what would correspond to their relative share in the sector. In Portugal and Belgium the relative shares of government financing are remarkably high (respectively 71.5% and 71.6%) – and higher than their respective shares

Table 3.4.2 Share of business R&D and of government financed BERD in firms with fewer than 500 employees, 1999

	Share of business R&D	Share of government-financed BERD
Germany (1997)	15	13.8
Sweden	16.9	23.7
France (1998)	21.1	12.7
Italy (1998)	24.3	36.2
UK	24.4	18.2
Netherlands (1998)	28.8	35.6
Finland	28.2	58.5
Belgium (1995)	36.2	71.6
Denmark (1998)	39.4	60.3
Spain	43.4	68.4
Portugal	66.8	71.5
EU-15	22.1	21.6
US	18.6	12.2

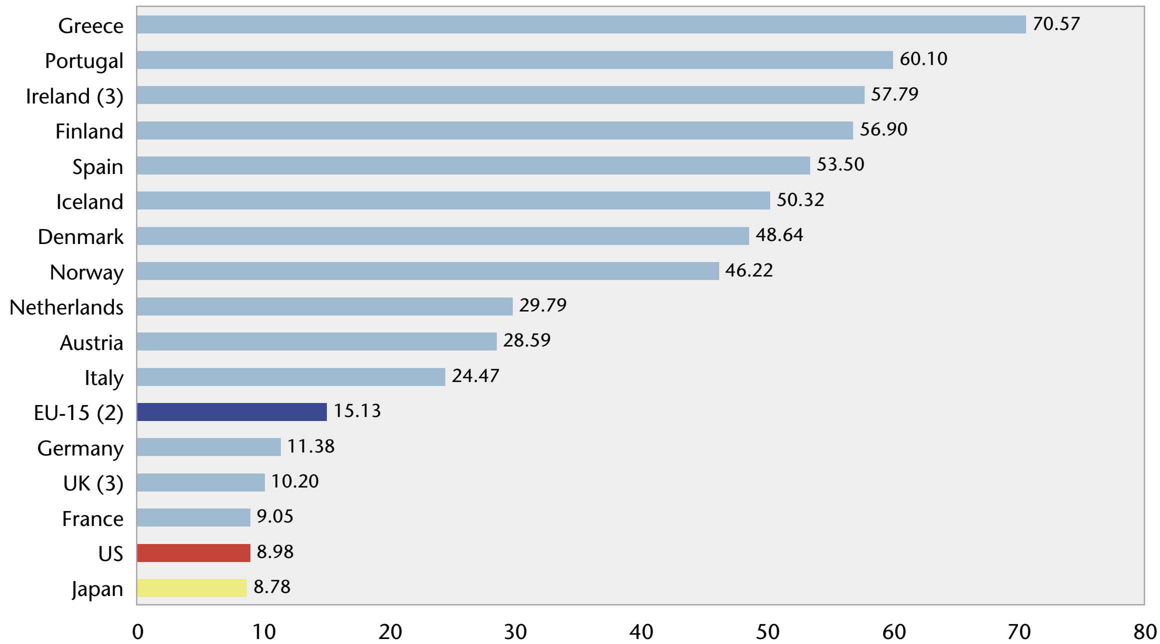
Source: DG Research
Data: OECD, STI/EAS Division, May 2001
Third European Report on S&T Indicators, 2003

in BERD – reflecting a high political priority for the SMEs. However once again, the overall assessment of policy support needs to look at the whole system of institutions and markets in supporting SMEs. However, these data have a limited information power as the classification of SMEs according to less than 500 employees does not necessarily provide adequate information about supporting high-tech start-ups which usually cannot be assumed to be very large.

Also when using a definition of less than 250 employees for the SMEs, their share in publicly funded R&D activities in the business sector differs considerably across countries. Figure 3.4.1 shows that on average in the EU (15.1% for 11 countries where data are available) this type of SME receives stronger support from public funding for their R&D activities than in the US (9%) and in Japan (8.8%). Surprisingly – according to table 3.4.1 – in the EU, it is predominantly the small countries – Greece, Portugal, Ireland and Finland – that allocate most public funding for R&D this type of SME. In contrast to this, we find that the larger countries Germany, the UK, France and the US are below the EU average, reflecting a relatively weaker support for SMEs with less than 250 employees.

The growth of publicly-funded R&D activities undertaken by SMEs with fewer than 250 employees since 1995 has, however, been much stronger in the US (with an average growth

Figure 3.4.1 Share of SMEs in publicly funded R&D executed by the business sector (%), latest available year (1)



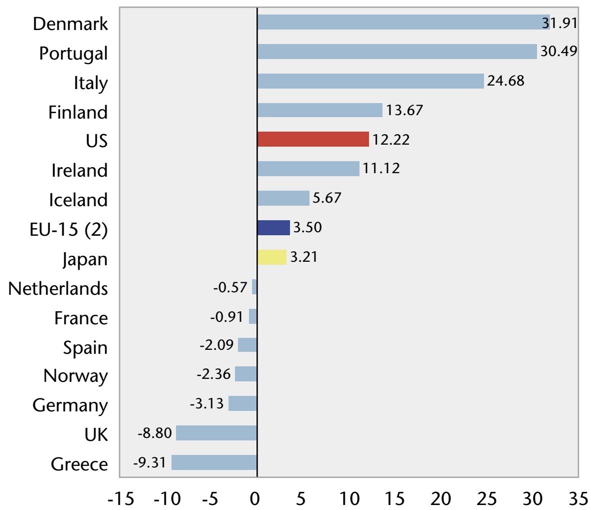
Source: DG Research (Key Figures 2002)
Data: Member States, OECD, the US (NSF), Japan (Nistep)
Notes: (1) JP, I, IS, E, FIN, P: 2000; A: 1998; IRL: 1997; all other countries: 1999; (2) B, L, S; are not included in EU-15 average
(3) Only independent SMEs included.

Third European Report on S&T Indicators, 2003

rate of 12.2%) than in the EU (average 3.5% for 11 countries where data are available), followed by Japan (3.2%). One reason for the relatively weak development in the EU is that six of the Member States show reduced public funding for R&D activities in this type of SME. Greece (1999) is one of the countries showing a large decrease, but which still displays high public involvement. The UK, also with a large decrease has however already a low level of involvement.

Germany and France do not only give low importance to publicly funded R&D activities conducted by this type of SME but are even reducing their financial involvement. The other European countries – the smaller ones with the exception of Italy – show strong positive growth rates at the end of the 1990s and they also have a higher level than the EU average but obviously they cannot compensate for the weight of the negative growth rates of the others.

Figure 3.4.2 Publicly funded R&D executed in the SME sector – average annual real growth (%), 1995 to latest available year (1)



Source: DG Research (Key Figures 2002)
Data: Member States, OECD, Japan (Nistep)
Notes: (1) I, P, FIN, JP: 1995-2000; EL, UK, NL, F: 1995-1999; IRL: 1995-1997; D, EU, US, DK: 1997-1999; E: 1999-2000. (2) B, E, IRL, L, A, S are not included in EU-15 average.
Growth rate is based upon million PPS at 1995 prices and exchange rates.

Third European Report on S&T Indicators, 2003

3. Top international R&D performers: the role of the giants in knowledge investment

The importance of top European R&D performers

Nevertheless, in most European countries and in the US the large firms (more than 500 employees) are in quantitative terms the main knowledge producers – only in Portugal is the share of these firms significantly less than 50% (table 3.4.1). The data are, however, too aggregated to be able to discern how strongly the R&D activities, i.e. investment in scientific and technological knowledge is concentrated in a limited number of very large internationally active firms. The role of very large firms in knowledge investment is examined with the help of the "R&D Scoreboard" database which provides a first insight into the very high concentration of R&D activities.

The R&D Scoreboard database contains information on the 500 top international R&D performers. It brings to light that these firms have made enormous contributions to R&D investment, amounting to 307 429 million euro in 2000. The quantitative importance of the EU firms is not very high in the R&D investment of the top 100 and 500 firms as it accounts for 29.2% among the top 100 and for 28% among the top 500 while the US firms account for 44% and 43.8% respectively. However, the presence of the European firms has increased more strongly since 1996 in comparison to the US firms (table 3.4.3).

Methodological note on the firms' data on R&D expenditure in DTI R&D Scoreboard

Scope

Published annual reports and consolidated accounts provide the information about R&D expenditure. In the UK the consolidated group accounts cover the ultimate UK parent company; for the international rankings, the consolidated group accounts cover the ultimate international parent company. R&D spending consists of the cash spent which is funded by the companies themselves. As the R&D spending is reported in the group accounts, the results are independent of the location of the R&D activity. This is a main difference with the BERD data.

Definitions

The R&D expenditure based on the annual report and accounts is subject to the accounting definitions of R&D (SSAP for the UK, IAS for the international companies). The basic limitation is, however, the reliance on disclosure of R&D spending in published annual reports and accounts. Systematic differences arise across the countries.

Table 3.4.3 Top 100 and 500 firms by trade zones

	Top 100 firms					Top 500 firms				
	number of firms		% of total R&D		average annual growth rate of R&D investment %	number of firms		% of total R&D		average annual growth rate of R&D investment %
	1996	2000	1996	2000	1996-2000	1996	2000	1996	2000	1996-2000
US	43	43	43.6	44.0	10.3	208	208	43.7	43.8	11.4
EU-15	30	31	24.0	29.2	15.6	132	132	23.6	28.0	16.3
Japan	22	21	26.2	21.6	4.9	127	127	27.2	23.1	7.0
Other countries	5	5	6.1	5.2	5.3	33	33	5.6	5.1	9.0
Total	100	100	100	100	10.1	500	500	100	100	11.4

Source: DG Research
Data: R&D Scoreboard (2000), DTI Future & Innovation Unit and Company Reporting Ltd.
Third European Report on S&T Indicators, 2003

An analysis at the European level reveals that the top international R&D performers coming from Europe are concentrated in Germany (34.7%), France (20.9%) and the UK (19.1%). As can be seen from table 3.4.4, companies in these three countries constitute the bulk (74.7%) of European knowledge investment conducted by top European R&D performers.

Making up the above aggregated information are many famous large global players that are listed in table 3.4.5.

Table 3.4.4 Top international companies by number and by R&D investment, 2000

Country	Number of firms	R&D expenditure in € million	Share in total (500 firms) %	Share in EU-15 total (132 firms) %
Belgium	2	542	0.2	0.6
Denmark	4	782	0.3	0.9
Germany	28	29 859	9.7	34.7
Greece	0	0	0.0	0.0
Spain	2	202	0.1	0.2
France	32	17 948	5.8	20.9
Ireland	1	325	0.1	0.4
Italy	7	4 538	1.5	5.3
Luxembourg	0	0	0.0	0.0
Netherlands	8	5 556	1.8	6.5
Austria	0	0	0.0	0.0
Portugal	0	0	0.0	0.0
Finland	5	3 343	1.1	3.9
Sweden	11	6 495	2.1	7.6
UK	32	16 402	5.3	19.1
EU-15	132	85 992	28.0	100
US	208	134 515	43.8	
Japan	127	71 135	23.1	
Other countries	33	15 787	5.1	
Total	500	307 429	100	

Source: DG Research
Data: R&D Scoreboard (2001), DTI Future & Innovation Unit and Company Reporting Ltd.
Third European Report on S&T Indicators, 2003

It informs us about the top 100 individual European firms and their nationalities within the group of the 500 top performers.

Apart from the changes in the quantitative role played by the top international R&D performers in world-wide knowledge production and absorption, certain interesting qualitative changes are taking place in the way their R&D activities are organised and conducted, these are discussed in the box.

Table 3.4.5 Ranking of Top 100 European companies by R&D investment

1	DaimlerChrysler, Germany	19	Unilever, UK
2	Siemens, Germany	20	Aerospatiale (now EADS), Netherlands
3	Ericsson, Sweden	21	Marconi, UK
4	Volkswagen, Germany	22	STMicroelectronics, France
5	GlaxoSmithKline, UK	23	SAP, Germany
6	AstraZeneca, UK	24	Boehringer Ingelheim, Germany
7	Alcatel, France	25	Sanofi-Synthelabo, France
8	Nokia, Finland	26	Schering, Germany
9	Philips Electronics, Netherlands	27	Snecma, France
10	Bayer, Germany	28	AKZO Nobel, Netherlands
11	Renault, France	29	Finmeccanica, Italy
12	Robert Bosch, Germany	30	Deutsche Telekom, Germany
13	Fiat, Italy	31	TotalFinaElf, France
14	Peugeot (PSA), France	32	Michelin, France
15	BAE Systems, UK	33	Rolls-Royce, UK
16	BASF, Germany	34	BT, UK
17	Aventis, France	35	Valeo, France
18	Istituto Finanziario Industriale, Italy	36	E.ON, Germany

37	Volvo, Sweden	69	Suez Lyonnaise des Eaux, France
38	E Merck, Germany	70	Rhodia, France
39	Reuters, UK	71	Oce, Netherlands
40	Alstom, France	72	Lundbeck, Denmark
41	RWE, Germany	73	Scania, Sweden
42	Schneider, France	74	Baan, Netherlands
43	BP Amoco (now BP), UK	75	Linde, Germany
44	Novo Nordisk, Denmark	76	UCB, Belgium
45	Invensys, UK	77	Deutsche Bank, Germany
46	France Telecom, France	78	Telia, Sweden
47	Continental, Germany	79	Dassault Systemes, France
48	Shell, UK	80	Corus, UK
49	Thales, France	81	Framatome, France
50	L'Oreal, France	82	Usinor, France
51	Solvay, Belgium	83	Bull, France
52	H'berger Druckmaschinen, Germany	84	Enel, Italy
53	Elan, Ireland	85	Merial, UK
54	Henkel, Germany	86	Electrolux, Sweden
55	Saint-Gobain, France	87	GKN, UK
56	Thomson Multimedia, France	88	Great Universal Stores, UK
57	ICI, UK	89	MG Technologies, Germany
58	DSM, Netherlands	90	Sandvik, Sweden
59	Nycomed Amersham (now Amersham), UK	91	Danone, France
60	ENI, Italy	92	Misys, UK
61	Groupe Lagardere, France	93	Legrand, France
62	Faurecia, France	94	Metso, Finland
63	Altana, Germany	95	Bouygues, France
64	ASM Lithography, Netherlands	96	Thyssen Krupp, Germany
65	Pirelli, Italy	97	Vodafone, UK
66	Rheinmetall, Germany	98	Fresenius, Germany
67	Autoliv, Sweden	99	Celltech, UK
68	MAN, Germany	100	Diageo, UK

Source: DG Research
Data: R&D Scoreboard (2001), DTI Future & Innovation Unit and Company Reporting Ltd.
Third European Report on S&T Indicators, 2003

Changes in basic research in large firms brought about by the new 'Industrial Ecology' approach

In recent years, large multi-product, multi-technology firms have found themselves in a new R&D environment in which technological self-sufficiency has been replaced by a model of network relationships. Their work is complemented by that of a dynamic population of smaller companies sustained by venture capital, from which they can select technologies through acquisition. At the same time, there has been a rapid increase in outsourcing to specialist research suppliers and universities. Combined with the trends of internationalisation, and with technological alliances described elsewhere in this report, these forces are stimulating new approaches to the organisation of research aimed at technological breakthroughs.

A recent study of six leading-edge firms – four in the US and two in Europe – has found strong evidence that corporate laboratories are replacing traditional discipline-based organisations with multi-disciplinary and cross-functional targeted programmes aimed at technology leaps in strategic areas. To encourage leading-edge research, peer recognition in public science as well as more conventional indicators such as patent production are rewarded through staff incentives. The relationship with the parent company has evolved from a simple customer-contractor model to one of joint production of knowledge with shared goals. R&D is often at the heart of corporate strategy, with Chief Executive Officers involved at critical points. The strategy-making process itself has had to adapt to new circumstances, introducing far greater speed and flexibility with a view to coping with radical compression of time-scales. 'Long-term research' used to be on a 10-year time-scale;

now work of an equivalent radical nature is targeted to deliver in two years. Companies such as Nokia combine their R&D and marketing capabilities in an on-going company-wide foresight activity to maintain the necessary agility.

Based on Coombs R and Georghiou L: 'A New Industrial Ecology', Science, Vol 296, 19 April 2002, p. 471; and Coombs R, Ford R and Georghiou: Generation and Selection of Successful Research Projects; Research Study for the Technology Strategy Forum (2001).

Sectoral distribution of the top 500 R&D performers

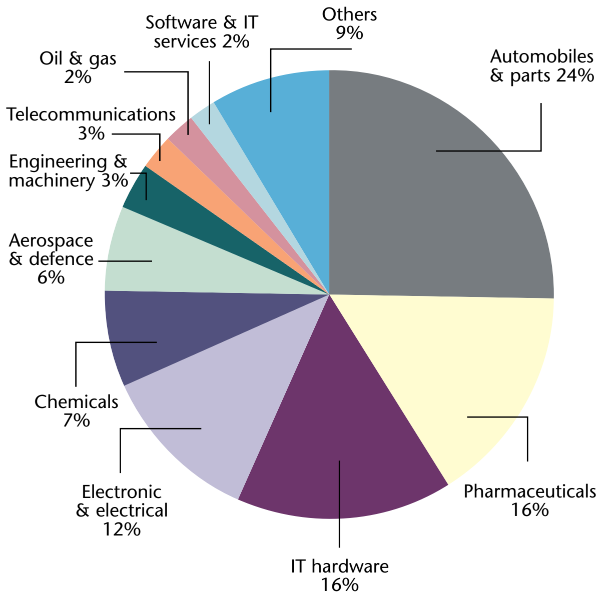
The sectoral breakdown of R&D investment by the 500 top international R&D performers indicates in which type of industrial and technological knowledge base these firms are mostly investing. The ICT sector with 27.4% is the most important target of knowledge investment among the 500 top R&D performers while in Europe its share comes up only to 16%. In Europe, automobiles rank the first with 24% and pharmaceuticals second with 16%. In the world ranking the reverse order is seen.

Table 3.4.6 Number of firms in top 500 by sector

	Proportion of total R&D investment by sector %	
1	IT hardware	27.4
2	Automobiles and parts	17.6
3	Pharmaceuticals	15.5
4	Electronic and electrical	9.7
5	Chemicals	5
6	Software and IT services	4.3
7	Aerospace and defence	3.9
8	Engineering and machinery	2.8
9	Telecommunications	2.2
10	Health	2
11	Diversified industrials	1.5
12	Oil and gas	1.4
13	Personal care	1.4
14	Media and photography	1
15	Food processors	0.8
16	Household goods	0.6
17	Electricity	0.6
18	Steel and metals	0.6
19	Construction and building	0.5
20	Tobacco	0.4
21	Leisure and hotels	0.2
22	General retailers	0.1
23	Financials	0.1
24	Beverages	0.1
25	Forestry and paper	0.1
26	Support services	0.1
27	Gas distribution	0.1
	TOTAL	100

Source: DTI
Data: R&D Scoreboard (2001), DTI Future & Innovation Unit and Company Reporting Ltd.
Third European Report on S&T Indicators, 2003

Figure 3.4.3 Sectoral breakdown of EU-15 firms in top 500



Source: DG Research
Data: R&D Scoreboard (2001), DTI Future & Innovation Unit and Company Reporting Ltd.
Third European Report on S&T Indicators, 2003

4. R&D investment gap between top EU and US international R&D performers

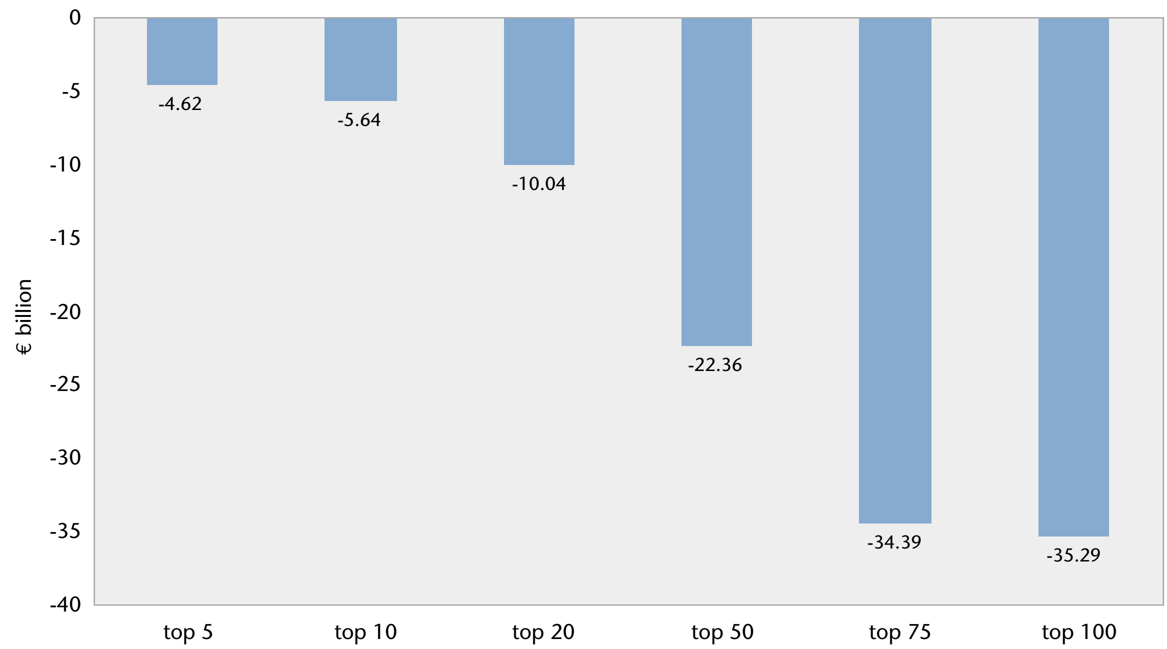
Cumulative R&D gap according to size among the top international R&D performers

The strong weight of the top international R&D performers – the global players – in scientific and technological knowledge investment both in the US and EU is evident. The present data on the top international R&D performers give us an opportunity to analyse the differences between the US and EU global players' knowledge investment, taking into account the size of the performers. Figure 3.4.4 presents the difference in the cumulative R&D expenditure of the top R&D performers according to the size of the firms (based on the number of employees).

Figure 3.4.4 on the total R&D gap between the top EU and US R&D performers shows clearly that the 5 top R&D performers in the US invest more than their European counterparts but this difference is not dramatic (4.62 billion euro). However, the total gap amounts to 35.29 billion euro for the 100 firms.

Previous information that the size of a firm might matter for the European R&D investment gap has already been found (Muldur, 2001) where it is shown that the gap is only quite small for the largest firms but increases with decrease in the size of the firms. In other words, the increasing gap indicates that in the US particularly the smaller R&D performers invest relatively more in R&D than in the EU. Europe's weak dynamics in BERD are therefore connected to the relatively lower level of R&D activities in the smaller top R&D performers.

Figure 3.4.4 Total R&D gap between the EU and the US - Top performers by firm size, 2000



Source: DG Research
Data: R&D Scoreboard (2001), DTI Future & Innovation Unit and Company Reporting Ltd.
Third European Report on S&T Indicators, 2003

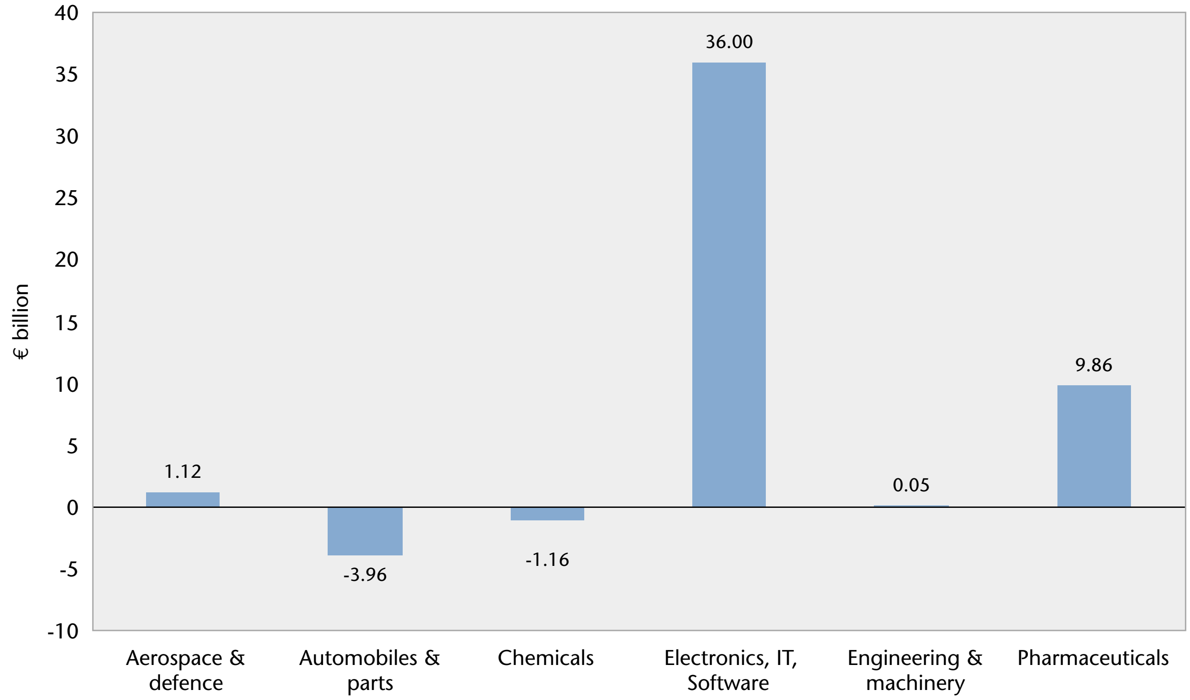
R&D investment gap according to sector among the top R&D performers

The present data allow one to derive new information about the differences in the US and EU global players' knowledge investment for some selected industries. Figure 3.4.5 presents the R&D gap between the EU and US firms by sector with the gap being calculated for the firms where data exist in the respective sectors. Clearly, the R&D investment gap is a result of various factors (such as the number of the firms) and not only of the level of R&D investment alone.

It is apparent that the European top R&D performers invest radically less (36 billion euro) in the ICT sector in comparison to the US counterparts. There are of course various reasons for this gap which cannot be analysed in detail here. Yet, the most important message is that in total, Europe invests less in research activities for ICT development and consequently, productivity is probably lower in the EU ICT sector. Therefore, Europe needs either to import the most modern and efficient ICT equipment or it ends up using less productive ICT equipment. This would seriously harm the emerging knowledge-based economy where the ICT sector plays a central role as it influences the productivity growth of the economy and also the dissemination of knowledge.

In the pharmaceutical industry too, the top R&D performers in Europe invest far less than the respective top US R&D performers. In contrast, the EU top performers invest more in medium-to-high-tech industries such as automobiles and parts, and chemicals. However, the differences are not significant, at 4 billion euro and 1 billion euro respectively.

Figure 3.4.5 R&D investment gap between US and EU-15 by sector



Source: DG Research
Data: R&D Scoreboard (2001), DTI Future & Innovation Unit and Company Reporting Ltd.
Third European Report on S&T Indicators, 2003

5. The innovation capacity of SMEs

Modern R&D policy with three target groups

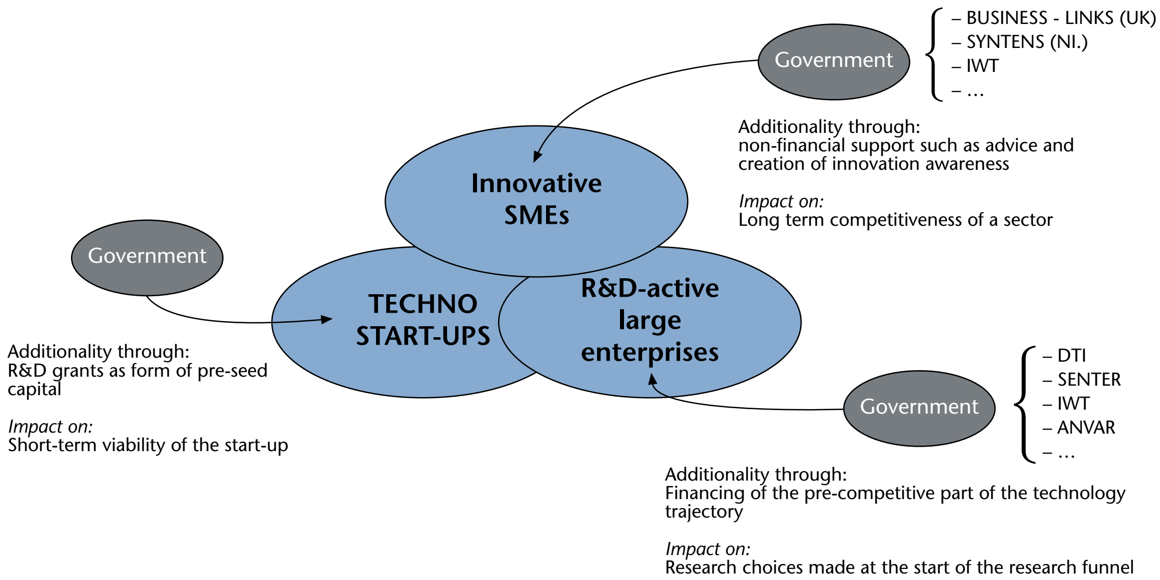
Three target groups can be distinguished in modern R&D policy (figure 3.4.7). The first group consists of large enterprises. The other two groups comprise SMEs, namely innovative SMEs and technology start-ups. In addition to direct R&D financing, the innovation systems approach also justifies indirect financing of innovation. Instead of financing the R&D costs of enterprises, it is possible to finance the operating costs of innovation agents, assisting those who by definition under-invest in R&D, such as SMEs. Various countries have created such innovation agents, which operate entirely or partly with public money (cf. for instance Bessant, 1999; Duchêne and Clarysse, fourthcoming).

Since in most European countries, 20% of R&D active enterprises account for 80% of BERD (R&D performed by the Business Sector), a select number of large enterprises have always been the main customer basis of R&D policy. In the mid-nineties in particular, R&D-granting public agencies had to cope with a distorted distribution of their R&D support, which in fact reflected the R&D situation in the country. In most countries, such large R&D-active enterprises are well known. It distinguished them from the two other target groups, in respect of which the total amount of reachable enterprises is difficult to determine.

Most R&D subsidies are regarded as incentives for increasing investment in R&D by recipient enterprises. R&D-granting organisations have to deal particularly with the increasingly international character of such efforts. Multinational corporations tend to share their R&D efforts in different countries, which makes it difficult for national agencies to realise potential returns. Instead, growing internationalisation increases the need for a public R&D policy at a European scale. At present, the European Commission only represents a small percentage of all public R&D support.

In the early 1990s in particular, increasing criticism was levelled at the exclusive orientation of R&D support towards large enterprises, which were mostly enhancing their competitive advantage by downsizing operations and reducing employment.

Figure 3.4.6 Three target groups recognised in modern R&D policy



Source: Clarysse and Duchêne, 2000

Third European Report on S&T Indicators, 2003

Types of SMEs

SMEs, on the other hand, are considered increasingly as being the powerhouse of Europe's economy; they account for 99.8% of the total number of companies, for two-thirds of employment and nearly 60% of value added. During the 1990s, they have been responsible for more than 80% of the new jobs that have been created and this general trend is continuing (European Commission, 1997). Because of the obvious significance of SMEs in terms of employment creation and value added, R&D policy throughout the world has been concerned increasingly with the specific needs of this very heterogeneous group of enterprises. Different studies have been trying to identify sub-groups, according to their innovation capacity. A large-scale survey on European SMEs conducted in 1988 by the Industrial R&D Advisory Committee of the European Commission (IRDAC) resulted in the recognition of three segments (Rothwell and Dodgson, 1989):

- 'technology start-ups' (1%-3% of the SME population);
- 'leading technology users', with or without sufficient R&D capacity[6] (10%-15% of the total population);
- 'technology followers' (80%-85% of the population).[7]

This segmentation has been confirmed in more recent research conducted by the European Commission (CEC, 1994). The major weakness in the classification is the absence of any subdivision in the third group, representing the major part of the SME population. For these reasons it is interesting to compare the European classification with a population segmentation carried out in the Netherlands (Prince, 1998). A comprehensive telephone survey (3000 SME responses, with an almost 100% response rate) has been conducted to question SMEs about their capacity for innovation in a very broad sense, for example implementation of IT, organisational dynamics, strategy, and new product introduction. The results of the survey have been subjected to a cluster analysis. The analysis classified SMEs into four different categories comprising the first two segments distinguished above – 'technology start-ups' and 'leading technology users'. It subdivided the third segment ('technology followers') into 'potential innovators' (39% of all SMEs) and 'non-innovators' (42% of all SMEs). According to this classification, the potential innovators are defined as companies that 1) sometimes employ people with university or equivalent higher education; 2) have, on average, introduced at least one product new to the market; 3) have an eye for client satisfaction and sometimes recognise the value of market research; 4) are willing to work

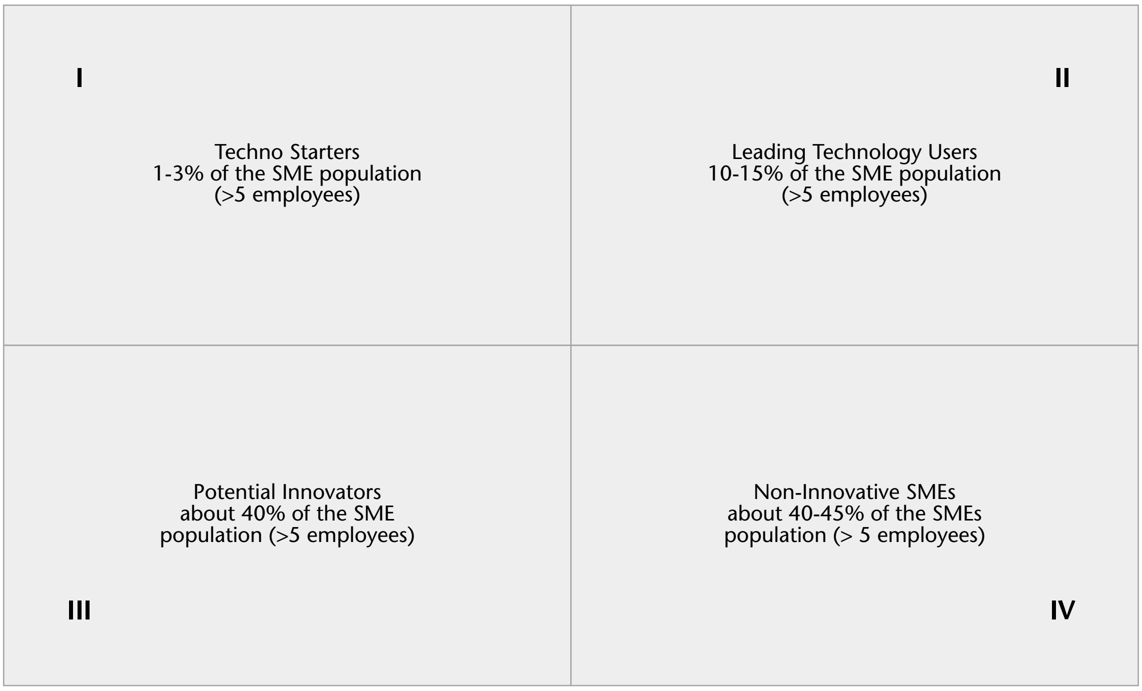
[6] *The distinction between leading technology users with and without sufficient R&D capacity requires clarification. The definition of R&D capacity is very similar to Cohen and Levinthal's (1991) definition of 'absorptive capacity', i.e. having a critical mass which guarantees the ability to recognise and adopt interesting technologies and incorporate them into existing products or new products with which the firm is familiar. Since such a critical mass is firmly idiosyncratic, there is no simple way to segment the population, a priori, into SMEs with and without. This does not mean that the distinction is not useful. The technology policy institutes might take into account the fact that some of their main potential clients may need help in recognising new technologies because they lack the critical mass to do it on their own.*

[7] *The "SME population" as used here slightly differs from the definition of the European Commission (see box above in this chapter), since it does not include the firms with fewer than 5 employees.*

with other companies, and finally 5) rarely use subsidies or own patents. The non-innovators, on the other hand, 1) often use old manufacturing processes according to the industry standard; 2) don't or rarely work with other companies; 3) have no development activities; and finally 4) rarely bring new products to market.

Figure 3.4.6 outlines the four different target groups in the SME population. The first three, i.e. the leading technology users, the potential innovators and the techno-starters, are discussed in the next section of the report. The fourth group, the non-innovative SMEs, is generally considered as being outside the scope of R&D policy and is not included in the analysis.

Figure 3.4.7 Two-dimensional plot of SMEs according to their innovative capacity



Source: Clarysse and Duchêne, 2000

Third European Report on S&T Indicators, 2003

Innovative SMEs: Difference between R&D active companies and potentially innovative companies

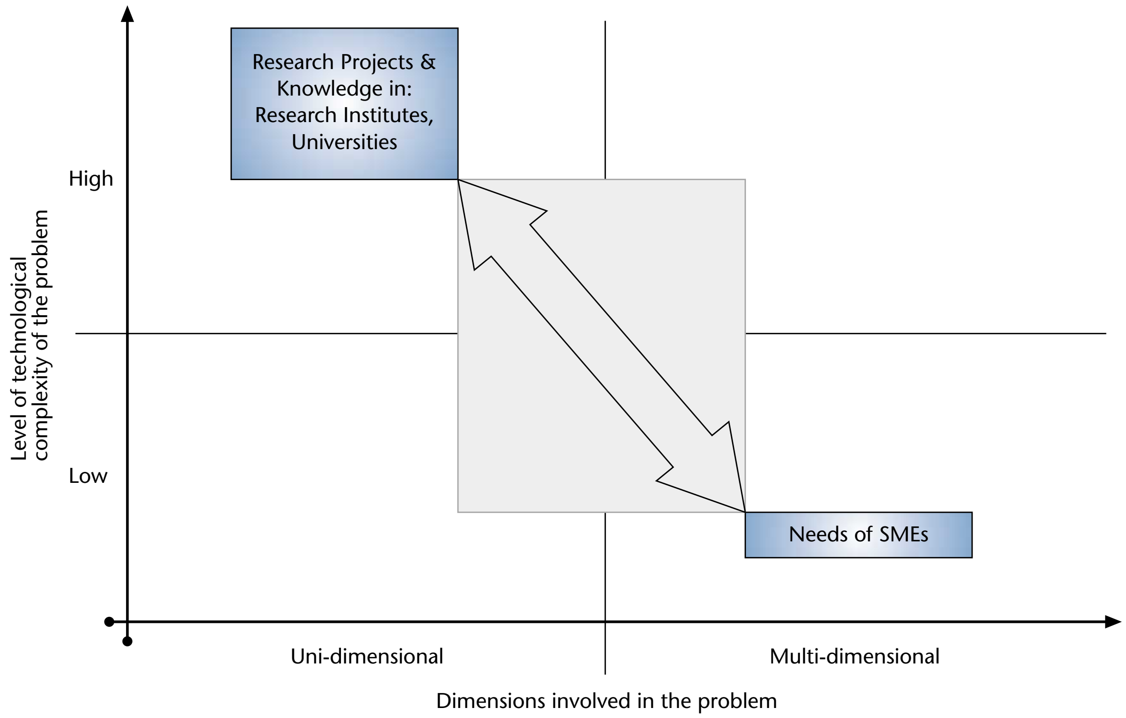
In terms of the segmentation of the SME population on the basis of their innovation capacity – as pointed out above – two subgroups, each with its specific needs and innovation capabilities, merit particular attention, i.e. the leading technology users and the potential innovators. These two sub-groups are discussed below, and the technology start-ups, although part of the SME population, are discussed afterwards.

SMEs that are defined as 'leading technology users' can be active in non high-tech and research-intensive sectors of the economy. In these areas, R&D activities consist mainly of looking for and testing new materials or processes. Even if leading technology users seldom generate new, leading-edge technology, they do have sufficient absorption capacity to implement best-of-breed technologies, or to adapt them in an innovative way. Although SMEs often lack the critical mass required to develop a proposal for obtaining a R&D grant, there is strong evidence that SME-customised programmes do reach the leading technology users and have a positive effect on their innovation capacities. It has been pointed out recently that R&D grants allocated to SMEs by the Flemish government have significantly affected the R&D expenditure of these SMEs in the following years (Meeusen and Janssens, 2000). Such programmes are usually characterised by lower entry barriers in terms of administrative requirements, technical novelty or time between submission of proposals and their evaluation / acceptance (Keeble and Lawson, 1997; Autio, 1997). In addition, SME-customised programmes allow financing of smaller projects, which are more in line with the capacity of most SMEs.

The basic rationale of R&D policy is that enterprises, and certainly SMEs, under-invest in R&D because they would never be able to fully capture the benefits of their efforts. Government should intervene and correct this market imperfection by making available financial incentives in the form of fiscal or R&D grants.

Potentially innovative SMEs, on the other hand, do not under-invest in R&D. They simply do not invest. SMEs in this category operate in a large variety of sectors, including manufacturing and services. They have as a common characteristic an openness towards new products and a sense of organisational innovation. They tend to experience problems which are, from a business point of view, quite complex and multi-dimensional, but for which the technological solution can be quite straightforward, as illustrated in figure 3.4.8. These may include cost/benefit calculations, complementarity with other technologies, and 'fit' in the product portfolio. Often, these companies are able to increase their competitive advantage significantly by adopting a standard technical solution that has already been developed in one of the research laboratories or technology centres. The challenge for these SMEs is to be convinced that technology providers are really able to offer them useful support. Often the scientists and engineers working in research labs are specialised in quite complex technologies, which can be used for uni-dimensional problems.

Figure 3.4.8 'Knowledge gap' between potential innovative SMEs and research institutes



Source: Duchêne and Clarysse, 2000

Third European Report on S&T Indicators, 2003

As potentially innovative SMEs do not practise any R&D activities, it is in general not useful to have an R&D policy for them that consists purely of financial support. Instead, public-sector support should be given to 'legitimise' the role of innovation agents that are actively closing the knowledge gap. The legitimising role consists of familiarising SMEs with the use of third party expert advice to leverage their internal operations. Since in this case the government is not adjusting for market imperfections, but legitimising, it is important to take into account from the outset the time horizon of this kind of innovation agent. Organisational ecologists who have studied the legitimatisation period of a large number of industries, cite periods of, on average, 10 to 15 years before a certain activity is considered to be legitimate. Once the legitimisation process is complete, the government might leave it to the private sector. Several countries have recently introduced this kind of SME support policy. Ireland, England, Scotland, Denmark, the Netherlands and, at a more regional level, Germany, have developed networks of innovation agents.

Technology start-ups: SMEs with the same problems as large R&D active enterprises

A specific sub-category of SMEs, known as 'technology start-ups' attract much attention and are in fact substantially different from the traditional, stable SME. Because they are start-ups they tend to fit, almost by accident, the legal definition of a SME, at least in the first few years after establishment. Apart from this similarity by definition, technology start-ups and traditional SMEs appear to be much different, both in their business models and needs. Technology start-ups often face an equity shortage in their starting phase, resulting from the high technological and market risks associated with their activity. Public involvement is often required in the first period since the risk is too high for private investors. This provides a new rationale for government involvement in investments, which start under uncertain conditions.

Technology start-ups, as described above, are new-technology-based firms with an emerging technology at the time of their establishment as their main competitive advantage. In the past five years, the majority of technology start-ups have been involved in Information and Communication-related technologies. At present, new emerging technologies such as nano-technology, bio-informatics and bio-electronics are avenues for start-ups. Research-based spin-offs are a sub-category of these technology start-ups.

Several studies have indicated that public funding in the form of R&D grants has played a decisive role in respect of techno-starters. According to Mustar (1997), about 70% of new-technology-based firms in France have benefited from public R&D grants distributed by ANVAR (Agence Nationale pour la Valorisation de la Recherche - French R&D-granting institute). Clarysse, Heirman and Degroof (2001) have found that 50% of Flemish research-based spin-offs received at least one R&D grant since their establishment. Moreover, the total amount of R&D grants received by these companies added up to one third of their cumulative capital. The same study shows that spin-offs only receive their first R&D grant two to three years after establishment. This means that R&D grants do not play a role as seed capital, but emerge in the phase of early growth. This is not surprising, as most R&D-granting institutes require that any company looking for public R&D support already has sufficient capital to commercialise the results of its R&D activities. This implies that the company should collect the capital before it applies for an R&D grant.

However, technology starters are most in need of public-sector support in the very early stage of their existence. To overcome this problem, various countries have developed programmes and vehicles customised to this category or sub-category of company. Such initiatives range from programmes in line with the normal portfolio of the R&D granting institute, to a complete reformation of the institute or creation of a new fund. The rationale is to use the competencies within the R&D-granting institute to create a vehicle for technology start-ups. Competencies developed in R&D-granting institutes are in general related to the undertaking of technological evaluations, or due diligence investigations, and financial management of projects. The box gives three examples of initiatives that have been created with the technology start-ups group as the target.

Examples of policies aimed at techno-starters

FIRST Spin-Off

This is a project created by the Walloon R&D granting institute, DGTRE, in Belgium. It is a classic scheme that fits in with the institute's portfolio and does not require new competencies. FIRST offers 20 scholarships to researchers each year. During the project, researchers work on the completion of a product, a procedure or a new innovative service concept. They carry out an economic and technical feasibility study, write a business plan for the creation of a spin-off and participate in entrepreneurship and management courses. The researcher is coached by someone with experience in the creation and management of companies. Financing covers the remuneration and course fees of the researcher, and is fully covered by the Walloon region. A lump-sum payment of 5000 euro is provided for the applying research institute. In accordance with the decree of 17 December 1997, research results belong to the university. However, if the researcher decides to start up a company, the university has to grant a licence to the researcher that:

- is free during the first 5 years after company start-up;
- cannot be ceded to third parties without the prior approval of the university; and
- is exclusive on condition that exploitation of results becomes effective in a time period determined by the university and the company; if the company fails to exploit the results before expiration of the period, the licence becomes non-exclusive.

This FIRST Spin-Off programme offers numerous advantages, but it has some shortcomings too. Firstly, the researcher must have a technical background, for example in engineering or natural sciences. Consequently, the recipient often lacks the commercial and financial background required to write the business plan and carry out the feasibility study. It also means that much depends on the business person in charge of the follow-up. Some experts, especially those from the industry or Venture Capital environment, point out that it does not encourage collaboration between people with a technical degree and those who have management experience. Consequently, although it provides researchers with pre-seed capital, it under-estimates the value of co-operation.

The Millennium Entrepreneur Fund

This is an initiative of Enterprise Ireland, which combines the technological and financial competencies of Enterprise

Ireland. Enterprise Ireland regards seed capital as a logical extension of its R&D granting activities (Clarysse and Duchêne, 2001). Next to its R&D grants, the Institute participates in three venture capital initiatives:

- the Seed and Venture Capital Scheme;
- the Millennium Entrepreneur Fund;
- the Business Angels network.

Of these, the Millennium Entrepreneur Fund is the most interesting. The fund offers seed finance to Irish entrepreneurs who want to start a business in Ireland. Investment ranges from 500 000 euro to 750 000 euro. Established in 1998 as a merger of engineers working at FORBAIRT (former Irish R&D-granting institute) and economists employed at the Irish Trade Board and Fàs (Irish Training Authority), Enterprise Ireland employs all its competencies to perform a due diligence investigation of a business plan for a high-tech start-up. When a technology start-up knocks on the door, the institute assesses whether a classic R&D grant or an equity investment would best fit the needs of the enterprise.

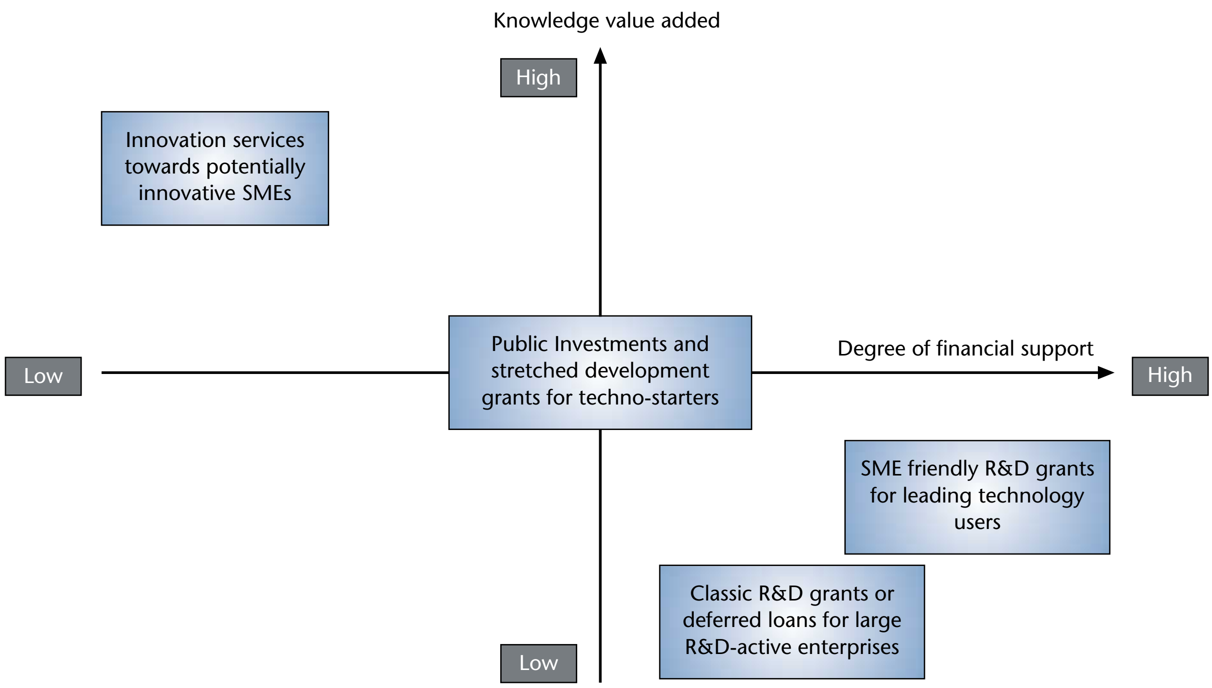
Twinning

This is a totally different fund in the Netherlands, created by the Dutch government to support technology start-ups. It functions separately from the R&D granting agency, SENTER. Although it was started with much higher ambitions some years ago, Twinning is currently a government-owned seed-capital fund. It invests amounts in the range of 125 000 euro to 250 000 euro. Investment activity in start-up capital is basically the only activity left from the initial concept of offering a complete, integrated incubation activity. The facility management activity has been sub-contracted to a third party, as Twinning finds it difficult to combine the skills of facility management with those of giving advice and investing in new start-ups. The business-coaching activity has also been abandoned. The fund now concentrates on the provision of early-stage seed capital.

An integrated framework of R&D related services for the three target groups

An overview of the services and products offered to the three target groups, i.e. large enterprises, and SMEs subdivided into leading technology users/potential innovators, and techno-starters, is presented in figure 3.4.9. The products and services are classified along two axes: the degree of financial support given on the one hand, and the knowledge value added offered to the company on the other hand.

Figure 3.4.9 'Knowledge gap' between potential innovative SMEs and research institutes



Source: Duchêne and Clarysse, 2000

Third European Report on S&T Indicators, 2003

The most traditional R&D subsidy mechanism is situated at the extreme end of the continuum, where the subsidy is only aimed at correcting an under-investment in R&D. Little knowledge is added to this source of finance, except for defining which technologies could receive finance over a five-year period. R&D grants offered to leading technology users differ very little from those presented to large enterprises. The main emphasis is on the financial part of the subsidy. However, a few services such as patent scans can be added before a project is accepted. This group of mechanisms is located in the lower right quadrant of figure 3.4.9.

A third group, which in fact is part of the second, constitutes potentially innovative SMEs. These SMEs seldom need financing, and the financial part of the support represents little more than being a minor motivator. Instead, they need knowledge-intensive services such as innovation agents, acting as stimulants for raising their awareness. The focus is exactly the opposite of the former two categories: a low degree of financial support associated with a large degree of knowledge transfer. Because the service is so different from a product such as an R&D subsidy, some countries, for example the Netherlands and the UK, have decided to set up separate organisations to deliver this kind of service to this specific population. Others like France have integrated these services with the R&D grant portfolio of ANVAR.

The final group, the technology start-ups, lies between the two. Financial support is important, but not overriding. In fact, once a R&D grant is allocated or a public fund invested, the start-up enterprise is able to attract money more easily. Apart from the financial gain, the start-up benefits from the technological due diligence performed. If positive, it diminishes the risk for potential investors.

Section V Venture Capital Investment in High-Tech Start-ups: Creation of new R&D performers

Knowledge-based economies are driven by the creation and expansion of new economic activities in the high-tech and knowledge intensive sectors and by diffusion of new technologies in the economy. However, structural change towards a knowledge-based economy depends to a crucial degree on the efficiency of the financial system in commercialising innovations and knowledge assets through creation and expansion of high-tech and knowledge-based start-ups.

Potential entrepreneurs wanting to realise their business ideas (cf. Florida & Kenney, 1988) require external financing, but debt financing on the traditional capital market is almost impossible for new business plans. This is a totally different situation in comparison to large, established companies with internal financing of their R&D and innovation activity (Model 2). Despite the fact that the new start-ups offer potentially the most profitable and exciting projects, they do not have ready access to financing in traditional capital markets. In particular, new, high-tech and knowledge intensive start-up activities require high, risky investment long before the expected high returns will be realised – indeed, if at all. Also the intangible nature of this kind of firm's assets is a further obstacle to acquiring funding in the traditional capital market.

Evidently, alternative sources of financing are needed. Such alternative sources of finance are provided by the venture capital industry, business angels, founder's own capital and other shareholders' participation or all types of government financing instruments. Recently, an increased interest has developed in Europe about the possibility of strengthening the role of the venture capital industry in financing the creation and expansion of high-tech and knowledge intensive start-ups.

In this section, the development of venture capital investment in financing new business plans and expansion of start-ups in Europe, the US and Japan is presented and examined. However, when making such comparisons one needs to take into account that countries differ strongly with regard to financing systems and rely therefore on various financial sources and instruments. Especially, the venture capital industry has a prominent role in financing start-ups in the US but is traditionally less important in many European countries that may utilise different types of instruments. In particular, naïve policy conclusions must not be made on the basis of a partial analysis of one indicator alone.

Venture capital firms provide equity capital for seed, start-up and expansion phases of new start-ups as well as management buy-outs and buy-ins. The venture capital industry collects and provides the funds for risky, promising business plans and investment while acquiring a participation in the equity capital of a project or a firm. Their profit consists of the sales of substantially increased equity capital shares in the firm. Therefore, the present crisis of the New Economy hits strongly at the venture capital firms as it is not easy to convert new firms into publicly quoted enterprises or the stock markets do not provide expected profits, leading to strong destruction of capital. Evidently, negative effects on the venture capital firms capabilities in financing start-ups can be expected.

Yet, the venture capital industry may play a critical role in commercialisation of innovations and knowledge assets when financing the seed, start-up and expansion phases of new firms' in high-tech and knowledge-intensive sectors. Therefore, the main function of venture capital financing for the creation and expansion of the knowledge-based economy is to establish new research and development performers who conduct additional profit oriented R&D at all successive stages of a firm's life cycle. Simultaneously, commercialisation of research results by the creation and expansion of high-tech start-ups intensifies the exploitation of the existing scientific and technological knowledge pool. Another essential role of the venture capital industry is to provide management skills and knowledge to new business plans and expanding start-ups. In particular, as the founders of high-tech and knowledge based start-ups often come from the research community, the competitiveness and survival of such start-ups – with a high potential for profits and growth – relies critically on access to this management knowledge.

This section starts with a description of the typical activities that are financed by the venture capital industry. This is followed by on analysis of levels and dynamics of venture capital investment in the EU, the US and Japan since 1995. The analysis covers only venture capital investment in the seed, start-up and expansion phases of a firm's life cycle in order to focus on the creation and expansion of new economic activities. The third part describes the allocation of venture capital investment by stages and in all sectors. The allocation of venture capital between high-tech and non-high tech sectors is examined after which the allocation of venture capital investment by stages (seed, start-up and expansion) is analysed in the EU Member States. Finally, the section concludes with a description of European level policy actions for supporting European venture capital and for financing high-tech and knowledge-based start-ups.

1. Typical Activities Financed by the Venture Capital Industry

The venture capital industry plays a strategic role in financing high-risk, potentially highly rewarding business projects, and providing management skills and competencies. The venture capital industry finances all types of necessary – intangible and tangible – investments – related to the setting up and starting of a new business venture, to the expansion of a start-up and to the restructuring of existing businesses. A better understanding about the types of investment is possible when it is assumed that certain types of investment typically belong to certain stages of a firm's life cycle.

Table 3.5.1 categorises the stylised relationship of these various types of investment financed by the venture capital industry to a particular stage of the firm's life cycle based on the experience of the European Venture Capital Association (EVCA, 2000). The early stage of a firm's life cycle – the seed capital phase – is typically related to certain types of firm or project activities that venture capital helps to finance initially. Building up a new profitable business venture requires investment in the strategic, competitive, intangible assets related to the research, assessment and development of an initial concept of the future profitable business.

During the start-up phase – though still without creating any profits – venture capital finances research activities in product development, and marketing strategies. In particular, the profit oriented venture capital industry finances the fulfilment and commercialisation of innovations and knowledge assets, though it does not usually fund research activities related to initial knowledge production in basic research. Venture capital investment is normally focused on research aspects related to market uncertainty issues, rather than to scientific and technological uncertainty. However, the venture capital industry's involvement in financing the more fundamental research activities of biotech firms is a new phenomenon that is probably linked to biotech sectors nearness to science.

In the expansion phase of a business, more finance is needed to develop production capacity. Market and product development activities may still be necessary. Alternatively, finance may be needed for a transition to a publicly listed company and for the cost of the related initial public offering (IPO).

Management buyouts take place at a firm's mature stage, but they are risky ventures often requiring high intangible investments – including R&D activities – and reorganisation efforts. Venture capital investment in a management buyout is often allocated towards intangible investment that supports the long-term development and competitiveness of the company, and ultimately restructures existing businesses. A case study conducted by EVCA has confirmed that venture capital indeed provides funding for R&D, marketing, capital expenditure, and training in the management buyout phase.[8]

[8] *All these investments increased considerably after the buyout (66%, 62%, 59% and 54%, respectively). The result is based on a sample comprising all sectors, of which only 9.7% are high-tech sectors (EVCA, 2001).*

Table 3.5.1 Types of activities financed by venture capital

Stage	State of business/ business plan	Type of activity being financed
Seed	Project	Financing provided to research, assess and develop an initial concept of a new business plan
Start-up	Companies may be in the process of being set up or may have been in business for a short time, but have not sold their product commercially; OR financing of companies that have completed the product development stage	Product development and initial marketing; OR further funds required to initiate commercial manufacturing and sales – not yet generating a profit
Expansion	Existing firm: financing provided for the growth and expansion of a company which is breaking even or trading profitably	Capital may be used to finance increased production capability, market or product development, and/or to provide additional working capital; OR financing made available in the period of transition from a private company to a public company; OR financing made available to an existing business which has been experiencing trading difficulties, with a view to re-establishing prosperity
Replacement	Existing firm	Purchase of existing shares in a company from another private equity, investment organisation, or from another shareholder or shareholders; OR reducing a company's level of gearing
Buyout	Existing firm at a more mature stage	**Management buyout:** Financing to enable current operating management and investors to acquire an existing product line or business; OR **management buy-in:** Financing provided to enable a manager or group of managers from outside the company to buy-in to the company with the support of private equity investors; OR **venture purchase of quoted shares:** Purchasing of quoted shares with a view to delisting the company

Source: DG Research
Data: EVCA

Third European Report on S&T Indicators, 2003

2. Increasing importance of Venture Capital Investment in Europe

Levels and dynamics of venture capital investment

Venture capital investment (in the narrow sense) comprises the seed, start-up and expansion phases of a firm's life cycle, which reflect the creation and expansion of new business activities and entrepreneurship. The share of venture capital in total equity capital investment reflects the role of venture capital industries in creating and expanding new business activities, rather than in financing exits (entering into the stock market by IPOs) and restructuring existing business activities.

European venture capital investment increased significantly during the second half of the 1990s, along with the development of the European venture capital industry. However, in comparison with the US, the dynamics of the European venture capital industry lag behind dramatically, reflecting a far weaker force in the creation and expansion of new business activities. In the EU, as in the US, investment has accelerated since 1998 but in the US the growth rate has been gigantic until 2000 but then breaks down abruptly both in the US and in the EU (figure 3.5.1).

There are huge differences between the US and the EU with regard to absolute level of venture capital investment in particular in 2001 in spite of the crisis (figure 3.5.2). In 2001, the venture capital investment in the US amounted to the equivalent of 36 981 million euro, i.e. 3.1 times higher than in the EU (11 626 million euro) (table 3.5.2) while in 2000 the US venture capital investment was even 4.6 times higher. This means that substantially less start-ups have been founded and expanded by the European venture capital industry (other sources of finance might have been available in Europe). In 2001, however, the crisis of the new economy has broken the upward trend abruptly with venture capital investment declining by 62% in the US and by 37.9% in the EU (table 3.5.2). Obviously, the crisis of the new Economy has had a more profound effect on the investment behaviour of the US venture capital industry indicating a great volatility in financing the emerging knowledge-based economy. When making such comparisons one should of course be aware of the traditionally more prominent role of the venture capital industry in the US.

Definition of venture capital

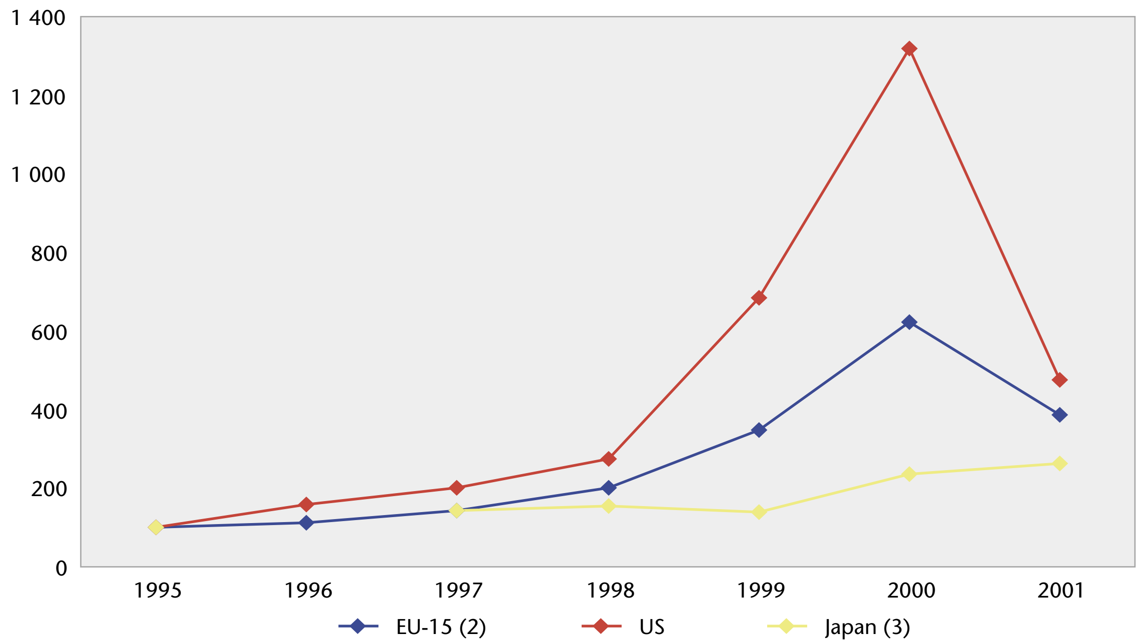
Venture capital comprises a subset of private equity and refers to equity investment made for the launch, early development, or expansion of a business (EVCA 2000, p.4). 'Real' venture capital finances the initiating and expansion stages of firms which is the focus of this study in the context of R&D financing and the creation of new R&D performers.

Total private equity capital comprises, in addition to venture capital in the strict sense, other qualitatively different types of investments, such as management buyouts, and funds for the restructuring of existing firms or for entering the stock exchange (cf. EVCA 2000, pp. 201-202, for stages/type of financing definitions).

The comparison of the EU data with that of the US and Japan is complicated by certain data differences. The US data are based on a slightly different concept of stages, but allows a comparison at a more aggregated level. The aggregated early stage investment which comprises the seed, start-up and other early stage financing is only slightly broader for the EU as it includes also bridge and rescue/turnaround financing. In the US data the later stage financing has not been included in the expansion phase because in this category only 'late stage' financing would correspond functionally to the objectives of this study but it cannot be calculated alone. The Japanese data, originally provided by the National Institute of Science and Technology Policy (NISTEP) for the DG Research exercise of Benchmarking of national research policies (cf. European Commission, 2001 and 2002), try as far as possible to follow EVCA classifications regarding the stages and high-tech sectors.

Source: EVCA 2002, NVCA 2002

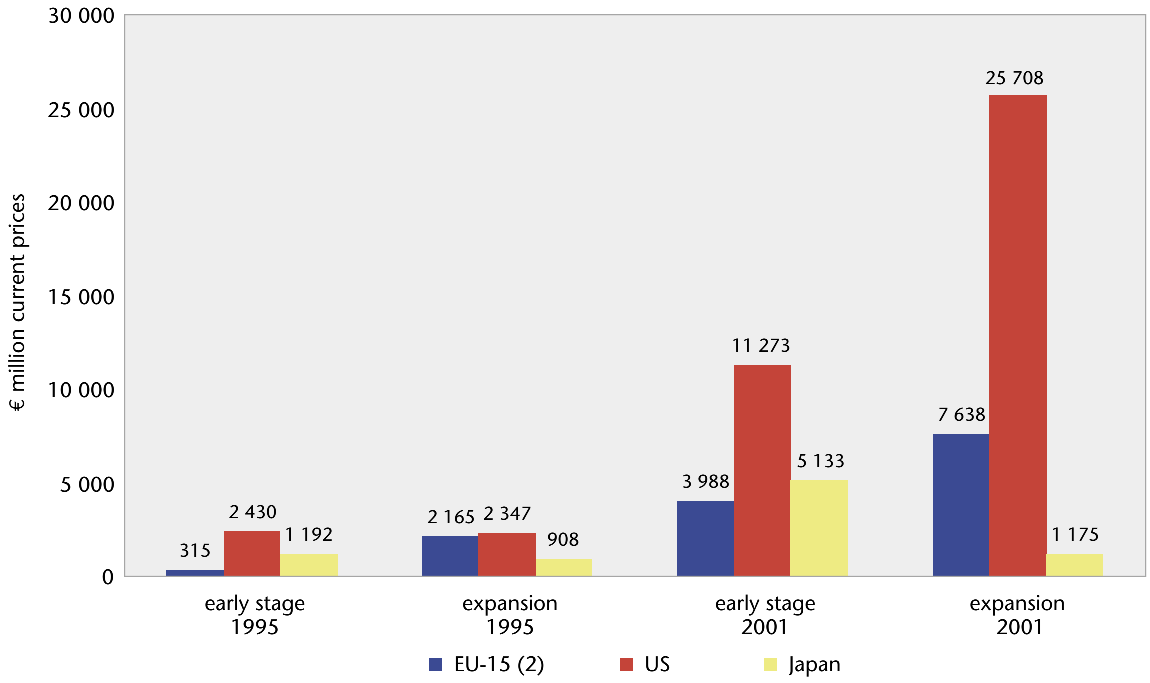
Figure 3.5.1 Growth of venture capital investment (seed, start-up and expansion) in the EU, the US and Japan, 1995-2001 (year 1995=100) (1)



Source: DG Research
Data: EVCA, NVCA, NISTEP
Notes: (1) Venture capital includes investment in seed, start-up and expansion stages. (2) L data are not included in EU-15 average. (3) JP: data for 1996 are not available.

Third European Report on S&T Indicators, 2003

Figure 3.5.2 Venture capital investment by stages EU-15, the US and Japan, 1995 and 2001 (1)



Source: DG Research
Data: EVCA, NVCA, NISTEP
Notes: (1) Early Stage (start-up+seed), US early stage (early+start-up/seed). (2) L data are not included in EU-15 average.
Third European Report on S&T Indicators, 2003

Venture capital investment per country since 1995

The importance of venture capital investment differs between the Member States, the US and Japan reflecting both their size and the institutional set-ups in financing new business ventures (table 3.5.2). Also the relative change in venture capital investment between 2000 and 2001 differs between the Member States, the US and Japan while there are differences in the reactions of the early stage and expansion phase investment as well.

In 2001, the US venture capital industry (81.5%) allocated considerably more of its equity investment to venture capital, i.e. to the creation and expansion of entrepreneurs, than was the case in Europe with 49.5% (table 3.5.2). Also across the Member States the allocation towards venture capital differs substantially. In Denmark, the share of equity capital allocated to the creation and expansion of new business activities (venture capital in the narrow sense) exceeds 90%, while in France, Italy, Sweden, the Netherlands and the UK, the share of venture capital is lower than the EU average. Since UK investment accounts for 32.6% of total European venture capital investment, it pushes down the EU average.

At the same time, the share of venture capital in gross domestic product (GDP) (‰) – quantitatively very low, but with immense qualitative importance in the creation and growth of new economic activities – varies greatly from country to country, reflecting the relative importance of venture capital financing in the economy (table 3.5.2). As expected, venture capital plays a more prominent role in the US (3.26‰), with the EU lagging behind (1.29‰). Again, there are considerable differences between the Member States as in Sweden and the Netherlands venture capital financing plays a fairly important role (around 2-4‰), while it plays a smaller role (below 1‰) in Austria, Portugal, Greece, Italy and France. However, it is very important to realise that these indicators – the share of venture capital in equity capital and in the GDP – conceal very different institutional structures in the financing of new business ideas and the expansion of new firms. Therefore, the differences in venture capital investment alone do not inform us about the efforts in creation and expansion of new firms but are connected to general institutional set-ups of financial systems, and the availability of various public financial instruments.

In the period 1995-2001, the dynamics of venture capital investment remained higher in the US than in the EU, which implies a persistence and even an increase of the venture capital investment gap, as seen in figure 3.5.1. Among the Member States, Austria and Sweden have venture capital investment growth rates that are higher than the US, which helps these countries and Europe to catch up in terms of venture capital financing.

More and more, the European countries and the EU recognise the importance of venture capital in creating new companies and financing innovation-oriented R&D activities. Consequently, they have been introducing different types of instruments for supporting their venture capital industries and the role of venture capital financing.

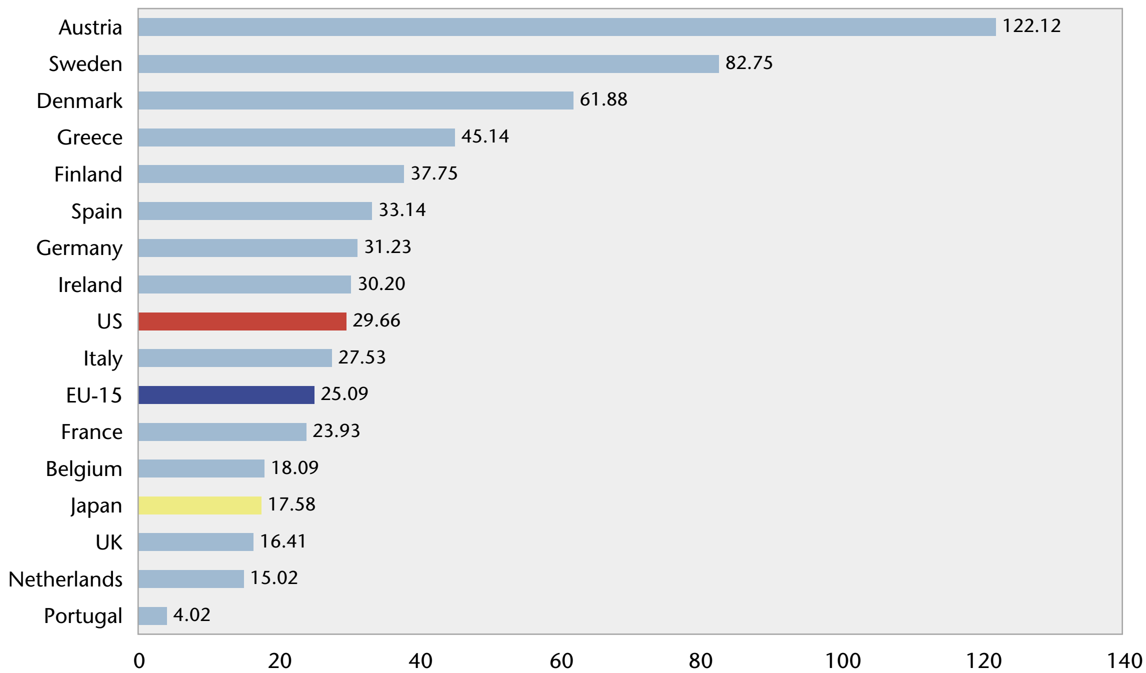
Table 3.5.2 Venture capital investment, 1995 – 2001

Countries	Venture Capital Investment, 2001 in € million: Seed	Start-up	Expansion	Total	Share of venture capital in equity capital, in %	Relative change, 2000-2001, in %: Seed	Start-up	Expansion	Total	Share in GDP, 2001 in ‰: Seed and start-up	Venture Capital
Belgium	27	72	201	300	73.3	-65.7	-61.3	-23.0	-42.9	0.39	1.17
Denmark	60	92	147	299	90.2	4 554.3	181.6	16.7	86.6	0.84	1.65
Germany (1)	172	982	1 554	2 709	61.1	-56.1	-22.1	-27.4	-28.6	0.56	1.30
Greece	1	31	60	91	88.0	:	232.7	-45.7	-23.5	0.24	0.70
Spain	5	106	763	874	72.9	61.4	-46.1	34.2	13.7	0.17	1.35
France	30	531	720	1 282	39.0	-57.2	-51.0	-61.8	-57.8	0.39	0.88
Ireland	1	37	86	124	85.8	-26.4	-66.8	-13.9	-41.5	0.32	1.06
Italy	21	270	745	1 037	47.4	-83.7	-33.8	-22.9	-31.2	0.24	0.85
Netherlands	1	183	745	929	49.2	174.6	-50.9	-28.7	-34.5	0.43	2.16
Austria	8	34	86	127	86.5	-34.4	-30.2	-2.9	-14.3	0.20	0.61
Portugal	0	16	57	73	67.4	:	-48.0	-45.1	-45.8	0.13	0.60
Finland	25	116	72	213	82.8	10.2	2.4	-35.8	-14.2	1.04	1.57
Sweden	24	215	664	902	44.2	-17.0	7.8	98.8	60.7	1.02	3.85
UK	125	804	1 736	2 666	38.5	94.3	-48.1	-61.3	-56.3	0.58	1.68
EU-15 (2)	500	3 488	7 638	11 626	49.6	-38.0	-37.7	-38.1	-37.9	0.43	1.29
US (3)	922	10 351	25 708	36 981	81.5	-72.5	-63.1	-61.1	-62.0	0.99	3.26
JP (4)	:	5 133	1 175	6 308	67.5	:	0.7	-4.0	-0.2	0.97	1.21

Source: DG Research
Data: EVCA, NVCA, NISTEP
Note: (1) D: expansion includes € 102.6 million Bridge and € 75.6 million Turnaround. (2) L data are not included in EU-15 average; EL data are not included in the EU-15 totals for 1993 and 1994. (3) US: start-up includes seed/start-up and early stage. (4) JP: seed is included in start-up. The definition of venture capital differs between EU-15, the US and Japan.

Third European Report on S&T Indicators, 2003

Figure 3.5.3 Average annual real growth (%) of venture capital, 1995–2001



Source: DG Research
Data: EVCA, NVCA, NISTEP

Third European Report on S&T Indicators, 2003

Policy actions by Member States to help create and support venture capital financing

United Kingdom 2000: Corporate venture capital tax relief to encourage corporate venture capital for small and medium enterprises (SMEs)

Denmark 1994: Equity Guarantee Programme Development Companies aim to create a venture capital market

France 1998: Nouveau Marché to support innovative SMEs in accessing external financing sources

France 1998: Public Venture Capital Fund (FPCR) is established to support innovative SMEs

Greece 1997: Venture Capital Companies are established for providing new financial institutions and tools that contribute to SME creation and growth

Sources: European Commission 2000, European Trendchart on Innovation; national and international sources

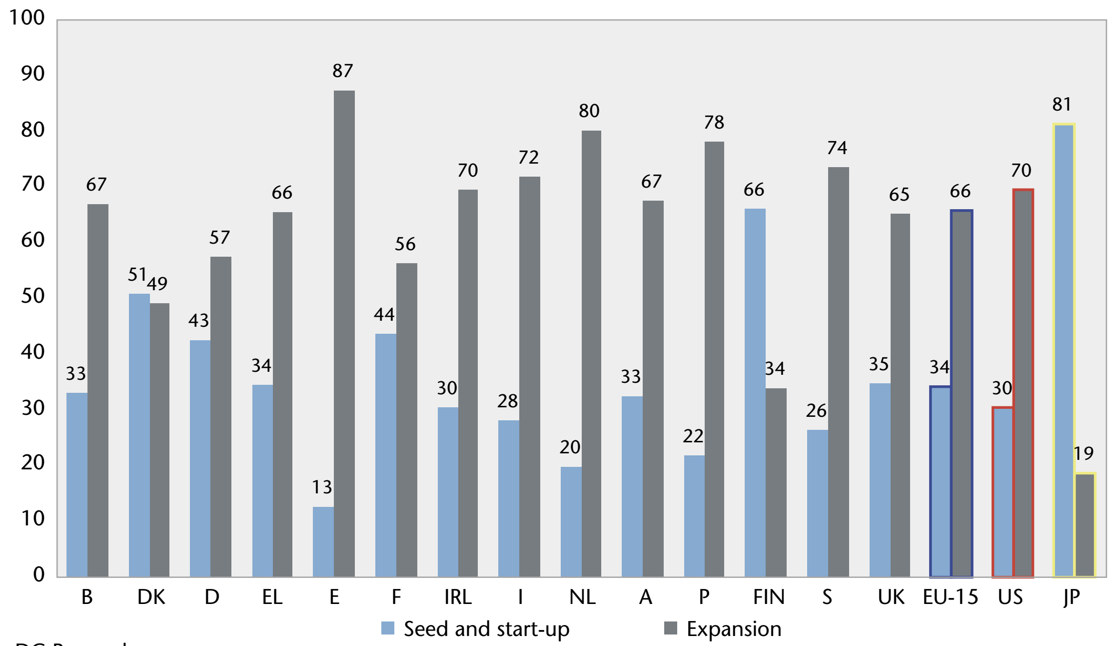
3. Venture Capital by Stages: creation and expansion of new business activities

The allocation of venture capital investment at various stages of a firm's life cycle provides an indication of whether the financing of creation or expansion phases of firms are more important. Interestingly, in 2001 the EU and the US (at a higher absolute level of investment) allocate venture capital investment more strongly in the expansion stage of firms while in Japan the allocation concentrates on the early stages (figure 3.5.4). In the EU the emphasis on the early stages (seed and start-up) is slightly stronger than in the US which points to a relatively higher allocation in the EU to the creation of new business activities in all sectors.

Also in all Member States of the EU – with the exception of Finland and Denmark – the venture capital industry tends to allocate investment in the expansion stage of the emerging business sector. In most Member States the share of venture capital allocated to expansion is higher than equal to the EU average. However, differences in the allocation and levels of venture capital investment do not – as already mentioned – reflect exclusively the role of venture capital in financing the various stages of a firm's life cycle. They also result from differences in the various national systems of financing start-ups, e.g. the role played by public support instruments or by private funds.

However, in contrast to the relative importance of the expansion stage in venture capital investment in 2001, in the EU and in many Member States the dynamics in the period 1995-2000 have been stronger in the early stage capital (figure 3.5.5). This phenomenon may imply a new orientation of the venture capital industry towards financing of the start-up phase, perhaps stemming from a higher number of start-up firms since the mid-1990s.

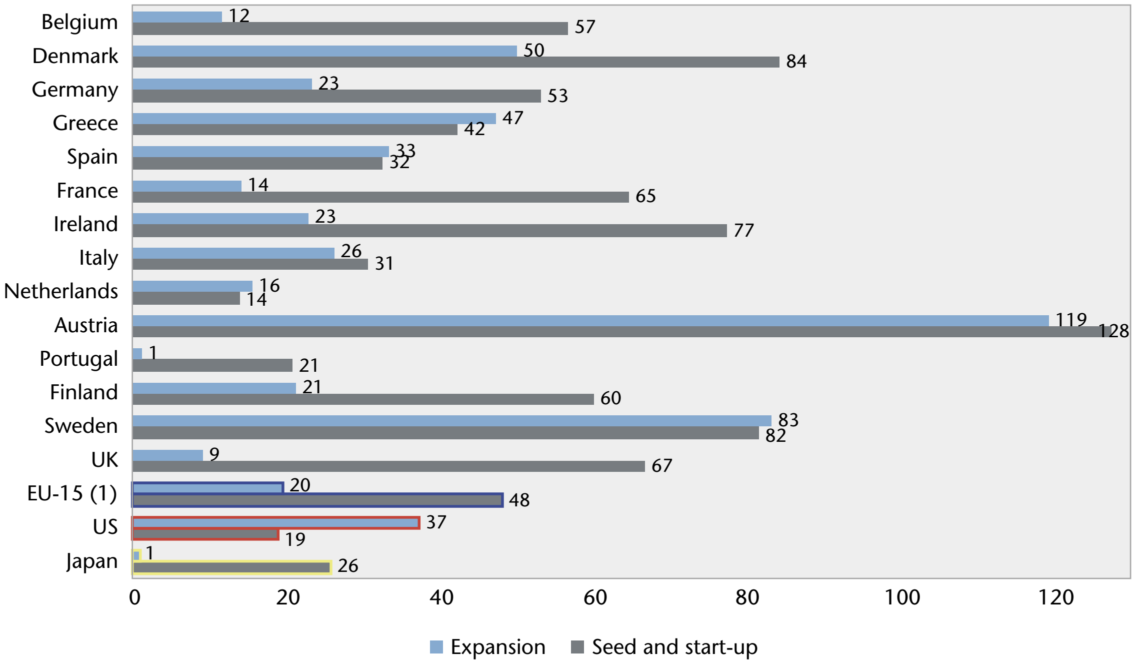
Figure 3.5.4 Venture capital investment by stage (%) in total venture capital, 2001 (1)



Source: DG Research
Data: EVCA, NVCA, NISTEP
Note: (1) Total = Seed, start-up and expansion.

Third European Report on S&T Indicators, 2003

Figure 3.5.5 Average annual real growth rates of venture capital by stages (%) – seed, start-up and expansion, 1995-2001



Source: DG Research
Data: EVCA, NVCA, NISTEP
Note: (1) L data are not included in EU-15 average.

Third European Report on S&T Indicators, 2003

4. Venture Capital Investment in High-tech Industries: financing the emerging knowledge-based economy

Venture capital investment in the high-tech sectors

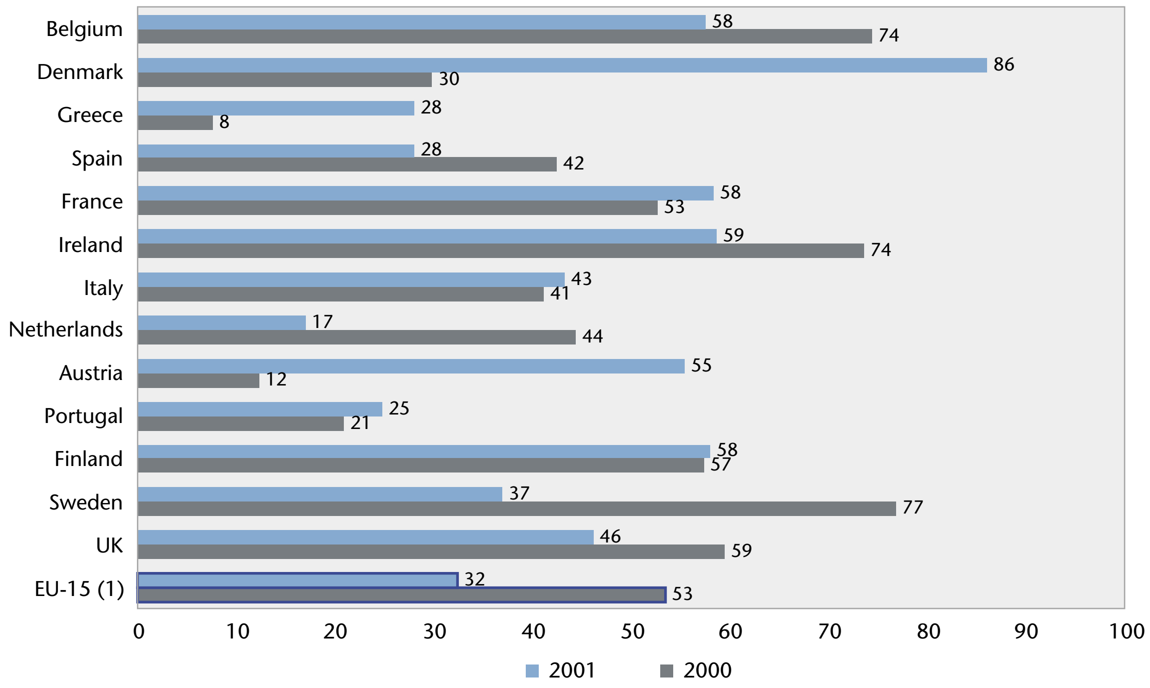
New high-tech and knowledge intensive business start-ups are to a large extent based on knowledge assets and innovations resulting from earlier research efforts in the public and private sector. The emerging knowledge-based economy depends importantly on the commercialisation of such innovations and knowledge assets which can take place through financing the creation and expansion of new high-tech start-ups. In addition, the role of the venture capital industry is not only a financial one. It also has a strategic dimension in providing management knowledge and competencies for the emerging knowledge-based economy.

In praxis, however, there is no possibility of investigating venture capital financing for high-tech start-ups because such information at firms level is not available. Therefore, it is assumed that the allocation of venture capital investment to the high-tech sector and the non-high-tech sector allows us to identify the commercialisation efforts of knowledge assets through creation and expansion of high-tech start-ups. Clearly, this is an assumption that ignores the existence of the high-tech start-ups in the non-high-tech sectors. It is also assumed that the investment finances a real asset in a high-tech, knowledge-intensive start-up and not something like a dot.com.

Venture capital investment in the new high-tech and non-high-tech business activities can be analysed with the use of data on venture capital investment in the high-tech sector by stages. These data are only available in respect of the EU and its Member States and, therefore, comparisons with the US and Japan are not possible. Besides, it would be speculative to draw general conclusions from them, as they cover the first semesters of 2000 and 2001 only, especially in view of the effect on the investment behaviour of European venture capital by the general crisis in the 'new' economy in 2001.

Because of the characteristics of new business projects in the high-tech and knowledge intensive sectors – the high level of intangibles and high market uncertainty, but high potential profits – the share of high-tech sector in venture capital investment is expected to be higher than in the non high-tech sector. Figure 3.5.6 shows the share of high-tech sectors in venture capital investment in various EU countries. Indeed,

Figure 3.5.6 Share of high-tech in venture capital (%), first semesters of 2000 and 2001



Source: DG Research
Data: EVCA
Note: (1) D and L data are not available; D and L data are not included in EU 15 average.
Third European Report on S&T Indicators, 2003

the share of the high-tech sector in venture capital investment confirms its prominent role in financing new business plans created through innovations and knowledge assets, and in financing the expansion of high-tech start-ups. The figure shows that in Belgium, France, Ireland, Finland and the UK, allocation was focused on the high-tech sectors. This was also the case in certain other countries, though for one year only. Only in Greece, Spain and Italy was venture capital investment more strongly concentrated on financing the creation and expansion of the non-high-tech sectors.

Venture capital investment by stages in high-tech sector

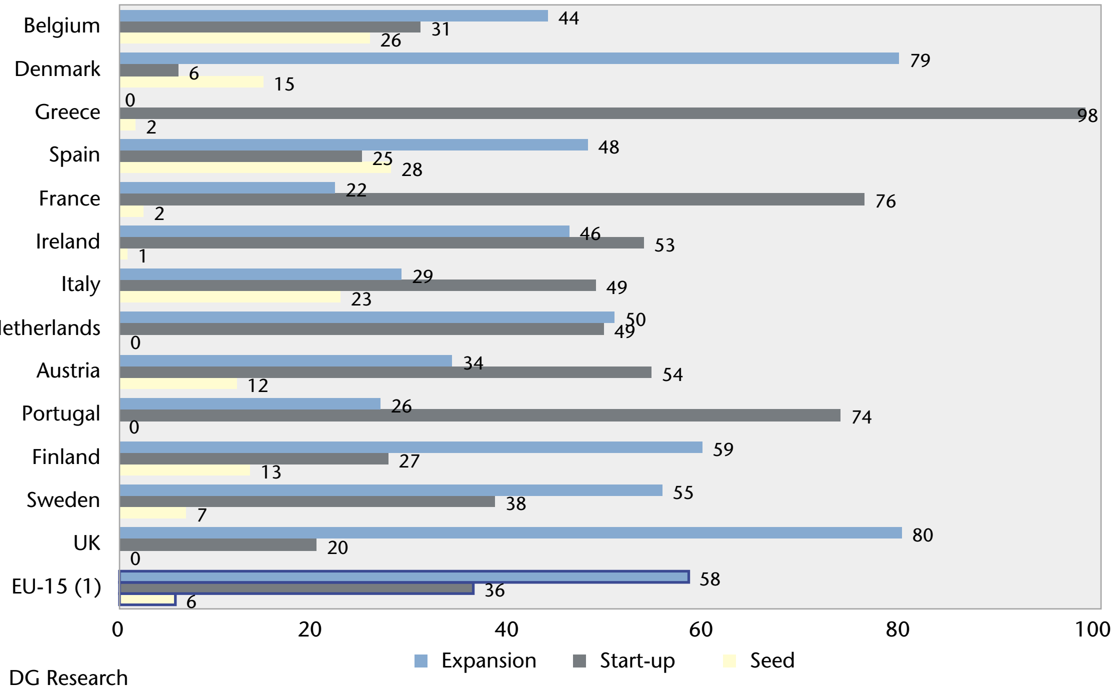
Furthermore, the allocation of venture capital investment in the high-tech sector in the various stages (seed, start-up and expansion) indicates the role of venture capital finance either in the commercialisation of innovations and knowledge assets or in the expansion of the knowledge-based economy. Essentially, seed and start-up capital investment in the high-tech sectors is assumed to reflect primarily the commercialisation of innovations and knowledge assets and the creation of new high-tech business activities, i.e. new R&D performers while the expansion stage finances the growth of the new start-ups.

In most countries the share of seed capital is the lowest, with the exception of Denmark and Spain in the first semester of 2000. The figures for the first semesters of 2000 and 2001 vary, but with the exception of Finland and Greece the relative rankings of the stages remain the same. This indicates a relative stability in the distribution between the stages.

Start-up capital investment also reflects the creation of new business activities with significant R&D activities, although at a later stage of a firm's life cycle, i.e. when it is building up its initial production capacity. In contrast to the expansion phase, the allocation of venture capital investment in the start-up phase is predominant in only a few countries – France, Ireland and Italy in both years, and Finland and Austria in one.

Therefore, in the EU and most Member States there is a relative dominance of the expansion phase in venture capital investment in the high-tech sector. This reflects the fact that the venture capital industry in Europe finances the expansion of the knowledge-based economy to a greater extent than the utilisation of the knowledge pool through creation of new high-tech business activities in Europe. Many Member States have realised the importance of venture capital financing for the early stage of high-tech start-ups. Different types of policy instruments have been created to ensure stronger venture capital involvement.

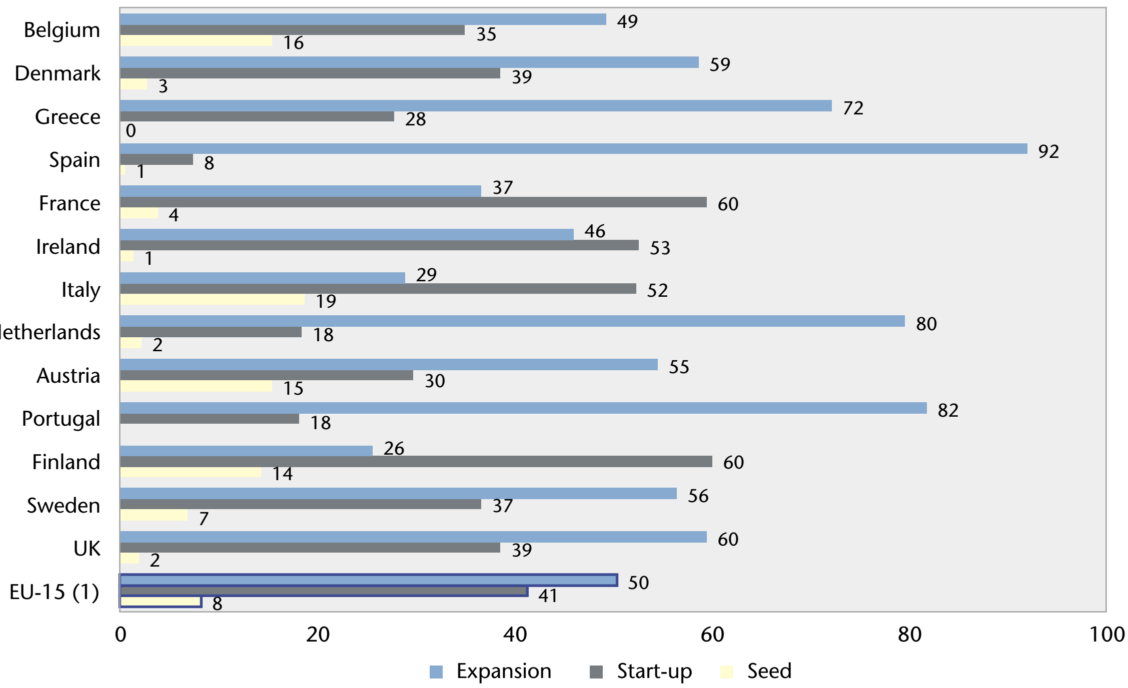
Figure 3.5.7a Venture capital investment in high-tech sector by stages (%), first semester 2000



Source: DG Research
Data: EVCA
Notes: (1) D, L data are not available; D, L data are not included in EU-15 average.
Venture capital includes seed, start-up and expansion.

Third European Report on S&T Indicators, 2003

Figure 3.5.7b Venture capital investment in the high-tech sector by stages (%), first semester 2001



Source: DG Research
Data: EVCA
Notes: (1) D, L data are not available; D, L data are not included in EU-15 average.
Venture capital includes seed, start-up and expansion.

Third European Report on S&T Indicators, 2003

Policy actions by Member States to create and support early stage venture capital financing for high-tech start-ups

United Kingdom 1999: Enterprise Fund to arrange more venture capital for very early stage high-tech firms and to extend and improve the Small Firms Loan Guarantee Scheme

United Kingdom 1998: University Challenge provides the opportunity for universities to compete for venture capital seed funds

United Kingdom 2000: UK High Technology Fund is a fund of funds and invests in venture capital funds that target the early stage high-tech SME sector

Ireland 1994-1999: Actions relating to Equity Finance for Innovation

The Netherlands 2001: Twinning funds high potential innovative ICT start-ups through Seed and Growth Fund (also networks and business management support)

France 1999*:* Support for the creation of seed capital funds to establish technology based firms, particularly in partnership with entrepreneurs from universities or public sector research bodies

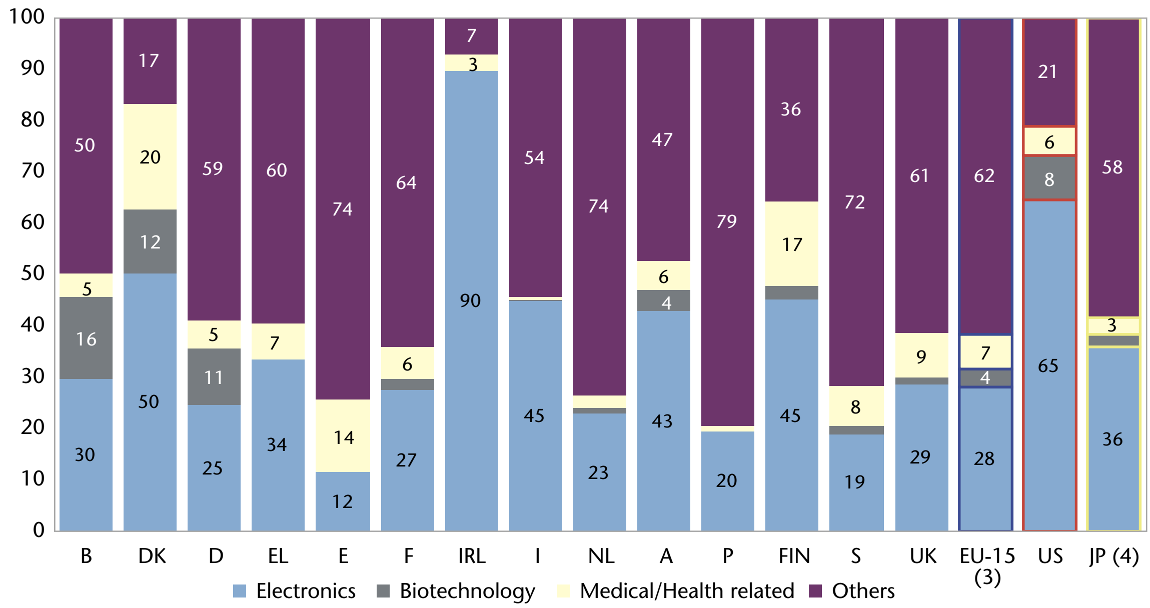
Sources: European Commission 2000, European Trendchart on Innovation, national and international sources

Finland created an instrument in 2001 which functions at the pre-seed phase of a business plan. The fund, "*PreSeed Finance*", aims to improve conditions for the commercialisation of technology projects and for opening venture capital funding to companies using innovative technology. Similarly, business angels and the European Business Angel Networks (BAN) operate at the very early stages of a firm's life cycle and provide informal risk capital to start-ups. Business angels bridge the financing and knowledge gap between the personal savings of entrepreneurs and the formal venture capital investor.

Venture capital financing across specific high-tech sectors (equity capital)

The allocation of venture capital finance across specific high-tech sectors and other non-high-tech ('old economy') sectors provides important information on to what extent the venture capital industry is financing the emerging knowledge-based economy. At present, data on venture capital investment in specific high-tech sectors exist only in respect of the total equity capital provided by the venture capital industry that includes, along with venture capital (in the narrow sense), management buyouts and replacement capital investment.

Figure 3.5.8 Share (%) of high-tech sectors (1) in equity capital (2) investment, 2001



Source: DG Research
Data: EVCA, NVCA, NISTEP
Notes: (1) Definition of High-tech for EU Member States and the US: Communications, computer related, other electronics related, biotechnology and medical/health related. (2) Private equity investment includes venture capital, replacement capital and management buy-out. (3) L data are not included in EU-15 average. (4) Definition of High-tech for Japan: (a) Computer related, telecommunication, semiconductor and other electronical products, internet related, medical and health care, biotechnology are included (b) includes only stages: early stage and expansion.

Third European Report on S&T Indicators, 2003

In 2000, the share of high-tech sectors in equity capital financing amounted to 78.9% in the US, which is considerably higher than in the EU (with 38.3%). The past disparities in the absolute levels of venture capital investment between the EU and US should nevertheless be kept in mind. The higher allocation of equity capital financing by the venture capital industry to high-tech sectors in the US implies a stronger role of the venture capital industry in financing structural change towards a knowledge-based economy since the mid-nineties until today. When making such comparisons one needs to recognise, however, that within Europe the role of other financial instruments might have been more important.

The share of high-tech sectors in equity capital varies considerably among the European countries. In Ireland, this share is (92.9%) even higher than in the US. In Ireland (89.7%), Finland, Italy and Austria (all three with over 40%) the information and communication technology (ICT) sector has been particularly important among the high-tech sectors. Biotechnology also has a relatively strong share (between 11% and 16%) in some of the Member States, such as Belgium, Denmark and Germany while equity capital investment in health and medical activities is important in Denmark (20.4%), Finland (16.7%) and Spain (4.0%).

5. European-level Policy Actions and Instruments for Financing of High-tech and Knowledge based Start-ups

The foregoing analysis of venture capital investment helps to shed more light on the critical role of capital markets in creating and expanding the emerging knowledge-based economy and provides strong evidence in this regard. Both the EU and its Member States have responded to the insufficiency of traditional capital markets with new policy instruments, not only in financing high-risk, potentially high-reward projects, but also in providing the managerial knowledge needed for new business plans.

Issues of efficient capital market and appropriate framework conditions for creating and expanding new high-tech ventures are even more serious at the European level. The EU has responded with several initiatives to create conditions conducive to the establishment and expansion of new high-tech performers and business firms, including support for entrepreneurship, SMEs, innovations and the provision of risk capital in Europe. The box summarises the most important initiatives at European level affecting the creation and expansion of high-tech start-ups, and thus the generation of new business sector R&D activities.

EU initiatives to support the creation and expansion of new high-tech start-ups

1. Risk Capital Action Plan

In addition to the general reluctance of traditional capital markets to finance new high-tech business plans, the European capital market is hampered by particular problems resulting from the fragmented venture capital industry in 15 separate markets among the Member States. These problems persist, even though some Member States have created new markets for the exit of venture capital investment (e.g. Neuer Markt, Nouveau Marché). As a result of this situation, the EU has set up the European Risk Capital Action Plan that ultimately improves access to risk capital finance and managerial knowledge required for start-ups and their expansion.

The rationale for the Risk Capital Action Plan is to increase the effectiveness of risk capital markets in supporting economic growth, the creation of new and sustainable jobs, and the promotion of entrepreneurship and innovation. Yet it is not only the amount of risk capital, but also its allocation that can be sub-optimal, in the sense that it is not sufficiently oriented towards newly created innovative companies.

2. Innovation 2000 Initiative (i2i)

The i2i initiative is a contribution by the European Investment Bank (EIB) to support the emerging knowledge-based economy and information society in Europe, as called for by the Lisbon Strategy, and pursued in subsequent Council meetings in Feira, Nice, Stockholm and Barcelona. The i2i programme implies a stronger shift in EIB lending towards innovation rich projects, and focuses on five key components.

3. EC-EIB Joint Memorandum

High-tech start-ups will benefit most from the Joint Memorandum by DG Research and the EIB aimed at optimising their actions in the field of research and commercial exploitation of these research results. The Joint Memorandum (signed by the Commission and the EIB on 7 June 2001) establishes a framework for co-operation between the community research framework programme and the i2i.

The objectives of the European Research Area (ERA) support the European strategy for achieving a fast transition to a competitive and dynamic knowledge economy. In particular, it is recognised that the EU must do more to support research and to finance talent to ensure that European ideas reach the European market place. Accordingly, the Joint Memorandum sets out a framework for co-operation between the DG Research Framework Programme and the EIB over the medium term. The aim is to optimise their actions in research and in the exploitation of their respective research results, with a view to improving the overall coherence and efficiency of the European system in the commercialisation of publicly funded research results.

Both the Framework Programme (FP) and i2i are seeking to develop new instruments to respond more effectively to key structural needs in financing the emerging knowledge-based economy, i.e. for creating the best value for interventions, both individually and in combination.

The Joint Memorandum enhances the commercialisation of publicly funded research results, as it reinforces the joint impact of the Framework Programme and of i2i by combining these two sources of financing for the RTD projects and the subsequent commercial exploitation of results.

Grants (Framework Programme) and loan and venture capital (i2i) can be complementary instruments in research financing, as well as during the subsequent phases of exploitation and commercialisation. The combinated use of these instruments will increase the efficiency of the system in boosting research and commercialisation.

4. European Investment Fund (EIF)

The European Investment Fund (EIF) is the European Union's specialised financial institution for venture capital and SME Guarantees. The EIF's function is to support the creation, growth and development of SMEs by means of instruments comprising mainly risk capital and guarantees. The EIF focuses essentially on the promotion of European technology through investments in early stage venture capital funds located in the EU and in accession countries.

EIF activities contribute to EU objectives, particularly to its commitment to the development of a knowledge-based society centred on innovation, growth and employment, the promotion of entrepreneurial spirit, regional development, and the cohesion of the Union. In 2000, the EIF was transformed to allow a rationalisation of the EU's venture capital activity linked to i2i.

Recently, the EC and the EIF signed agreements on the implementation of the Multiannual Programme for enterprise and entrepreneurship, in particular SMEs (Multiannual Programme (MAP) 2001-2005). The MAP provides the new legal basis for the EU funded financial instruments, ETF Start-up and the SME Guarantee Facility. The intention was to extend MAP to the accession countries in the first half of 2001.

Conclusions

In the US, GERD is mainly financed by the profit-oriented business sector (68.2%) and also its dynamics are stronger in comparison to the EU in 2000/1999. Within the EU Member States, however, there are considerable differences in the relative importance of business sector financing of GERD ranking from 70.3% in Finland to 21.3% in Greece. Very large differences can be found in the share of government R&D expenditure financed by industry that reflect industry's effort to utilise the knowledge pool of other sectors and links between science and industry. In Europe during the 1990s the share of business sector financing of BERD has tended to increase, i.e. the direct role of government financial support or foreign sources are declining in terms of relative share. However, the increases have not been strong enough to be able to reach the US levels where business sector financing of BERD traditionally plays the most important role.

The relative importance of foreign sources in financing business sector R&D also differs across countries with Austria, Greece and the UK at the top. However, the data do not allow us to identify whether the source is the R&D expenditure of foreign firms (multinationals) or the finance coming from the Framework Programme.

Although the EU *business sector R&D expenditure* has increased considerably in absolute terms since the mid-nineties, the EU has not been capable of catching up with the US which both started at a higher level of knowledge investment as well as showing stronger growth. Consequently, the gap between EU business sector R&D investment and that of the US has actually increased during recent years. However, in some of the Member States such as Sweden and Finland, the business sector invests even more in R&D in relation to GDP than the US. In particular, Finland is currently investing at an increasing rate in spite of its already high level of business sector R&D investment. Some other countries like Ireland and Portugal are catching up but only Finland and Sweden have been able to close the investment gap with the US.

The difference in the R&D intensity of the business sector between the countries depends to a large extent on the differences in the industrial structure of the economy and the types of products produced. The US manufacturing sector has a considerably higher R&D intensity than that of the EU. Again, Finland and Sweden present the highest relative values. As expected, the R&D intensities differ considerably across industries indicating the differing importance of knowledge for the competitiveness of an industry. However, the R&D intensities of a particular industry, i.e. its relative

R&D efforts also differ across the countries. This result indicates different specialisation patterns within the same industry which is a result of differences in the specialisation towards high quality. High quality products are expected to be associated with higher innovation efforts and higher R&D intensity. Obviously, the factors behind the relatively low level and dynamics of EU manufacturing R&D investment can be found both in the relatively weak specialisation in the high-tech sectors as well as in the low R&D investment in the lower quality products within the industries. Such differences in specialisation are also reflected in the differences of the allocation of the BERD investment according to the high-tech, medium-high tech and low-tech industries.

One important determinant for the overall R&D intensity is the relative importance of the service sector which traditionally is considered to be a low R&D intensive activity. However, the R&D intensity of the service sector – although at a relatively low level – differs considerably across countries. This probably depends on the relative share of the knowledge-intensive services which not only are relatively R&D intensive but also play an important role in the production and dissemination of knowledge. The internationalisation of R&D activities is obviously increasing in most of the countries as reflected by the information on foreign R&D activities, cross-border M&A and joint ventures.

The distribution of R&D investment according to the types and size of firms provides important information about the roles of various types of firms in knowledge production and absorption. The business sector R&D activities concentrate in Europe, the US and Japan in firms with more than 500 employees with the exception of Portugal and Spain. This result indicates that the large firms invest more in the knowledge-based economy. Yet, in reality R&D investment is even more concentrated in a particular type of firm, i.e. in the top international R&D performers. The R&D Scoreboard data indicate that the European top international R&D performers invest only slightly less than their US counterparts. However, the difference increases with smaller (measured by numbers of employees) top international R&D performers (Muldur, 2000). This results from the specialisation of the EU top international R&D performers in the more medium high-tech industries such as automobiles their parts or chemicals. However, the role of the small firms and new technology-based firms in a knowledge-based economy is very important for its dynamics and demand special policy support.

Venture capital industry plays a special role for the dynamics of the economy as it finances risky, promising new business plans. Since 1995, venture capital investment was steadily increasing in the EU and very rapidly in the US until the crisis of the new economy in 2001 with a subsequent abrupt decline. However, both the level and the dynamics of European venture capital investment are at a much lower level than in the US. Again, the situation differs strongly between the different Member States. The allocation of venture capital investment to the new high-tech sectors is very important for the emerging knowledge-based economy as it sheds light on the creation and expansion of new R&D performers. In most Member States and in the EU, venture capital investment in the high-tech sector is directed more towards the expansion phase than to the seed and start-up phases. This implies that the venture capital industry tends to finance the expansion of the knowledge-based economy, rather than the initial creation of new high-tech business activities in Europe. The idea that the role of venture capital is more important in the later phases of a firm's life cycle is also supported by a case study about the creation of spin-offs from publicly financed research.

Selected Bibliography

Autio, E. (1997) 'University Links and Technology Based SME's in the Helsinki Region', in: Keeble, D. and Lawson, C. (eds.), *University Research Links and Spin-offs in the Evolution of Regional Clusters of High Tech SME's in* Europe, 1997, pp. 51-83.

Arrow, K. (1962) *Economic Welfare and the Allocation of Resources for Invention*, reprint in: Rosenberg, N. 1971, pp. 164-181.

Bessant, J. (1999) 'The rise and fall of 'Supernet': a case study of technology transfer policy for smaller firms', in: *Research Policy*, vol. 28, nr. 6, pp. 601-614.

Black, B.S. (2000) *The First International Merger Wave (and the fifth and last U.S. Wave)*, University of Miami Law Review.

Clarysse, B. and Duchêne, V. (2000) 'Het innovatiebeleid in Ierland als geïntegreerd element van het ontwikkelingsbeleid: van buitenlandse investeringen naar 'home spun growth', [Innovation policy in Ireland as integrated component of economic development policy: from Foreign Direct Investments to 'Home spun growth'], *IWT-study* No. 34, Brussels.

Clarysse, B. and Duchêne, V. (2000) *Participation of SMEs in Government R&D Programmes: Towards a Segmented Approach to SME Innovation Policy*, Working Paper presented at the OECD-Working Group on Innovation and Technology Policy, 20-21 June 2000, Paris, 37 p.

Clarysse, B., Heirman, A. and Degroof, J.-J. (2001) 'Het fenommen spin-off in België', [The spin-off phenomenon in Belgium], *IWT-study* No. 36, Brussels.

Cohen, W.M. & Levinthal, D.A. (1991) 'Absorptive capacity: A New perspective on Learning and Innovation', *Administrative Science Quarterly*, No. 35-1, March 1991.

Cohen, W.M. & Levinthal, D.A. (1989) 'Innovation and Learning: The two Faces of R&D', *The Economic Journal*, 99, pp. 569-596.

Colombo, M., P. Garrone (2002) *part of a larger study (contract number: ERBHPV2-CT-1999-13) on 'Mergers and Acquisitions and Science and Technology Policy'*, commissioned by the European Commission in the framework of the Common Basis for Science, Technology and Innovation Indicators (CBSTII), part of the Improving Human Potential specific programme; Consortium consisting of: IDEA Consult: Dr. G. Steurs (Contractor); Catholic University of Leuven: Prof. Dr. R. Veugelers; Universitat Pompeu Fabre: Prof. Dr. B. Cassiman; Politecnico di Milano: Prof. Dr. M. Colombo; University of Reading: Prof. Dr. J. Cantwell.

Contractor, F.J. and Lorange, P. (1988) *Co-operative Strategies* and *International Business*, Lexington Books, Lexington (MA).

Coombs, R. & Georghiou L. (2002) 'A New Industrial Ecology', *Science*, Vol. 296, 19 April 2002, p. 471.

Coombs R, Ford R. & Georghiou L. (2001) *Generation and Selection of Successful Research Projects; Research Study for the Technology Strategy Forum*, August 2001, http://les.man.ac.uk/prest/tsf/downloads/tsf_report.pdf

Coombs, R., Richards A., Saviotti P. (1996) *Technological Collaboration: The Dynamics of Cooperation in Industrial Innovation*, Edward Elgar, Cheltenham, UK.

Dasgupta, P. & David, P. (1994) 'Toward a new economics of science' *Research Policy*, 23, pp. 487-521.

David, Paul A. & Foray, D. (1995) 'Accessing and expanding the science and technology knowledge base', *STI Review*, 16, pp. 13-68.

Djellal, F. & Gallouj, F. (2001) 'Innovation Surveys for Service Industries: a Review' in: Eurostat 2001

Dodgson, M. (1993) *Technological Collaboration in Industry*, Routledge, London.

DTI (2000) R&D Scoreboard, Company data. www.innovation.gov.uk/projects/rd_scoreboard/introfr.html

Duchêne V. & Clarysse, B. (forthcoming) 'Competitive Intelligence and Technology Watch in Europe: a benchmarking of public initiatives', *European Association of SMEs Journal*, No 1.

Dunning, J.H. (1992) 'Transatlantic Foreign Direct Investment and the European Economic Community', *International Economic Journal*, Vol. 6, No. 1, pp. 59-81.

Edquist, Ch. (1997) *Systems of innovation. Technologies institutions and organisations*, Pinter, London.

European Commission, Directorate-General for Research (2002) *Towards a European Research Area, Key figures 2002, Science, technology and Innovation*, OPOCE, Luxembourg.

European Commission, Directorate-General for Research (2001a) *Towards a European Research Area, Key figures 2001, Special edition, Indicators for benchmarking of national research policies*, OPOCE, Luxembourg

European Commission (2001b), EC-EIB Joint Memorandum. http://europa.eu.int/comm/commissioners/busquin/pdf/memorandum-eib-en.pdf

European Commission (2000) *Towards European Research Area*, OPOCE, Luxembourg.

European Commission, Directorate-General for Economic and Financial Affairs (2000), *European Economy*, Supplement A, Economic Trends, Mergers and Acquisitions, No. 5/6.

European Commission, Directorate-General Enterprise (2000) *European Trend Chart on Innovation*. Luxembourg.

European Commission, Directorate General for Economic and Financial Affairs, (1999) *European Economy*, Supplement A, Economic Trends, Mergers and Acquisitions, No. 2.

European Commission, Directorate-General for Research (1997) *Second European Report on S&T Indicators*, Report EUR17639, OPOCE, Luxembourg.

European Commission (1996), 96/280/EC: *Commission Recommendation of 3 April 1996*

European Commission, Directorate-General for Research (1994) *First European Report on S&T Indicators*, Report EUR15897, OPOCE, Luxembourg.

European Commission, Risk Capital Action Plan. http://europa.eu.int/comm/internal_market/en/finances/general/01-1490.htm

European Commission, Innovation 2000 Initiative (i2i). http://www.eib.org/i2i/en/ and http://www.cordis.lu/finance/src/inno2000.htm

European Commission. SMEs Multiannual Programme (MAP) 2001-2005: http://europa.eu.int/comm/enterprise/enterprise_policy/mult_entr_programme/programme_2001_2005.htm

European Investment Fund (EIF). www.eif.eu.int

Eurostat (2001) *Innovation and Enterprise Creation: Statistics and Indicators 2001*, Luxembourg.

Eurostat (2001) *Statistics in focus, Computer Services*, Theme 4, 11/2002

EVCA (2002) *EVCA Yearbook2002*, EVCA.

EVCA (2001) *Survey of the Economic and Social Impact of Management Buyouts & Buyins in Europe.*

EVCA (2000), *Mid-year Survey 2000*, January-June 2000.

Florida, R. & Kenney, M. (1988) 'Venture capital-financed innovation and technological change in the US' *Research Policy*, 17 (3), pp. 119-137.

Green L. et al. (2001) Services and innovation. Dynamic of service innovation in the European Union, University of Manchester, PREST, CRIC

Hagedoorn, J., Link, A. & Vonortas, N. (2000) 'Research partnerships', *Research Policy*, 29(4-5), pp. 567-586.

Keeble, D. and Lawson, C. (eds.) (1997) *University Research Links and Spin-offs in the Evolution of Regional Clusters of High Tech SME's in Europe*.

Leiponen, Aija (2000) *Essays in the Economics of Knowledge: Innovation, Collaboration, and Organizational Complementarities*, ETLA A 31, Helsinki

Meeusen, W. & Janssens, W., (2000) 'Additionaliteit- versus substitutie-effecten van overheidssteun aan O&O in bedrijven in Vlaanderen: een econometrische analyse aangevuld met de resultaten van een kwalitatieve bevraging' [Additionality versus substitution effects of government R&D support to Flemish companies: an econometric analysis combined with results from a qualitative survey], *IWT-study* No. 33, Brussels.

Metcalfe, J.S. (1995) 'The Economic Foundations of Technology Policy: Equilibrium and Evolutionary Perspectives', In: Stoneman, P. (1995) *Handbook of Economics and Innovation*, Oxford and Cambridge, pp. 409-512.

Muldur Ugur (2001) 'Is Capital Optimally Allocated in the Overall process of European Innovation?' in *Revue d'Economie Industrielle, Numéro spécial: What Policies in Support for* R&D, No 94 (1er trimestre 2001), pp. 115-152

Mustar, Ph. (1997) 'How French Academics create High-Tech Companies: Conditions of Success and Failure of this Form of Relation between Science and Market', *Science and Public Policy*, 24, 1, pp 37-43.

National Science Board (2002) *Science and Engineering Indicators - 2002*. Arlington, VA: National Science Foundation (NSB-02-1).

National Science Board (2000) *Science and Engineering Indicators - 2000*. Arlington, VA: National Science Foundation (NSB-00-1)

Nelson, R. (1959) *The Simple Economics of Basic Scientific Research*, reprint in: Rosenberg, N. 1971, pp. 148-163

Nelson, R. (1961) 'Uncertainty, Learning, and the Economics of Parallel Research and Development Effort', *Review of Economics and Statistics*, 43, pp. 351-364.

Nelson, R. & Winter, S. (1982) *An Evolutionary Theory of Economic Change*, Cambridge (Mass.) – London.

National Science Board (NSB) (2000) *Science and Engineering Indicators 2001*, Vol. 1, National Science Foundation, Arlington VA. pp. 2-49.

NVCA (2002), *Yearbook 2002*, Thomson Financial Venture Economics.

OECD (2001a) *New Patterns of Industrial Collaboration. Cross-border M&A and Strategic Alliances*, OECD, Paris.

OECD (2001b) *Science, Technology and Industry Scoreboards - Towards a Knowledge-Based Economy*. OECD, Paris.

OECD (1999) *Activities of Foreign Affiliates Database*, May 1999, OECD, Paris.

Petersen J. and Sharp M. (1998) *Technology policy in the European Union*, St. Martins Press, New York.

Prince, Y. (1998) 'De innovativiteit van de Nederlandse industrie', [Innovation capacity in the Dutch industry], *EIM-reports*.

Rosenberg N. (1990) 'Why do Firms do Basic Research', *Research Policy* 19, pp. 165-174.

Rothwell, R. and Dodgson, M. (1989) 'Technology-based small and medium sized firms in Europe : the IRDAC results and their public policy implications', *Science and Public Policy*, Guildford, Vol. 16, No. 1, Feb. 1989, pp. 9-18.

Sandven,T. & Smith, K. (1998) *Understanding R&D intensity indicators*, IDEA paper, Step Group, Oslo.

Santos, R. (2001) *Definition matters: Methodological reflections on the "SME" indicator in the benchmarking exercise*, document presented in Eurostat 11th Working Party meeting « R&D and Innovation Statistics», Luxembourg, 13-14 September 2001.

Smith, K. (1995) 'Interaction in knowledge system : foundations, policy implication and empirical methods' *STI Review*, 16, OECD, Paris, pp. 69-105.

Teece, D. (2000) *Managing Intellectual Capital*, University Press, Oxford.

Tether B. & Metcalfe J.S. (2001) *Horndal at Heathrow? Cooperation, Learning and Innovation: Investigating the Processes of Runway Capacity Creation at Europe's Most Congested Airports*, CRIC Discussion Paper No. 46, University of Manchester, June 2001

Tether, B. & Miles, I. (2001) Surveying Innovation in Services – Measurement and Policy Interpretation Issues. in: Eurostat 2001

Vonortas, N. S. (2000) 'Multimarket contact and inter-company co-operation in RTD', *Journal of Evolutionary Economics*, 10, pp. 243-271.

Vonortas, N. S. (1997) *Co-operation in Research and Development*, Kluwer Academic Publishers, Boston (MA) & Dordrecht, Netherlands.

Young, A. (1996) 'Measuring R&D in the Services', *STI Working Papers*, 7, OECD, Paris.

DOSSIER II
Research Based Spin-offs as a Vehicle to Commercialise Technology

Since the mid-nineties, several authors have been emphasising the strength of Europe's educational and science base on the one hand, but particularly its inability, on the other hand, to convert this advantage into strong technological and economic performance. As a phenomenon, this has become known as the "European Paradox" (European Commission, 1994; Green Paper on Innovation, 1995; Caracostas and Muldur, 1997). In the meantime, the commercialisation of science and technology has become a prominent issue on the European policy agenda.

Despite the wealth of academic work focusing on "technology transfer" from research organisations or universities to the incumbent industry, little is known about "creating new ventures" as a way of commercialising research and technology. This does not mean, however, that creation of spin-offs for technology transfer purposes, is an entirely new phenomenon. Already in the nineteenth century, scientists such as Werner von Siemens and Gerard Philips set up spin-offs that would later develop into multinational players (Mustar 1995). Nevertheless, the creation of spin-offs in Europe has long been a marginal phenomenon, emerging despite the indifference or active opposition of European universities (Nlemvo, Pirnay et al. 2000).

It is only since the mid 1990s that academics and policy-makers have shown more interest in such spin-offs from research in universities and other public research organisations. This interest has been spurred by the US based success stories emanating from the high-tech clusters of Silicon Valley and Route 128, associated with Stanford University and the MIT/Boston area respectively. A number of articles have been published in which new technology based firms (NTBFs) and a sub-category of these firms – academic spin-offs – are the central topic of interest (Autio and Yli-Renko, 1998; Stankiewicz, 1994; Downes and Eady, 1997; Tether and Storey, 1998; Chiesa and Piccaluga, 2000; Debackere, 2000; Mustar, 1995, 1998; Surlemont and Pirnay, 2001; Degroof, 2001; Clarysse et al., 2001; OECD, 1999; European Commission, 2000).

Most of these authors suggest that the spin-offs in their countries are very different from the US based success stories that policy-makers have in mind. More specifically, European spin-offs are reported to be mostly one-person SMEs, with limited ambitions for growth and no clear commercial strategy. Publications on the importance of spin-offs in different European regions also point to tremendous diversity. For example, in the small area around the University of Twente in the Netherlands (OECD, 1999), 72 spin-offs have been officially recorded, whereas surprisingly Cambridge in the UK, probably the most technologically advanced high-tech cluster in Europe, is estimated to have only slightly more than 300 spin-offs (Segal Quince Wicksteed, 2000).

This paper is based upon empirical findings in the literature and extensive research conducted by the University of Ghent on European and Belgian spin-offs. It consists of:

- firstly, an exploration of the spin-off concept and focusing particularly on 'academic spin-offs', or spin-offs for which business activity is founded on a technological development or innovative concept developed at the university;
- then analyses of the different phases in the development of these companies in their first years of existence, trying to define their typical pace of growth, and explores their critical resources base (knowledge resources, financial or physical resources, etc.);
- finally, it ends with a section on the policy implications of its findings.

Section I Research based spin-offs, concepts and definition

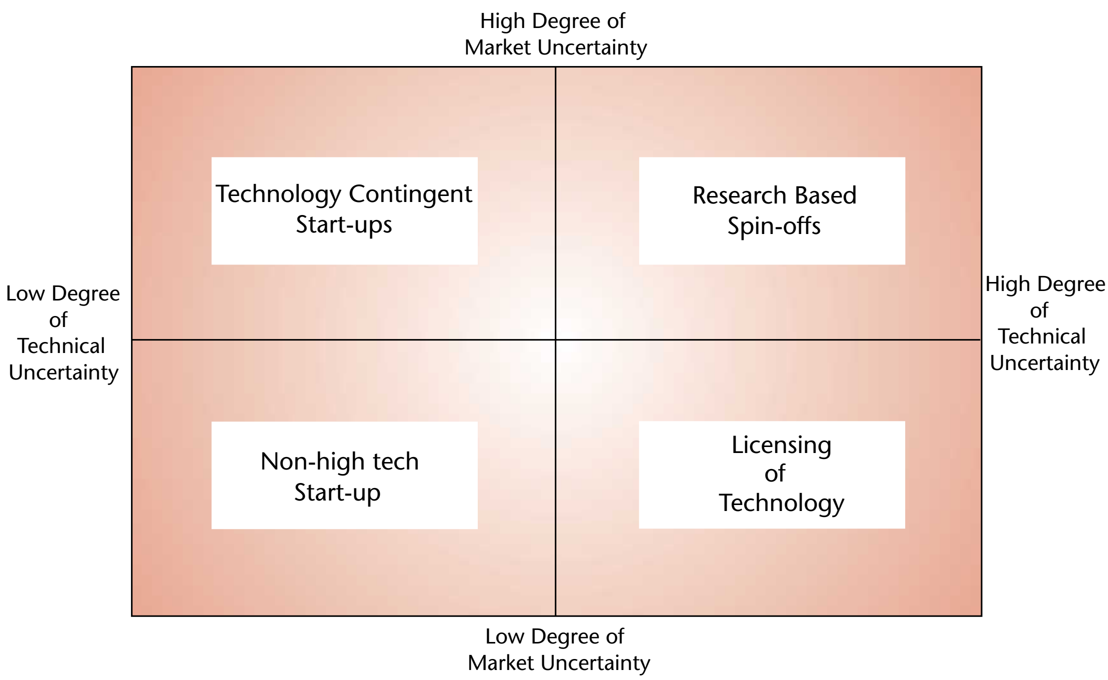
Positioning the 'research based spin-off'

A first step in analysing the spin-off process is to position research based spin-offs, both among high-tech start-ups and among other vehicles for technology transfer. High-tech firms can be categorised according to technical uncertainty, ranging from pure innovator to pure imitator (Storey and Tether, 1998) and market uncertainty (Teece, 1986). When a totally new market has to be created, market uncertainty is very high and incumbent firms (existing companies) are unlikely to monopolise the downstream value chain, which is necessary to penetrate the market and realise economic profits. At the other end of the continuum, where market uncertainty is quite low, the value chain is normally monopolised by a few incumbents.

This observation can be portrayed as a two-dimensional figure consisting of four distinct quadrants (figure D2.1.1). Each quadrant represents a 'pure' type with typical characteristics relating to market and technical uncertainty. In the upper left quadrant are the so-called imitators, or technology-contingent start-ups. They use new technologies to enter new markets or to launch new ways of doing business (Hellman and Puri, 2000), but do not really invest in research and development (R&D). They might perform some engineering work to adapt the technology to a commercial product, but there is no technical uncertainty involved. The proliferation of so-called dot.coms is a recent example of this kind of company. Because of the market uncertainty encountered by these start-ups, incumbent firms are unlikely to enter the markets as first movers. Hence, the first-mover advantage is their core competence (Coviello and McAuley, 1999). An interesting phenomenon in this category is the emergence of "spin-ins". This refers to companies created by entrepreneurs who have a business idea and search for the appropriate technology in universities or research organisations to support their idea.

In the lower left quadrant of figure D2.1.1 are the companies that face little uncertainty, both technically and in terms of the market. They are called non-high-tech or non-innovative start-ups. A typical example of this kind of start-up in a university environment is a service company testing water pollution, or a small auditing company. The market is certain, but also settled. The company has a local or a person-related customer base and economic profits are usually quite small. In a non-university or research environment, it would be a typical SME start-up, for example a grocery shop.

Figure D2.1.1 Market and technical uncertainty as determinants of commercialisation vehicles



Source: Clarysse, Heirman and Moray, 2001

Third European Report on S&T Indicators, 2003

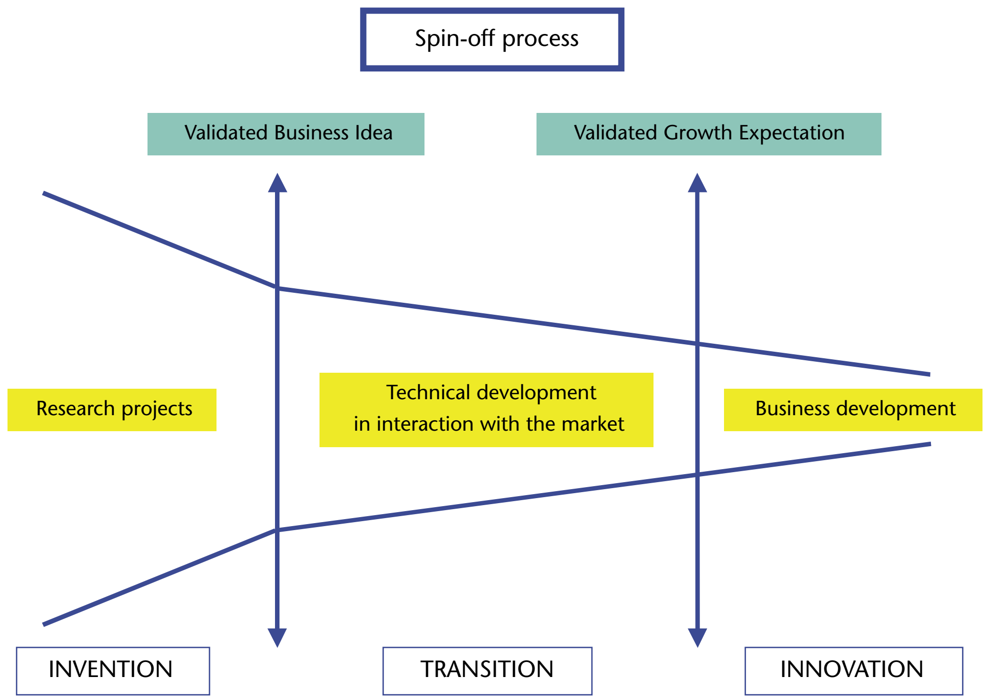
In the lower right quadrant are the start-ups characterised by high technical uncertainty and low market uncertainty. In this category, an entrepreneurial venture might not be the most efficient way of commercialising research and technology; contract research or some form of licensing with the existing industry seems preferable. The reason is straightforward: in existing markets, companies want to improve their competitive positions by introducing either process or product innovations that would give them a first-mover advantage over their direct competitors. Technology licensing nevertheless has some disadvantages, which seem to be twofold. Firstly, the nature of the new technology may not be easily patented and transacted via a licence agreement. Secondly, universities may not be able to capture the full value of a technology through a licensing arrangement. Therefore, they may seek a more direct involvement in the commercialisation of new technology by spinning out a company (Locket et al., 2001).

In the upper right quadrant of figure D2.1.1 is the research-based spin-off. Smilor, Gibson and Dietrich (1990) define an academic spin-off as an enterprise of which the entrepreneur is an academic, a research worker or a student who left the university to start a company, or who started a company while still at the university. Alternatively, the business activity is founded on a technological development or innovative concept developed at the university. The main difference between the research-based spin-off and the technology licensing category is the degree of technical uncertainty. Typically, the research based spin-off has a technology platform as its core competence, but it has to be adapted to specific market applications. Often the start-up still has to develop a prototype. The core competence is not so much its first-mover advantage in the market, but its technological novelty. A transfer of technology would be a prerequisite for defining a particular company as an academic spin-off. Whether this transfer takes place when the company is established, or only later on, is not a material consideration. In most cases there is also a transfer of researchers, but it is not a prerequisite for the definition of an academic spin-off. It is also possible that the parent organisation invests capital and provides additional services for the spin-off (physical incubation like office space, network access, shared use of technical resources, management consulting, etc.).

The Spin-off Funnel: a Conceptual Framework

Drawing on the results of an in-depth field study of a Belgian spin-off over a period of two years, Clarysse and Moray (forthcoming) suggest that the establishment of a spin-off can be seen as a process consisting of three different stages: the invention phase, the transition phase and the innovation phase. The study uses participant observation as the main data collection technique, following the Eisenhardt (1989) design to produce theory from the ground up.

Figure D2.1.2 The spin-off funnel



Source: Clarysse, Heirman and Moray, 2001

Third European Report on S&T Indicators, 2003

Firstly, there is an invention phase during which the business idea is validated. Before the start-up is actually founded, most research teams continue their activities in the parent organisation, i.e. the university, research institute or institutional laboratory. Secondly, there is a validating phase of the growth expectations, known as the "start-up" or transition phase. Lastly, there is a business development or "innovation" phase.

The idea of dividing the spin-off funnel into different stages concurs with organisational life-cycle theory. In his study of new technology-based firms, Kazanijan (1988) identifies four phases through which high-tech start-ups develop: conception and development; commercialisation; growth; and stability. Other scholars in the organisational life-cycle tradition described three stages: Roberts (1991), studying the life cycle of MIT spin-offs classifies the different phases in their growth path as start-up, initial growth and sustained growth. The start-up phase embodies both Kazanijan's conception and development stage and a part of the commercialisation stage. In a recent review of the literature, Foh and Tan (2001) conclude that current thinking converges on the idea that the life cycle of high-tech firms includes the three stages of start-up, growth and maturity. The three stages in the spin-off process suggested by Clarysse and Moray constitute a further elaboration of the first stage – the start-up – found in the organisational life cycle models.

The spin-off process is presented as a funnel: from the relatively large number of business ideas during the invention phase, only a few will be validated. During the transition phase a further levelling off takes place, with the result that even fewer business ideas will show growth prospects and enter the post start-up or business development stage. What has emerged is an empirically grounded conceptual framework of the spin-off process – see below – constructed through an in-depth analysis of one case study, further validated by interview data on 88 cases out of 13 different European regions (cf. box).

Next to elaborating on the organisational life cycle theory, a characteristic of our model lies in the fact that we 'stretch' the founding moment of a spin-off. From a legal point of view, a company is founded when it is registered as a company, and this is usually a point in time. However, before a spin-off is legally founded and reaches the start-up phase, it can have gone through a number of different phases. For many reasons this pre-start-up process can vary a lot from spin-off to spin-off (e.g. because of differences in the resources base, see below). The foundation of a spin-off should be considered as a phase and not as a point-in-time. Statistics on growth and start-up rates that do not take this into account risk mixing different kinds of companies.

In-depth analysis of one spin-off – further validated by the interview data of the Clarysse, Heirman and Degroof study

Comparing the in-depth case data (Clarysse and Moray, forthcoming) with data from interviews at 88 European companies across 13 regions (Clarysse et al. 2001), a first interesting finding is that the legal establishment of a spin-off does not always take place at the end of the invention phase. Some research institutes, which act as venture incubators or accelerators, prefer not to spin off the research team before growth expectations have been validated so that real venture capital can be attracted. Instead of creating a new company at this stage, they allocate a maximum budget to the research team for a limited period of time, usually one to two years. In this period, the business idea is tested in the market with potential clients. The development of the venture "officially" enters the incubation phase, which is similar to the start-up period defined in the case. It is not clear yet whether the technology platform developed in the spin-off can lead to a real growth oriented business. The spin-off remains largely technology oriented and looks for partners willing to share the risk of bringing the technology to the market. The validation stage of growth expectations takes place in the parent organisation in order to facilitate a venture capital injection further down the line. In this spin-off sample, it was found to take one to eight years, and on average three years, depending on the environment in which the company was created. During this period, the companies tend to generate revenues through consulting, contract research or advance payment of licensing fees. It is only afterwards that the venture will be legally established and physically spun off from the parent organisation. This type of spin-off is only established officially once business development can start. Conceptually, however, this period is similar to the innovation phase described in the in-depth case study.

It has also been observed that often an intermediary and separate legal entity is established during the validation phase of the business opportunity. Such entity is incorporated when the spin-off is legally established. The data suggests two main arguments for establishing a separate legal entity at this stage. First, the researchers want to protect the developed technology separately from the parent organisation. Second, they want to create a mechanism to access revenues from present or future contract research or consulting. Mostly, the legal entities formed at this stage of the process are so-called "sleeping companies". In addition to creating the technical developments, the research team also starts with the development of a preliminary business plan. So, although during this phase a "go decision" to spin off has been taken, the formal, legal registration of an entity does not necessarily result into the creation of a new business.

Section II Financial and knowledge resources as environmental determinants of successful spin-off activity

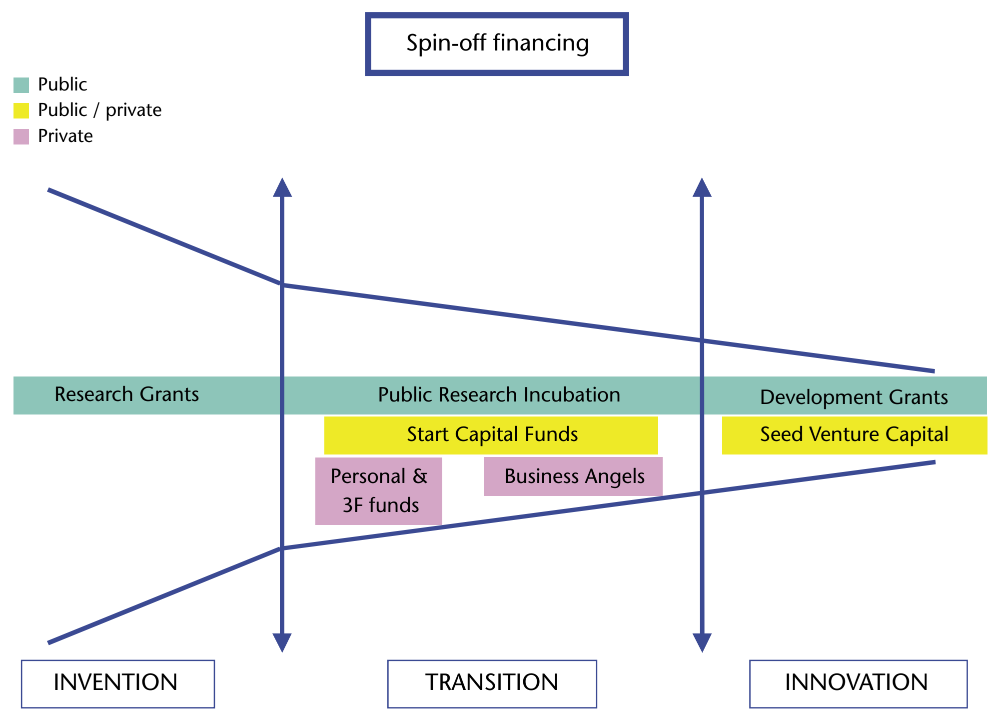
Research has shown that the availability of high level research universities, institutes and embedded laboratories is a prerequisite for enhanced spin-off activity in a region (Saxenian, 1994; Segal Quince Wickstead, 2000). However, the presence of technology laboratories alone is not sufficient to enhance the creation of growth oriented spin-offs which progress to the business development phase and show validated growth ambition. Suchman (1995:62) argues that the diffusion of two types of resource flows is necessary for an entrepreneurial technology cluster to emerge: operational resources, such as financing, and knowledge resources, such as summary information on entrepreneurial competence. Research into high-tech clusters emphasises the importance of efficient risk capital markets in supporting entrepreneurial activity (Lerner and Gompers, 1999; Sahlman, 1990). They also stress the key role of social networks and institutional forums in diffusing best practice (Hellman, 2000; Saxenian, 1994) and in selecting the best projects (Roberts and Malone, 1996).

The distinction between financial and knowledge resources is important because the latter is often overlooked, despite it being particularly critical in an emerging entrepreneurial environment where information is insufficient and not well disseminated (Saxenian, 1994). Moreover, it might be useful to distinguish between technological knowledge (which is usually the core competence of the spin-off starting team) on the one hand and business knowledge (which is necessary to assess the growth potential of a spin-off and the configuration of the management team) on the other hand. The complementarity of financial resources and knowledge resources is also apparent, because knowledge and competencies infuse financial resources. For instance, venture financing at an early stage of the enterprise is only efficient if accompanied by appropriate competencies in high-tech entrepreneurship. The rest of this section analyses how financial and knowledge resources can be defined over the course of the spin-off funnel.

Financial resources along the spin-off funnel: empirical findings

To determine which financial resources are available and used by enterprises in the spin-off funnel, 34 intermediaries that are active in spinning off companies were visited in 13 different regions. The regions were chosen on the basis of availability of technology. Spin-offs are mostly localised in

Figure D2.2.1 Financial resources along the spin-off funnel



Source: Clarysse, Heirman and Moray, 2001

Third European Report on S&T Indicators, 2003

nature, initially centred around the university or research laboratories. Only in regions such as Cambridge or l'Île de France which have an established tradition in spinning off companies, has the phenomenon spread wider than the local environment.

Without exception, in the pre-start phase, research grants to research organisations such as universities, public research laboratories and corporate laboratories, play a very important role. Grants favouring industry-science collaboration in particular are often the basis for start-ups, but regional differences do exist in relation to the source of the grants. In Italy for instance, most of the eventual spin-offs were initially based on a project sponsored by the European Commission; in other regions the source of funding was more balanced, spread between EC, national and regional grants. The grants are invariably given to the research organisation, and not to the start-up process.

In the second phase – the transition phase – funding becomes much more complex. As explained earlier, during this phase externals validate the business idea. However, it is hardly ever evident whether it would be possible to accomplish a growth-oriented business based on repetitive sales. Therefore, venture capitalists are normally not interested in investing during this phase[1] and, in general, three kinds of funding emerge (figure D2.1.3): the pure public funding consisting of grants or deferred loans, the public/private partnerships that invest in the capital of the spin-off, and finally informal forms of capital provision. The three forms of finance are discussed below.

Public Forms of Capital For Spin-Offs in the Transition phase

Public forms of capital are usually so-called 'stretched' forms of research or development grants. An example of a 'stretched' or 'extended' research grant is the FIRST spin-off scholarship in Wallonia, Belgium. These are grants given to researchers at universities who want to establish a spin-off venture. The grant covers two years of salary for the researcher who, in turn, has to develop a business plan and create a spin-off. Extended development grants are R&D subsidies given to industry. One of the most important criteria for the allocation of such grants is the technological uncertainty and novelty of a project. By extending the strict R&D definition to include innovation, the grants become quite attractive to start-ups aiming for market validation of a technological concept.

The major drawback of these grants is that they are awarded on the basis of a project proposal. Spin-offs, on the other hand, during the transition phase at least, only have a business plan. An analysis of the R&D grants received by Flemish spin-offs from the IWT (Flemish Institute for Applied Research and Innovation) shows that they account for about one third of the cumulated capital of Flemish spin-offs in the 1990s. Flemish spin-offs are usually between two and three years into the transition phase before they receive this kind of grant.

Public/Private Partnerships Providing Capital For Spin-Offs in the Transition phase

In most countries, public/private partnership funds are established to invest in spin-offs. The partnerships are organised differently in different countries. In Belgium, Germany (Munich) and various parts of the UK, most research organisations or universities participate in a starter capital fund with the specific objective of investing in spin-offs during the transition phase. In the UK, for instance, 15 university challenge funds have been established through the University Challenge Competition. In Flanders, similar university funds have been created mostly as partnerships with local financial institutions wishing to identify earlier in the process the most interesting investments and research universities from which such companies are spun off. The research organisations use public money to invest in the fund. Usually they assume a minority position (20%), with the result that their weight in the fund may depend on informal factors. The funds differ in size, ranging from 2.5 million euro to 12.5 million euro, and invest between 250 000 euro and 750 000 euro per start-up. The interesting characteristic of these funds is that they conduct a financial due diligence exercise on the business plan proposed by the researchers. Often research organisations complain that they are not able financially to engage competent people to do a financial evaluation of a preliminary business plan, because the tariffs are too high for a start-up enterprise. Since the financial institutions co-participate in the funds, they help by definition to perform the due diligence. The availability of this kind of starter capital fund allows the spin-off in the transition phase to start up as a legal entity and seek validation of the business in the market. In addition to public/private partnership funds, informal capital also plays an important role.

Informal Forms of Capital For Spin-Offs in the Transition phase

Most American publications on entrepreneurship refer to so-called 3F money (fools, friends and family) as the major source of capital. In most European countries this kind of money is not as readily available as in the United States. Whereas in the US, about 7% of the population had invested

[1] *When the stock markets are extremely favourable, like in 2000, venture capitalists tend to take more risks and conversely invest smaller amounts of money.*

in a start-up during the three years preceding the survey, the European average is about 2-3% (GEM, 2000). This means that on average the amount of available informal capital of the 3F variety is at least twice as much in the US, compared to European countries. A second source of informal capital is provided by so-called business angels (BAs). Unlike 3Fs, business angels do not necessarily know the entrepreneurs personally. They invest, among others, in a business, because they like the idea (Ardichvili, A. et al., 2000; Leleux, B. and Surlemont, B., 2000). To the majority of spin-offs in the survey, this kind of capital is of no consequence. Only 5% of the spin-offs have been financed by BAs during the transition phase and 18% during the innovation phase. Only in denser high-tech clusters, such as Cambridge in the UK, are BA investments in high-tech start-ups more common than in the rest of Europe.

Section III Venture Nurturing as a necessary complement to a finance and science/technology base

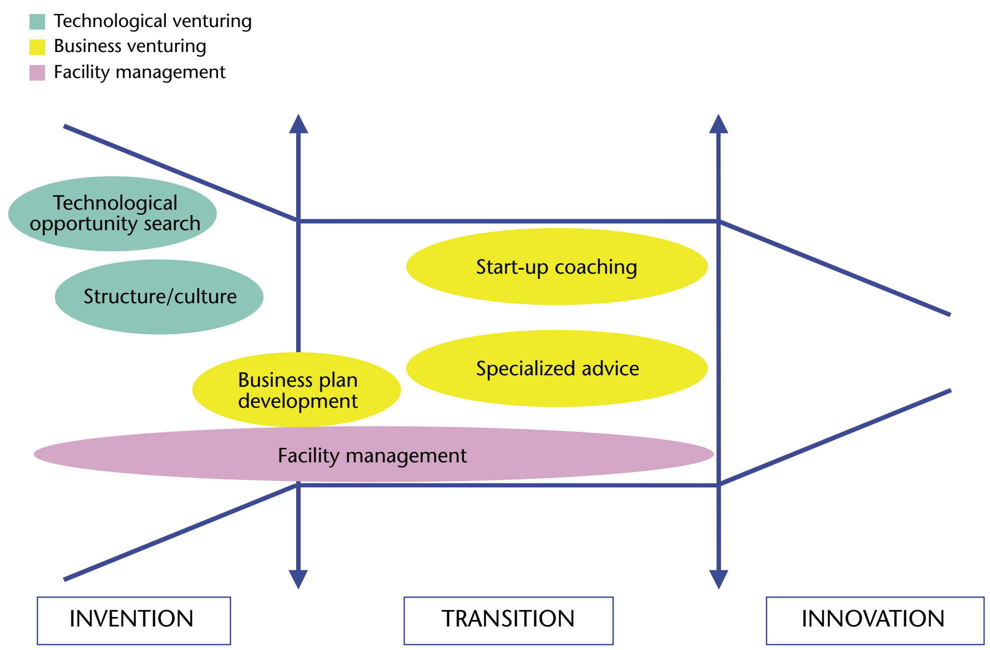
As stated earlier, Suchman (1995) suggests that, apart from financial resources, the availability of knowledge resources during the start-up phase also plays a crucial role in fostering growth oriented spin-offs. His study of high-tech start-ups in Silicon Valley emphasises the important role played by lawyers as bearers of knowledge between different companies in the area. In Europe, the role of knowledge brokers tends to be fulfilled by intermediary organisations and research institutes setting up spin-off activities.

Clarysse, Heirman and Degroof (2001) analyse the different services offered to spin-offs by different forms of intermediary organisations during the spin-off process. They divide the different support activities into three distinct categories: technological nurturing, business coaching and facility management (figure D2.3.1).

Technological Nurturing

The first activity, technological nurturing, includes three elements: searching for ideas that can be commercialised in a research organisation or university; creating fertile ground for spin-off activity in this environment; and protecting the technology base. Searching for opportunities is often seen as a "missionary" activity to convince professors and researchers to commercialise their research ideas. The second activity is the establishment of a professional project management structure for applied research activities. Steffenson et al

Figure D2.3.1 The Venture Nurturing Process: empirical findings



Source: Clarysse, Heirman and Moray, 2001

Third European Report on S&T Indicators, 2003

(1999) indicate that most start-ups are not spun off from the basic research department in the university. Instead they are associated with applied research centres linked to universities' basic research departments. Such a research centre affords the professor the opportunity to recruit senior researchers into a structure much more flexible than the classic university (Debackere, 2000). It is the senior researchers, rather than the professors, who have the profile of technical entrepreneurs initiating spin-offs. It would be hardly possible to encourage spin-off activity without this management structure. The third activity involves knowledge protection or intellectual property rights (IPR). It has been shown that 50% of research projects initiated at universities involve research that has already been patented or even published by others. Universities and research organisations should be sensitive about how the results of their research activities are protected and prized. Only when the research organisation itself has a well formulated and healthy knowledge protection strategy, can different commercialisation options be considered.

Business coaching

When the potential spin-off project reaches the transition phase, technological nurturing gives way to business coaching. Business coaching activities are classified into three groups: business plan development, start-up coaching and specialised advice or consulting. The first activity – business plan development – is probably the best known. Once the spin-off is established, a need arises for specialised consulting and coaching on the business process. Start-up coaching includes the strategic management of the commercial, financial and legal aspects of a technology venture. In large companies, the chief executive or a directors' committee takes care of such tasks, but in a technology start-up it is hardly possible to recruit such as person or team of persons (Clarysse and Moray, 2001). A high-tech start-up has specific needs not found in the businesses of the old economy. Therefore, a network of specialised advisers is needed to help the spin-off form a knowledge protection strategy, establish co-development contracts, recruit high-level engineers and scientists and set up a specific human resource and incentive system. For regions lacking an entrepreneurial base, it is critically important to attract the expertise of such specialised consultants into their areas.

Facility Management

Incubation facilities – affordable premises adapted to the needs of high-tech start-ups – is probably one of the most extensive knowledge resources in Europe, at least at the beginning of the spin-off funnel. As far back as 1984, the European Commission initiated Business Incubation Centres through structural funds. The nature of facility management also tends to evolve along the spin-off process. In the invention phase, start-ups need relatively small premises, including facility services such as reception, cleaners, network access, etc. Later on in their development they need more complex and difficult-to-find facilities located on science parks. Their increasing needs in terms of highly skilled human resources recruitment and of high-tech equipment make science parks indeed very attractive locations for the growing research based spin-off. Since most high-tech regions are quite densely populated, space for science parks has become hard to find.

Conclusions

Stimulation of research based spin-offs requires to take into account that spinning-off is a process and not a momentum. We identified three crucial conditions to create an environment that is fertile for spin-off activity: first, a sound science/technology base is needed, including research universities, public research organisations and embedded corporate laboratories. Second, financial resources are needed to support the spin-offs along the spin-off process. Third, knowledge resources (not only technological but also business knowledge) should be developed to support the spin-offs. This means that any public policy that wants to generate or stimulate spin-off activity should bear in mind that this can only create substantial returns if these three conditions are combined in an efficient way.

High-tech clusters have become a popular objective for regional innovation policy. It was argued in the paper that spin-offs, which are often referred to as the driving forces behind these clusters, are very dependent upon the local science/technology base which is usually provided by research universities, public research laboratories and embedded corporate labs. If this science/technology base is not already present, it will be very difficult if not impossible to develop this kind of knowledge cluster out of scratch. It is therefore not easy to understand why structural funds are used to stimulate high tech or at least knowledge-based entrepreneurship in underdeveloped regions where they do not have sufficient back up by a local science and technological base.

However, even if the science/technology base is present, it is no guarantee for a fertile spin-off environment. Along the spin-off process, the financial resources needed by the new venture change both in nature and size. In the invention phase, some form of stretched research grants that give the researcher some time and budget to validate his business idea might be sufficient. In the transition phase, small amounts of capital (250K euro - 500K euro) are needed complemented with subsidies to develop the prototype and to validate the growth expectation of the business. Unfortunately, most policy initiatives have exclusively been oriented towards the stimulation of formal venture capital and the creation of business angel networks. However, both are relatively unimportant in the transition phase of the spin-off process. The relatively low amounts of capital needed by these spin-offs in this phase and the inexperience to evaluate new technologies economically make them an inefficient and risky investment for most venture capitalists. It is only at the time that the growth expectations are validated that formal venture capitalists come into the picture. Especially in the transition phase during which these growth expectations need validation, financial resources have usually been lacking and continue to fall short despite several efforts which were undertaken in the recent past.

Both European and national actions are needed to correct for this market failure. One correction, as initiated in a number of countries, consists of using the experience present within the R&D granting institutes to perform the technological evaluation, and to extend their development grants to the transition phase of the spin-offs. This already decreases the risk for the private investor since he can trust the technical evaluation made by a third party. In addition, public/private partnerships might be needed to increase efficiency in the allocation of the invested amounts. Universities and research organisations can create with the help of private and public investors' funds that invest in companies[2].

Of course, in order to be credible towards these private partners, the universities and research organisations have to set up a professional technological venturing activity as well. Again government initiatives might be needed to encourage the universities to set up this kind of services. This can be done by taking these initiatives into account when the financial funds are divided among the universities (instead of only taking students or publications as an indicator to divide budgets). It is clear that interface services need to be supported to set up technology venturing activities. This means that also the regulatory framework with for instance a clear intellectual property law and fiscal policy towards royalties and extra earnings of researchers and professors at universities is needed. Next to opportunity seeking activities, these venturing activities also include the creation of professional management structures for applied and contract research. In Europe, very little experience is available with these structures. In different countries, the regulatory framework is lacking, while Europe might play a proactive role in the exchange of experiences.

Finally, any effective policy to encourage the commercialisation of research will need to integrate both different public departments and different networks of actors. First, the need to integrate different public departments is reflected in the fact that along the spin-off process different public agents with a very different cultural background are implicated. At the very start, the ministries of education and research have to take actions to encourage universities to engage into technology venturing activities and to stretch research grants. In a later phase, the ministry of economics will be involved to organise the financial conditions and maybe to subsidise the need for venture coaching. Technology policy will need to consider stretching development grants into the transition phase of start-ups. Second, an effective policy will have to bring very different networks into contact with each other: the network of government officials who evaluate technological subsidy projects is complementary to the one of the financial investors who are specialised in a financial/commercial due diligence of a business plan. One problem is that both networks seldom overlap, they do not know each other. The network of university professors and researchers has to be related to the network of the business managers. Again, both are complementary, but seldom overlap. Finally, the different networks grouping the financial resources has to be brought into contact with the network knowledge resources. There are only a few examples in the world where this mixture of networks is accomplished of which Silicon Valley is probably the most well-known.

Selected Bibliography

Ancona, D. & Caldwell, D (1992) 'Demography and design: predictors of new product team performance', *Organisation Science* 3, pp. 321-341.

Ancona, D. & Caldwell, D. (1992) 'Bridging the boundary: external activity and performance in organisational teams' *Administrative Science Quarterly* 37, pp. 634-665.

Ardichvili, A., et al. (2000) 'The Role of Angel Investors in the Assembly of Non-Financial Resources of new Ventures' *Frontiers of Entrepreneurship Research 2000*, pp. 244-257.

Autio, E. & Yli-Renko, H. (1998) 'New technology-based firms in small open economies – An analysis based on the Finnish experience' *Research Policy* 26, pp. 973-987.

Bozeman, B. (2000) 'Technology transfer and public policy: a review of research and theory' *Research policy* 29, pp. 627-655.

Branscomb, L.M. & Auerswald, P.E. (2001) *Taking Technical Risks. How innovators, Executives, and Investors Manage High-Tech Risks.*, The MIT Press, Cambridge Massachusetts.

Brown, S.L. and Eisenhardt, K.M. (1995) 'Product development: past research, present findings and future directions' *Academy of Management Review* 20 (2), pp. 343-378.

Caracostas, P. and Muldur, U. (1997) *La Société, Ultime Frontière. Une vision européenne des politiques de recherche et d'innovation pour le XXXIème siècle*, Commission européenne, Etudes, EUR 17655, OPOCE Luxembourg

[2] *In some countries this might require the removal of legal barriers that prohibit universities to engage in this kind of activity.*

Chiesa, V. and Piccaluga, A. (2000) 'Exploitation and diffusion of public research: the general framework and the case of academic spin-off companies' *R&D Management* 30, pp. 329-340.

Clarysse, B., Degroof, J.J. and Heirman, A. (forthcoming) *Analysis of the Typical Growth Path of Technology-based Companies in Life Sciences and Information Technology, and the role of different sources of innovation financing*, European Commission, Directorate-General Entreprise.

Clarysse, B., and Duchêne, V. (2000) 'Het innovatiebeleid in Ierland als geïntegreerd element van het ontwikkelingsbeleid: van buitenlandse investeringen naar 'home spun growth'' *IWT-Study* no. 34.

Clarysse, B., Heirman, A. and Degroof, J. (2000a) 'An institutional and resource based explanation of growth patterns of research based spin-offs in Europe' *Frontiers of Entrepreneurship Research 2000*, pp. 545-559.

Clarysse, B., Heirman, A. and Degroof, J. (2000b) 'Influence of the environment on the starting configuration of research based spin-offs in Europe', *STI review*, OECD/2000 (accepted for publication).

Clarysse, B., Heirman A., Degroof, J. (2001) *Het fenomeen spin-off in België*, ISBN: 806488.

Clarysse, B., Heirman, A. and Moray, N. (2001) 'Transferring Technology by Spinning Off Ventures: Towards an Empirically Based Understanding of the Spin Off Process', *Working Paper Gent University*.

Clarysse, B. and Moray, N. (forthcoming 2003) 'A process study of entrepreneurial team formation: the case of a research-based spin-off', *Journal of Business Venturing, special issue on technological entrepreneurship*, In Print.

Coviello, N. and McAuley, A. 1999) 'Internationalisation and the Smaller Firm: A Review of Contemporary Empirical Research', *Management International Review* 39(3), pp. 223-256.

Debackere, K., (2000) 'Managing academic R&D as a business at K.U. Leuven: context, structure and process', *R&D Management* 30, pp. 323-328.

Eisenhardt, K. (1989) 'Building theories from case study research', *Academy of Management Review* 14 (4), pp. 532-550.

Eisenhardt, K. (1989) 'Making fast strategic decisions in high-velocity environments', *Academy of Management Journal* 32 (3), pp. 543-576.

Eisenhardt, K. (1989) 'Agency Theory: an assessment and review', *Academy of Management Review* 14(1), pp. 57-74.

European Commission. (1994) *Second European Report on S&T Indicators*, Luxembourg, OPOCE

European Commission. (1995) *Green Paper on Innovation*.

GEM (2000) *General Entrepreneurship Monitor*, Belgium Report.

Gompers, P. (1998) 'Venture capital distributions: Short-run and long-run reactions', *The Journal of Finance* 53, Iss. 6; pp. 2161-2184.

Hellmann, T. and Puri, M. (2000) 'The Interaction Between Product Market and Financing Strategy: The Role of Venture Capital', *The Review of Financial Studies* 13 (4), pp. 959-984.

Kazanijan, R.K. (1988) 'Relation of dominant problems to stages of growth in technology-based new ventures', *Academy of Management Journal* 31 (2), pp. 257-279.

Leleux, B., Surlemont, B. (2000) 'Angel Networks for the 21st Century: A Review of Best Practices in Europe and the USA', *Frontiers of Entrepreneurship Research 2000*, p. 288.

Lerner, J. and Gompers, P. (1999) *The Venture Capital Cycle. Cambridge*, MA, MIT Press.

Mustar, P. (1995) *The Creation of Enterprises by Researchers: Conditions for Growth and the Role of Public Authorities. High Level Workshop on SMEs: Employment*, Innovation and Growth, OECD, Washington, 16.–17 June.

Mustar, P. (1997) 'Spin-off enterprises. How French academics create hi-tech companies: the conditions for success and failure', *Science and Public Policy*, 24, pp. 37-43.

Nlemvo, F., et al. (2000) *Technology transfer from university to industry by spinning off new firms: an assessment of the Belgian situation*, 11th Nordic Conference RENT, Aarhus.

OECD. (1999) *Special issue on spin-offs*, STI Review.

Office of Science and Technology (2001) *Summary Report on the First Year of Operation of the Fifteen University Challenge Seed Funds. 9*.

Roberts, E.B. (1991) *Entrepreneurs in hightechnology. Lessons from MIT and beyond*, Oxford University Press, New York.

Roberts, E.B., Malone, D.E. (1996) *Policies and structures for spinning off new companies from research and development organisations*. RandD Management 26, pp.17-48.

Sahlman, William A. (1990) 'The structure and Governance of Venture-Capital Organisations', *Journal of Financial Economics* 27 (2), pp. 473-522.

Sahlman, William A. (1990) 'Why Sane People Shouldn't Serve on Public Boards', *Harvard Business Review* 68(3), pp. 28-33.

Saxenian, A. (1994) *Regional advantage. Culture and competition in Silicon Valley and Route 128*, Harvard University Press.

STI. (1996) *The White Paper*. p. 10.

Segal Quince Wicksteed. (2000) *The Cambridge Phenomenon Revisited Part One*. SQW Ltd.

Segal Quince Wicksteed. (2000) *The Cambridge Phenomenon Revisited Part Two*. SQW Ltd.

Smilor, R.W., Gibson, D.V. and Dietrich, G.B. (1990) 'University Spin-out Companies: Technology Start-Ups from UT-Austin', *Journal of Business Venturing* 5, pp. 63-76.

Steffenson, M., et al. (1999) 'Spin-offs from research centres at a research university', *Journal of Business Venturing* 15, pp. 93-111.

Storey, D.J. and Tether, B.S. (1998) 'New technology-based firms in the European Union: an introduction', *Research Policy* 26, pp. 933-946.

Suchman, Mark C. (1995) 'Managing legitimacy: Strategic and institutional approaches', *The Academy of Management Review* 20 (3), pp. 571-611.

Surlemont B, Pirnay F., Nlemvo F. (2001) *A stage model of academic spin-off creation. Techovation* (paper accepted for publication).

Teece, David J. (1986) 'Profiting from Technological Innovation: Implications for Integration, Collaboration, Licensing and Public Policy', *Research Policy* 15 (6), pp. 285-306.

CHAPTER 4

Human Resources in Science & Technology

"People are Europe's main asset and should be the focal point of the Union's policies. Investing in people and developing an active and dynamic welfare state will be crucial both to Europe's place in the knowledge economy and for ensuring the emergence of this new economy does not compound the existing social problems of unemployment, social exclusion and poverty."

European Council Lisbon, 2000, paragraph 24

Human resources play a crucial role in knowledge production and, therefore, for economic and technological development. Because people both produce and convey knowledge, the availability and quality of human resources in S&T form key elements of today's global knowledge-based economy. Technology creates jobs and facilitates the sustainable production of goods and services, which both bring with them a rise in living standards and have an overall positive impact on social well-being.

In a knowledge-based economy, where ideas and knowledge are central to innovation and growth, investment in human resources is an important factor in remaining competitive. This investment must take place at national and regional levels, as well as at enterprise level. However it takes time to produce highly skilled human resources but investment in education and learning reaps great benefits. Investment in areas such as the mobility of skilled people, however, can have both positive and negative impact on a country's human capital base.

This means that it is necessary not only to maintain a certain level of production of human resources in S&T (for example, through education), but also to monitor trends in order to be able to anticipate shortfalls in supply and non optimal utilisation of these scarce and highly skilled resources. How to preserve scientific and technological excellence and progress in Europe are challenges facing both individual countries and EU policy-makers.

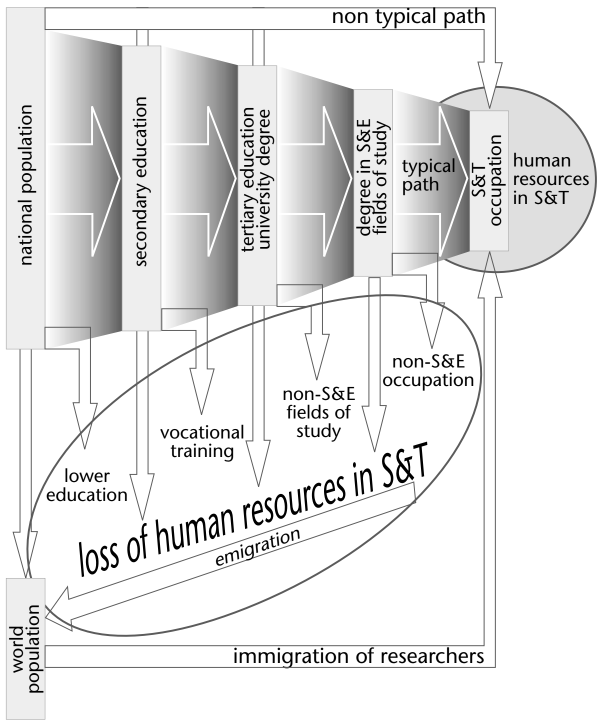
The OECD Canberra Manual on "The Measurement of Human Resources in Science and Technology" produced in collaboration with the European Commission (Eurostat and DG Research) presents two key approaches to measuring human resources in S&T:

- measurement of human resources based on formal qualifications in S&T; and
- measurement of human resources based on occupations in S&T.

Human capital can be measured based on the highest level of qualification attained. This approach, however, has limitations in that it does not, for example, take into account non-formal qualifications such as in-service training or skills acquired through networking and personal growth. Another popular approach is to evaluate and grade the economic activities of a person – the type of work is used to define skills levels. In this way an occupation is classified as "high skill" and a person in such an occupation is rated as "highly skilled".

The following figure 4.0.1 shows the education pipeline for human resources in S&T. The typical path goes via secondary education and tertiary studies. After getting a first degree from a university, ideally in science and engineering (S&E), followed by a PhD, typically the individual concerned takes up an S&T post in either research, teaching or another occupation requiring a high level S&T qualification.

Figure 4.0.1 The education pipeline for human resources in S&T



Source: DG Research
Third European Report on S&T Indicators, 2003

In principle, the whole population of a country forms the pool of potential human resources in S&T. But with every further step in the education pipeline, some people qualify more for S&T and others are excluded. For instance people only achieving a low level of education or a higher level but in non-S&E fields diminish the potential pool of human resources in S&T. Non typical career paths such as an occupation as a researcher without usual formal educational qualifications in S&T remain exceptions.

A second group of people who are lost from a country's pool of human resources in S&T are those who emigrate, possessing S&T qualifications or others leaving S&T occupations. When taken together with the inflow of immigrants qualified in S&T or entering into S&T occupations, the overall effect of migration on the national pool of human resources in S&T can be seen.

A third outflow from the pool of human resources in S&T results from the ageing and death of researchers. This outflow is also important, but not displayed in the figure. There is also a small outflow from the pool when unqualified personnel performing S&T occupations leave the sector.

This chapter examines human resources in S&T at different levels in the education pipeline. In Section I, key statistics on human resources in S&T are presented, such as indicators on researchers and graduates. They are provided for the 15 EU Member States and for comparison, statistics for the US and Japan are also included. In Section II reasons why the EU may be facing a shortage of human resources in S&T are discussed, supported by an analysis of education figures and employment figures. Section III analyses investment in education as a possible starting point for increasing the knowledge base of society and therefore expanding the pool of human resources in S&T. Section IV shows how the pool of people with S&T skills in the EU is topped up by foreign-born researchers taking advantage of the increasing international mobility of highly skilled personnel. Section V deals with augmenting the pool of human resources in S&T by better integrating and involving women, who are not yet utilised to the full and are even, to a certain extent, an excluded section of the population. (Its political implications are presented in the subsequent dossier on women in science.)

Section I Human resources in S&T in the EU, US and Japan

This section starts off by analysing key indicators used to quantify human resources in S&T. The most well known and highly developed indicators on the use of human resources for technological and economic purposes are the numbers of researchers and other R&D personnel found in the different sectors, such as in higher education, government, and business enterprise. This is followed by an analysis of the production side, as well as of the number of graduates in the fields of study (science and engineering – S&E) that are most relevant to S&T at university and postgraduate level. Finally, the figures on researchers and S&E graduates are brought together to try to draw conclusions about possible shortages.

1. Researchers and other R&D personnel

Within R&D personnel, the distinction is made between researchers – i.e. researchers, scientists and engineers (RSEs) – and technicians and other support staff[1]. Both groups are covered in the total number of R&D personnel. The two indicators that can be used for measuring human resources in S&T are the total number of R&D personnel; this is an input figure for all R&D related activities; and the number of researchers.

Number of researchers in the Triad

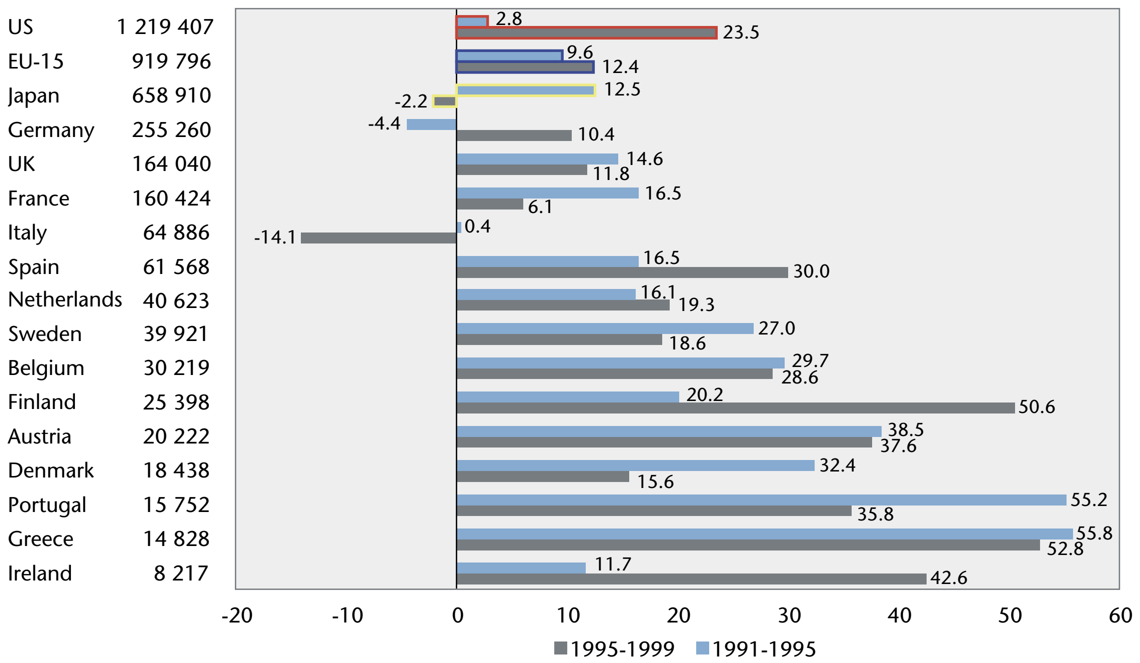
Figure 4.1.1 shows the total number of researchers in 1999 for the Triad of the US, Japan and the EU-15 Member States. The growth rates for the 1990s are also shown and compared with the total numbers.

In 1999, approximately 920 000 people were working in the EU as research scientists and engineers (RSEs, referred to as researchers in the rest of this chapter). This is about 300 000 less than the total number of researchers in the US, and about 260 000 researchers more than in Japan. Within the EU, the largest numbers of researchers are in Germany, the UK and France, which between them host over 60% of all the researchers in the EU Member States. Italy and Spain follow but with each of them less than half the number of researchers of France. It is important to keep in mind this concentration within three EU countries when considering other aspects of R&D and S&T in general.

During the 1990s, the number of researchers increased in all the countries surveyed, although at varying rates. Over the decade, the number of researchers in the EU rose by 24% with a higher rate of growth recorded in the second half of the decade. This was slightly below the 26% increase in

[1] *For the various definitions of human resources in S&T cf. the methodological annex at the end of this report.*

Figure 4.1.1 Total number of researchers 1999 and total growth in % (1991-1999)



Source: DG Research
Data: OECD, MSTI database
Note: Number of researchers are given in field-time equivalent (FTE). No data for L, which is not included in the EU average. 1999: data for IRL, I, UK, US are estimated; 1991: data for NL and P are estimated. Estimates: DG Research.

Third European Report on S&T Indicators, 2003

researchers in the US, where almost all of the growth took place in the second half of the decade. In Japan, the first half of the decade saw the number of researchers growing by 12.5%, but a drop of 2% occurred in the second half. This resulted in growth of 10% over the whole period.

In most EU Member States, the total number of researchers increased during the 1990s. Only Italy suffered an overall decrease of 14% due to a drop in the second half of the decade. The highest overall rates of growth were recorded in Greece, Portugal and Austria. In Spain, the Netherlands, Finland and Ireland, there was more growth in the second half of the decade. In Germany, the negative growth rate of the beginning of the 1990s was followed by a positive one at the end.

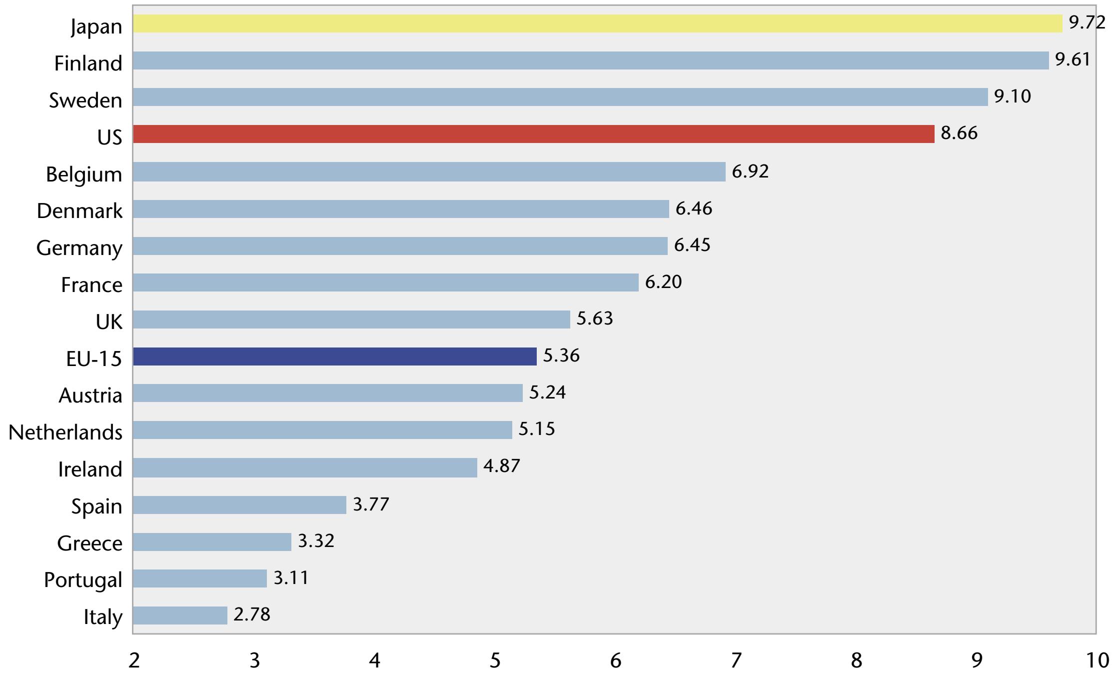
Share of researchers in the labour force

European countries differ considerably in terms of their population and labour force sizes, so it can be misleading to use the percentage share of researchers in the population as being representative of national or regional R&D effort. It is more useful to look at how many people are actively involved in R&D, and establish the number of full-time equivalent (FTE) researchers relative to the total number of people (headcount – HC) in the labour force. This indicator signifies the relative importance of research jobs in the labour market and can therefore be seen as an appropriate indicator for looking at the knowledge base of an economy.

In 1999, the EU reported 5.4 researchers per 1 000 in the labour force. Japan is the top country in the Triad, reporting 9.7 researchers per 1 000 labour force in 1999. The US reported 8.7 researchers per 1 000 in its labour force. Among EU Member States, Finland and Sweden rank higher than the US. Another group of EU countries – including Belgium, Denmark, Germany, France, the UK, Austria, the Netherlands and Ireland – has between five and seven researchers per 1 000 labour force, which is around or slightly above the EU average. Spain, Greece, Portugal and Italy come in below the EU average with only between 2.5 and 4 researchers per 1 000 labour force (figure 4.1.2).

In the 1990s, the number of researchers per 1 000 labour force increased most markedly in Greece and Portugal, where increases of more than 100% were recorded. There was over 50% growth in Austria, Finland, Denmark, Sweden and Belgium. The other, and mostly larger European countries – Spain, Ireland, the UK, the Netherlands, France, Germany and Italy – all had total growth rates well under 50%. France and Germany showed growth below the EU average, but so did the US and Japan. Italy had even negative rates (figure 4.1.3).

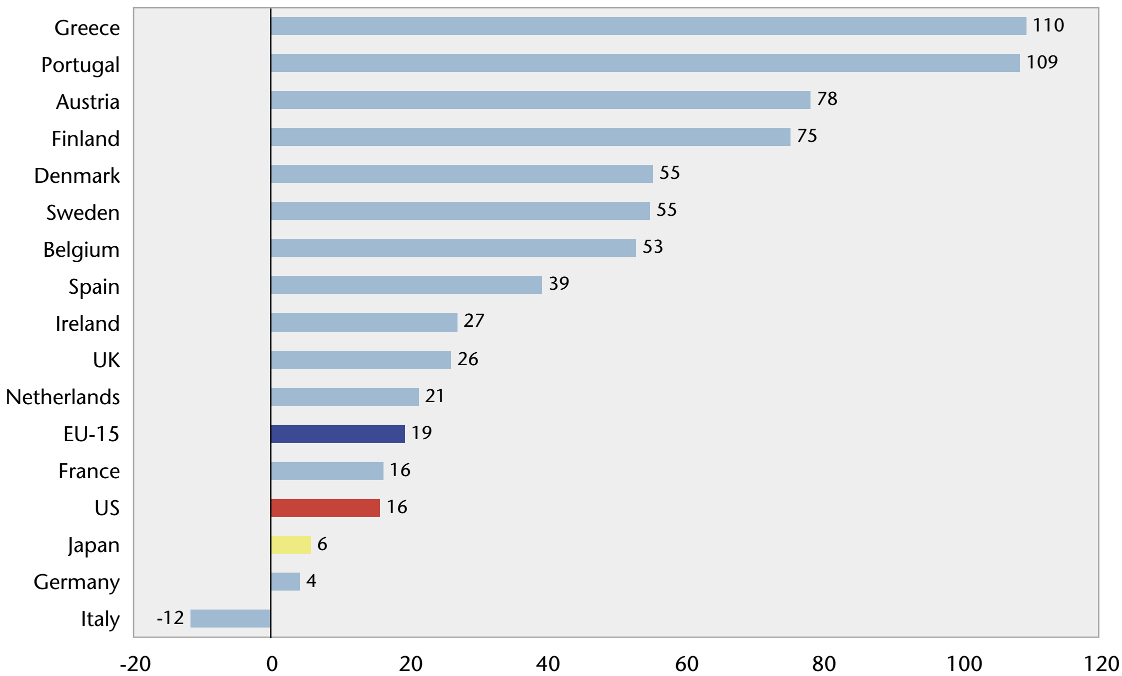
Figure 4.1.2 Researchers per 1000 labour force (1999)



Source: DG Research
Data: Researchers, labour force JP/US: OECD, MSTI database; labour force EU: Eurostat
Note: Total numbers are in FTE; data for labour force are HC. No data for L, which is not included in the EU average.

Third European Report on S&T Indicators, 2003

Figure 4.1.3 Researchers per 1000 labour force: total growth in % (1991-1999)



Source: DG Research
Data: Researchers, labour force JP/US: OECD, MSTI database; labour force EU: Eurostat
Note: Total numbers are FTE; data for labour force are HC. No data for L, which is not included in the EU average.

Third European Report on S&T Indicators, 2003

Distribution of researchers by sector

Table 4.1.1 shows how the number of researchers in the business, government, and higher education sectors of the economy varies across the different countries.

In 1999 in the business sector, the US leads with more than one million researchers, this is more than double the number recorded in either the EU or Japan. Germany leads in the EU with 150 150 researchers, next come the UK (92 133) and France (75 390). In the government sector, the EU has the largest number of researchers with 130 636. This is almost three times more than the 46 098 reported in the US. Within the EU, Germany leads with 38 415 researchers in the government sector, followed by France with 25 187. Japan, with 30 987, has fewer researchers in this sector than Germany. In the higher education sector, the EU, with 315 212, also reported more researchers than the US and Japan. It is interesting to note that, in the higher education sector, Japan comes in above the US (136 936) with 178 418 researchers. Germany (66 695) once again is the leading EU Member State, followed by France and the UK.

When proportions of researchers in the three sectors are examined, the regional differences are rather striking. The EU has 34% of its researchers in the higher education sector and with 14%, the EU Member States have the highest proportion of researchers in the government sector in the Triad. In the US and Japan, it is the business sector that dominates: it employs

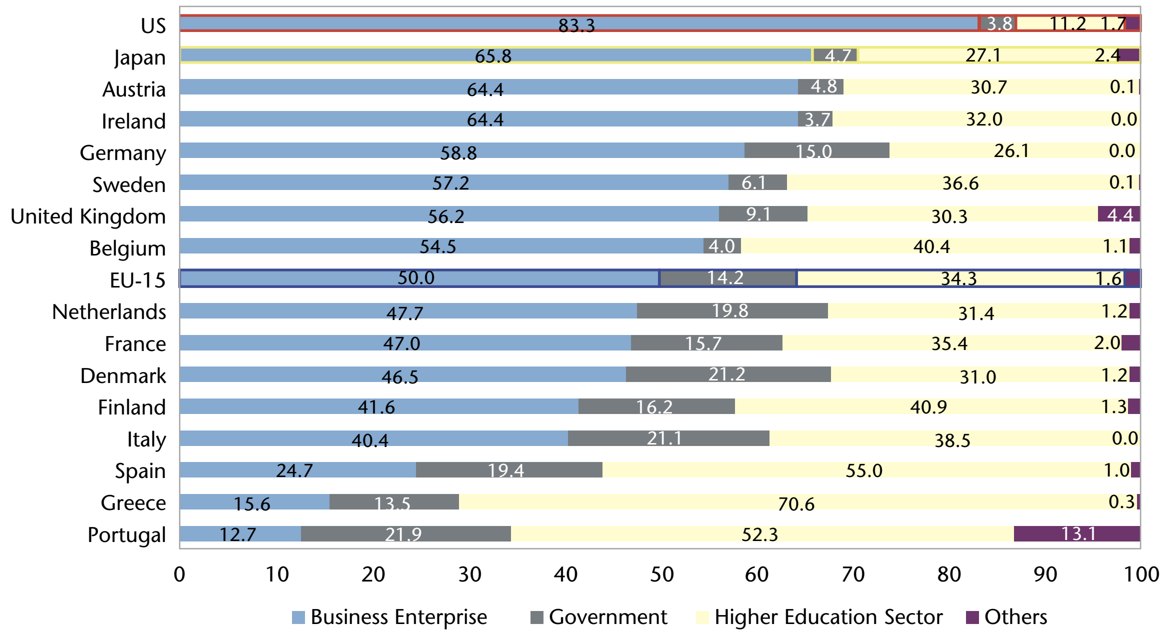
Table 4.1.1 Business, government and higher education researchers: absolute numbers (1999)

	Number of researchers in 1999		
	Business Enterprises	Governmental institutions	Higher education sector
Belgium	16 476	1 210	12 209
Denmark	8 575	3 918	5 722
Germany	150 150	38 415	66 695
Greece	2 315	2 000	10 471
Spain	15 178	11 934	33 840
France	75 390	25 187	56 717
Ireland	5 290	300	2 627
Italy	26 192	13 697	24 997
Netherlands	19 359	8 048	12 740
Austria	13 021	965	6 209
Portugal	1 994	3 445	8 243
Finland	10 555	4 115	10 395
Sweden	22 822	2 423	14 623
UK	92 133	14 980	49 724
EU-15	459 450	130 636	315 212
US	1 015 700	46 098	136 936
Japan	433 758	30 987	178 418

Source: DG Research
Data: OECD, MSTI database
Notes: Absolute numbers are in FTE. No data for L, which is not included in the EU sum. Data for EU sum, A, UK and US are estimated or provisional. Estimates: DG Research

Third European Report on S&T Indicators, 2003

Figure 4.1.4 Business, government and higher education sector researchers: shares of total researchers in % (1999)



Source: DG Research
Data: OECD, MSTI database
Note: Total numbers are in FTE. No data for L, which is not included in the EU average. Data for EU average, A, UK and US are estimated or provisional. Estimate: DG Research.

Third European Report on S&T Indicators, 2003

more than four fifths of researchers in the US and more than two thirds of researchers in Japan (figure 4.1.4).

The EU, of course, is not homogeneous and there are significant differences among Member States. The highest proportions of researchers in the business sector – around 60% – are found in Austria, Ireland, Germany, Sweden, the UK and Belgium. The lowest proportions are found in Spain, Greece and Portugal and in these three countries, the percentage of researchers in higher education is high, exceeding 50%.

Proportion of researchers in total R&D personnel

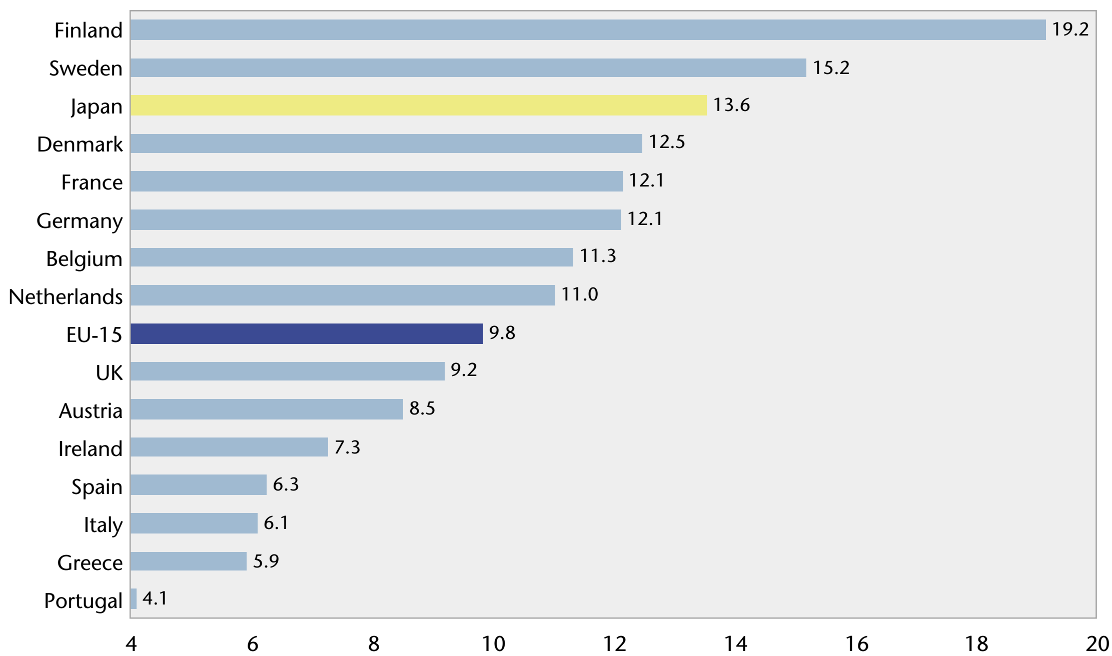
As stated earlier, researchers are not the only category of employees engaged in R&D activities. It is worthwhile to have a closer look at total R&D personnel and the percentage of researchers within total R&D personnel. Figures 4.1.5 and 4.1.6 show the number of R&D personnel per 1 000 labour force and the proportions of researchers in relation to total R&D personnel for the year 1999.

Once again, Finland and Sweden lead with 19.2 and 15.2 full-time equivalent R&D personnel per 1 000 labour force, respectively. Japan follows with about 13.6 per 1 000. This is significantly higher than the EU average of 9.8 per 1 000. The southern European countries, Spain, Italy, Greece and Portugal, again have the lowest numbers with only between 4.1 (Portugal) and 6.3 full-time R&D personnel per 1 000 labour force (figure 4.1.5).

The percentage of researchers within total R&D personnel also varies from Member State to Member State. Portugal and Ireland have the highest proportion, with 75.7% and 66.9%, respectively, which places them on a par with Japan's 71.7%. The values for the other EU Member States vary from 61.5% (Austria) to 45.5% (Italy), the EU average being 54.4% (figure 4.1.6).

Remarkable differences also exist between the different sectors employing R&D personnel (figure 4.1.7). In the EU Member States, the highest percentage of researchers relative to total R&D personnel – 65% – is in the higher education sector. The business and government sectors show lower proportions with around 49% and 51%, respectively. In the Member States, the range of shares is between 90% in the Portuguese higher education sector and 34% in the Irish government sector.

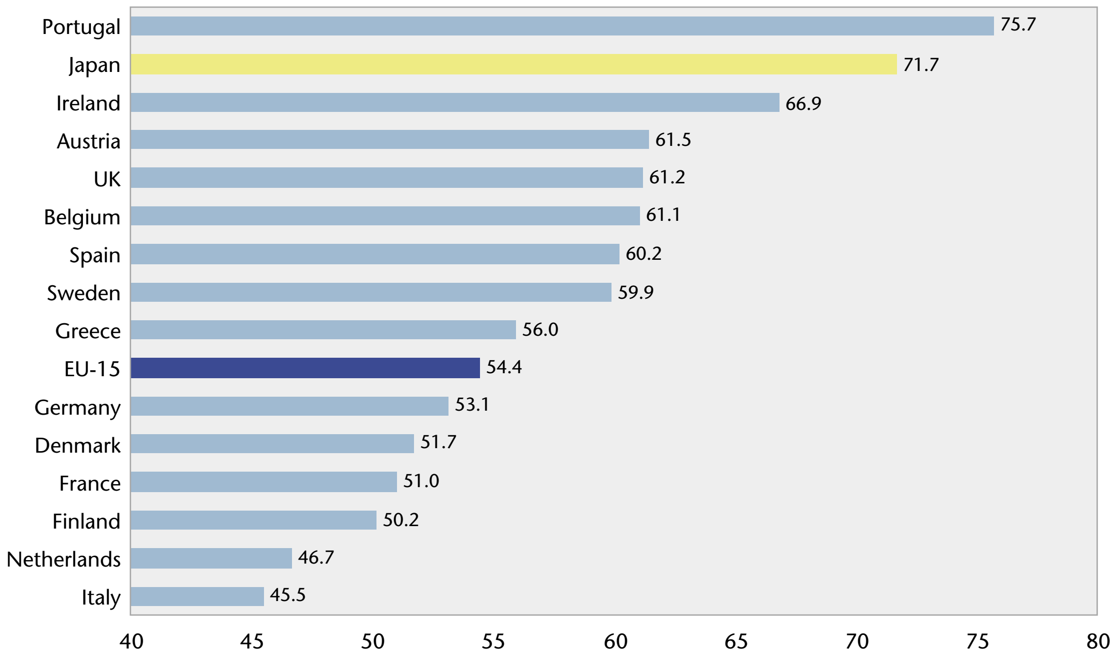
Figure 4.1.5 R&D personnel per 1000 labour force (1999)



Source: DG Research
Data: R&D personnel, labour force JP: OECD, MSTI database; labour force EU: Eurostat
Note: Data for R&D personnel are in FTE; data for labour force are in HC. No data for L or US; L is not in the EU average. R&D personnel: Data for EU average, A and UK are estimated. Estimates: DG Research.

Third European Report on S&T Indicators, 2003

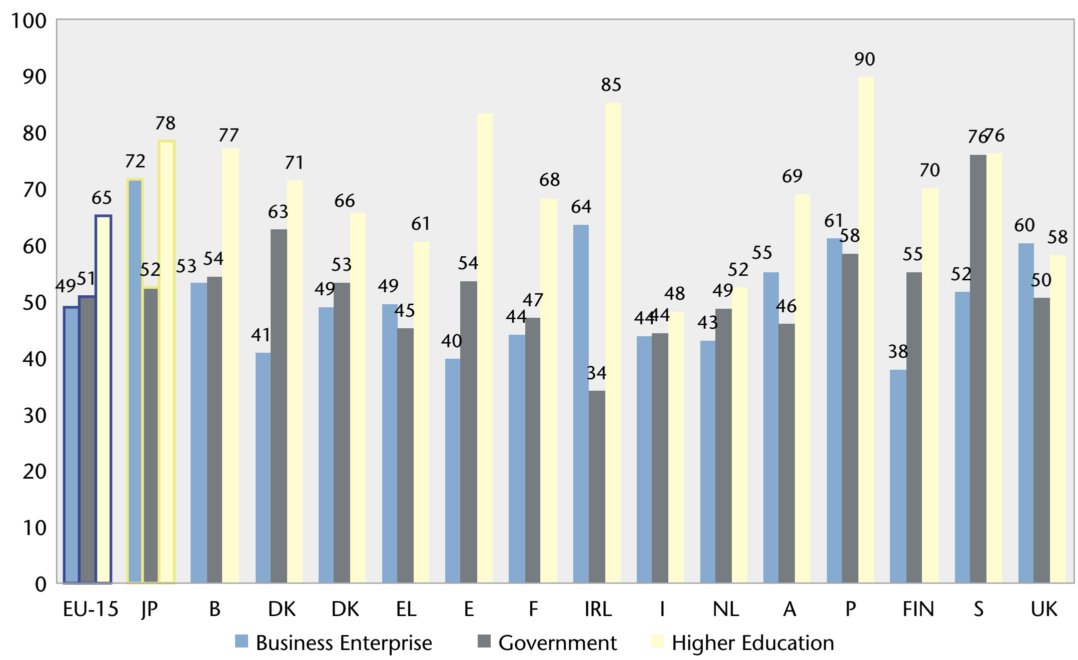
Figure 4.1.6 Researchers as shares of R&D personnel, totals (1999)



Source: DG Research
Data: R&D personnel, researchers, labour force JP: OECD, MSTI database; labour force EU: Eurostat
Note: Data for R&D personnel and researchers are in FTE. No data for L and US; L is not in the EU average. Data for EU average, A and UK are estimated. Estimates: DG Research.

Third European Report on S&T Indicators, 2003

Figure 4.1.7 Researchers as shares (in %) of R&D personnel by sector (1999)



Source: DG Research
Data: MSTI database
Note: Data for R&D personnel and researchers are in FTE. No data for L or US. L is not in the EU average. Data for EU average, A and UK are estimated. Estimates: DG Research.

Third European Report on S&T Indicators, 2003

2. S&E graduates

One way of increasing a country's reserves of human resources in S&T is to produce science and engineering graduates. Degrees in S&E fields of study, especially PhDs, formally qualify their holders for employment as researchers (cf. annex on methodology).

Graduates in S&E produced by the EU Member States

In 2000, the EU produced a total of 2.14 million graduates (table 4.1.2), compared to the US's 2.07 million graduates and just over 1.1 million graduates produced by Japan. Five EU Member States accounted for almost 80% of EU graduates. The UK dominated, on its own contributing 504 000, closely followed by France (500 000), Germany (300 000), Spain (260 000) and Italy (190 000).

Among the more than 2 million graduates in the EU in 2000, just over one quarter (555 647) were in science and engineering (S&E) fields of study. The largest proportion of graduates (1 123 519 equivalent to 52%) came from social sciences, humanities and education fields. 351 814 (equivalent to 16% of the total) graduated with degrees in health and food sciences.

Factors that provide a degree of insight into the relative importance that is attached to science, technology and innovation in any given country are participation rates in science and engineering post-secondary education programmes, S&E graduates as a share of total graduates, and the growth patterns of S&E graduates. It is also useful to look at science and engineering separately and at their different participation rates in the different EU Member States and between the EU, the US and Japan. In 2000, in the EU taken as a whole, there were more graduates in engineering (300 475 representing 14%) than in science (255 172 equivalent to 12%). The EU, with its 26% of S&E graduates, comes out higher than Japan (21%). The US comes out with the lowest proportion (17%) in the Triad (figure 4.1.8).

The highest proportions graduating in S&E fields of study are in Ireland (35%), Sweden (31%), France, Austria and Finland (all 30%). Germany, Spain, the UK and Italy are at the EU average of 26%. All the other countries are below 20% and thus similar to the levels seen in the US (17%) and Japan (21%).

Among the S&E graduates, it is Ireland (22%), the UK and France (both 15%), where science graduates account for most of the S&E graduates. The shares of engineering graduates are high in Austria, Finland (both 23%) and Sweden (21%). In Japan, engineering is, with a share of 19%, also clearly dominant – especially compared to the low 2% in science. The US data present a more balanced picture with 9% of the graduates in science and 8% in engineering. This equilibrium can also be seen in France with a level of 15% for each discipline.

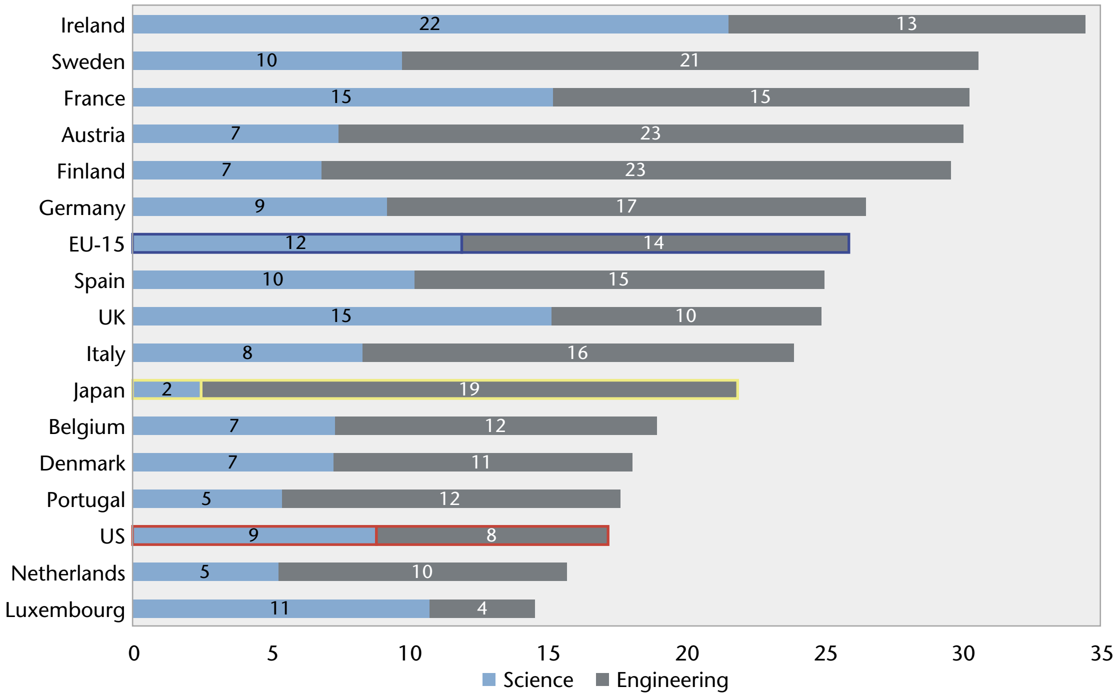
Table 4.1.2 Graduates (ISCED 5 and 6) by fields of study: total numbers (2000)

	Totals (all fields of study)	Science	Engineering	*S&E (Science + Engineering)*	Health and Food	Social Science/ Humanities/ Education
Belgium	68 225	5 013	7 906	***12 919***	15 208	38 735
Denmark	33 188	2 419	3 579	***5 998***	10 292	15 871
Germany	302 094	27 871	52 174	***80 045***	87 193	121 359
Spain	260 225	26 496	38 584	***65 080***	37 011	145 188
France	500 079	76 052	75 387	***151 439***	41 397	288 179
Ireland	42 009	9 057	5 415	***14 472***	3 995	22 168
Italy	190 280	15 841	29 689	***45 530***	36 084	108 124
Luxembourg	680	73	26	***99***	:	538
Netherlands	79 416	4 218	8 254	***12 472***	19 060	45 669
Austria	24 981	1 864	5 642	***7 506***	3 331	13 109
Portugal	58 456	3 173	7 148	***10 321***	9 143	36 813
Finland	38 075	2 600	8 674	***11 274***	9 373	14 960
Sweden	42 391	4 146	8 824	***12 970***	9 748	18 632
UK	504 081	76 422	49 199	***125 621***	69 979	254 712
EU-15	2 143 500	255 172	300 475	***555 647***	351 814	1 123 519
USA	2 066 595	169 311	179 238	***348 549***	322 758	1 301 199
Japan	1 107 332	25 021	209 808	***234 829***	128 157	541 431

Source: DG Research
Data: Eurostat
Notes: No data for EL which is not in the EU average. US and JP: 1998

Third European Report on S&T Indicators, 2003

Figure 4.1.8 S&E graduates as percentages of all disciplines 2000



Source: DG Research
Data: Eurostat/OECD
Note: No data for EL which is not included in the EU average. Data for DK, F, I and FIN refer to 1999.

Third European Report on S&T Indicators, 2003

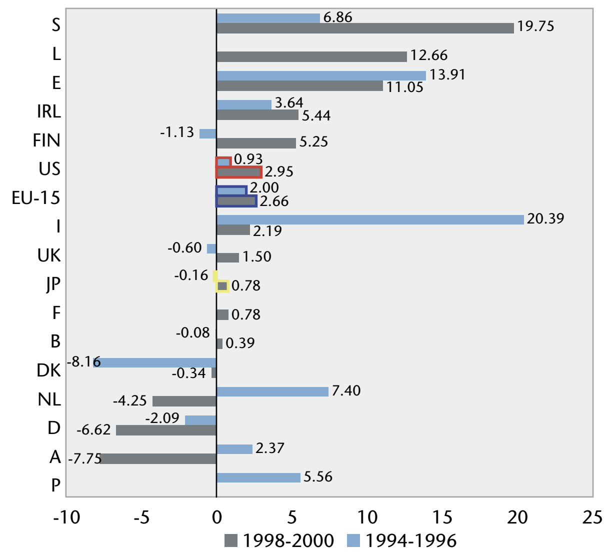
Dynamics of the number of graduates in S&E

The number and proportion of S&E graduates changed considerably during the 1990s. Figure 4.1.9 shows growth rates for 1994 to 1996, which were calculated according to the old International Standard Classification of Education (ISCED) 1976 classification, while the growth rates for 1998 to 2000 were determined by using the new ISCED 1997 classification.

Between 1998 and 2000, Sweden, Luxembourg and Spain had the highest growth rates (between 10 and 20%) per year of the countries surveyed. Ireland and Finland follow with 5%, while Italy, the UK, France, Belgium and Denmark are below the EU average of 2.7%, as is Japan. The US is slightly above the EU average (3%). Remarkably negative annual growth rates of -4, -7 and -8%, respectively, are recorded for the Netherlands, Germany and Austria.

Average annual growth rates calculated for 1994 to 1996 were rather different. The EU average of 2% was higher than the growth rates of the US (0.9%) and Japan (-0.2%). Italy, Spain, the Netherlands, Sweden and Portugal all had significant growth with average annual rates of between 20 and 6% in the period regarded. The UK, Finland, Germany and Denmark all experienced annual declines of between 0.6 and 8%.

Figure 4.1.9 Graduates in S&E: Average annual growth rates in % (1994-1996 and 1998-2000)



Source: DG Research
Data: Eurostat
Note: 1998-1999: No data for EL, P, which are not in the EU average. Data for DK, F, I and FIN refer to 1998-1999; 1995-1996: No data for EL, F, which are not in the EU average. No time series for B because of different populations covered (Flemish community and total Belgium). B is not in the EU average.

Third European Report on S&T Indicators, 2003

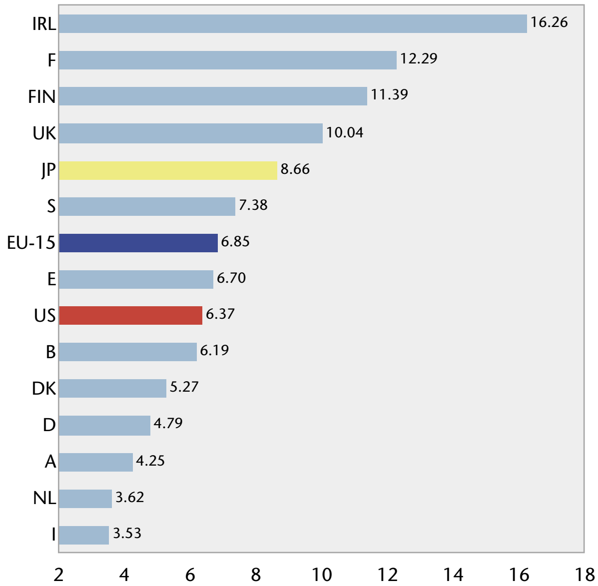
Proportion of S&E graduates in the younger population

Normalised for population size, the data give a better idea of the distribution of S&E graduates and postgraduate students in the relevant age groups.

In the EU in 2000, 6.9 per 1 000 people aged 20 to 34 earned a degree in S&E (figure 4.1.10). This is higher than the US (6.4 per 1 000), but below the 8.7 in 1 000 rate reported for Japan. The leading EU Member State is Ireland with 16.3 per 1 000, followed by France with 12.3, Finland (11.4), the UK (10) and Sweden (7.4). The other EU Member States are all below the EU average, with the lowest ratios of around 4 per 1 000 reported in Austria, the Netherlands, and Italy.

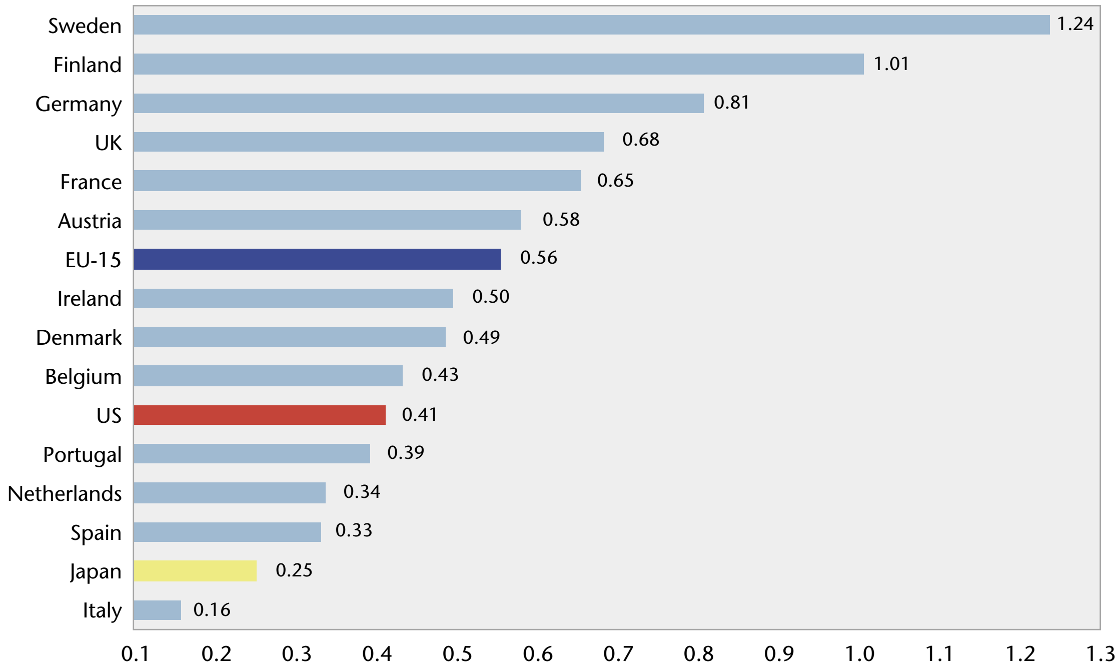
In the EU, about 0.56 per 1 000 people aged 25 to 34 obtained a PhD in S&E in 2000 (figure 4.1.11). The EU figure is above the US rate of 0.41 and above the rate of 0.25 in Japan. Among the EU Member States, Sweden has the highest rate with 1.24 new PhDs in S&E per 1 000 in the age group. Finland follows with 1.01 and Germany is next with 0.81 S&E PhDs awarded per 1 000 in the age group. The lowest ratios are found in Italy, which reports a rate of 0.16 and is thus even below Japan. The other EU Member States reported rates of between 0.33 (Spain) and 0.68 (UK).

Figure 4.1.10 S&E graduates per 1000 population aged 20-34 in 2000



Source: DG Research
Data: Eurostat; Population data EU: Eurostat, NewCronos database; Population data US and JP: United Nations
Note: No data on S&E graduates for EL, L and P, which are not in the EU average.
Data for DK, F, I and FIN refer to 1999.
Third European Report on S&T Indicators, 2003

Figure 4.1.11 PhDs in S&E per 1000 in the age group 25-34 in 2000



Source: DG Research
Data: Eurostat; Population data EU: Eurostat, NewCronos database Population data US, JP: United Nations
Note: No data on PhD for EL and L, which are not in the EU average. Data for DK, F and I refer to 1999.
Third European Report on S&T Indicators, 2003

If one, therefore, looks at human resources in S&T from the perspective of production rather than of employment, the US is no longer the ideal performer, but only a rather average player. The EU has strengths in several countries, the best examples being Ireland and France, for higher education in S&E, and Sweden and Finland, for the production of PhDs in S&E.

3. Researchers and S&E graduates: Potential shortages identified

The data in the section on the share of researchers in the labour force showed the US in the lead along with Japan and demonstrated that the two best-performing EU countries, Finland and Sweden, were at comparable level. How many researchers does the EU as a whole need to match the high levels achieved by these countries? This question was raised at the Lisbon Summit, where a political goal of becoming “the most dynamic and competitive knowledge-based economy in the world” was articulated. In order to have the same proportion of researchers in the labour force as the high performing US, the EU needs an additional 550 000 researchers by 2010. This is equivalent to roughly 50 000 extra researchers per year with the proviso that the US does not increase its proportion of researchers in the short to medium term.

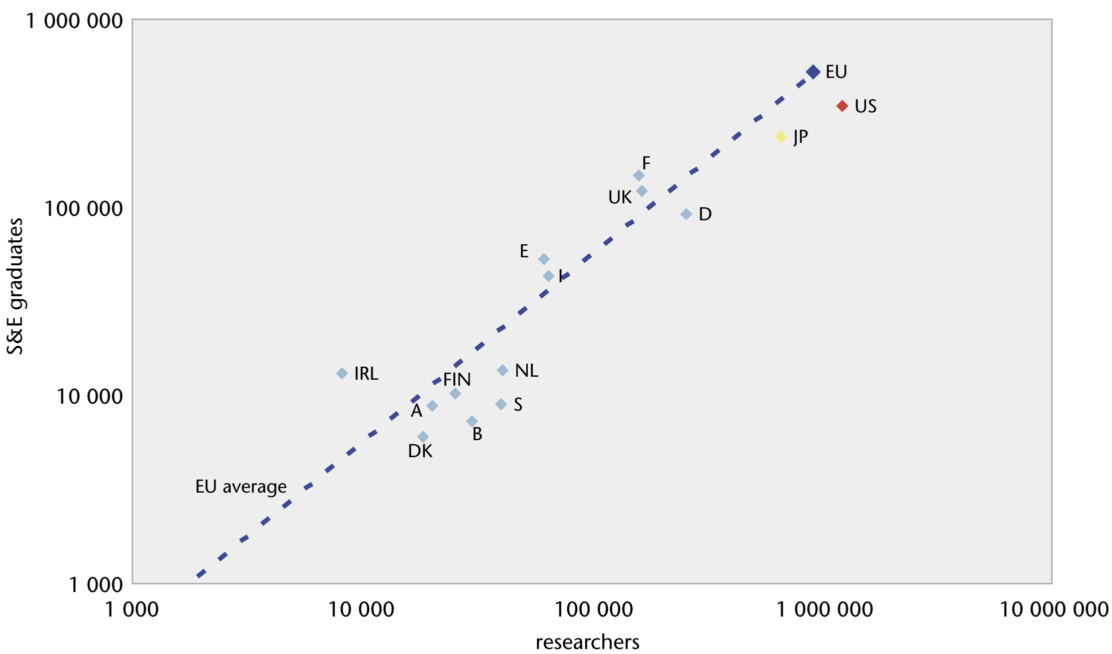
If the current growth rate in the number of researchers in the US continues until 2010, the EU will need more than the 550 000 additional researchers in order to draw level with the US share of researchers in the labour force. In fact, it will need an additionnal 835 000 researchers. This is equivalent to an annual increase of more than 80 000 researchers and an average annual growth rate of 6%. Such a growth rate is way above the average annual growth rate of 2.6% achieved by the EU during the 1990s. Thus these figures suggest that the EU has a long way to go if it is to match US efforts and even further to catch up with Japan.

In this context two crucial questions need to be answered:

- Does the education system adequately meet the demand for highly skilled R&D personnel?
- Is the relatively small number and proportion of researchers in the EU, compared to the US and Japan, linked to a still insufficient numbers of S&E graduates, in particular PhDs?

A correlation can be observed between the number of researchers and the number of S&E graduates, but this is of course primarily due to the size of the countries in question (figure 4.1.12a).

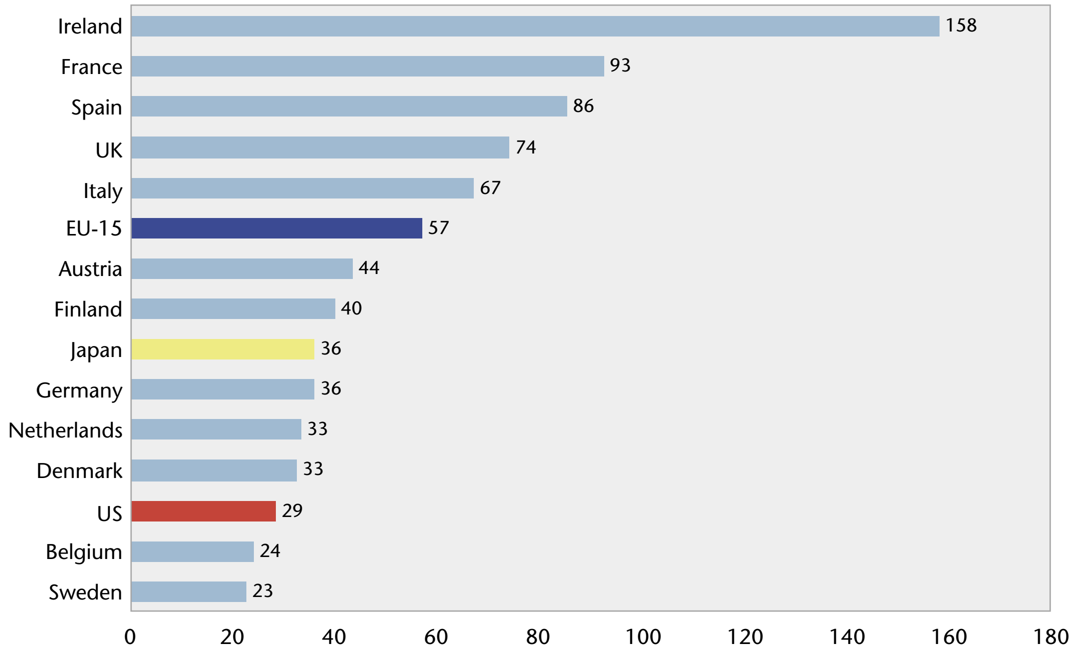
Figure 4.1.12a Researchers and graduates in S&E: Comparison of absolute numbers (1999)



Source: DG Research
Data: Eurostat/OECD
Note: No data for EL, L or P, therefore, the EU total and average is calculated only for the other 12 Member States. S&E graduates for B include only Flemish community.

Third European Report on S&T Indicators, 2003

Figures 4.1.12b Ratios S&E graduates/researchers in %, 1999



Source: DG Research
Data: Eurostat/OECD
Note: No data for EL, L or P, therefore, the EU sum and average is calculated only for the other 12 Member States. S&E graduates for B include only Flemish community.

Third European Report on S&T Indicators, 2003

However, looked at in relative terms, there are some interesting results for the relationship between the number of S&E graduates and researchers (figure 4.1.12b). For example, the total of one year's S&E graduates in the EU Member States is the equivalent of 57% of all researchers. The ratios for Japan and the US are much lower at 36% and 29% respectively. Within the EU, the range is quite broad – from 158% in Ireland to 23% in Sweden, which means that even in Sweden the total number of researchers is the equivalent of only five years worth of graduates produced by that country.

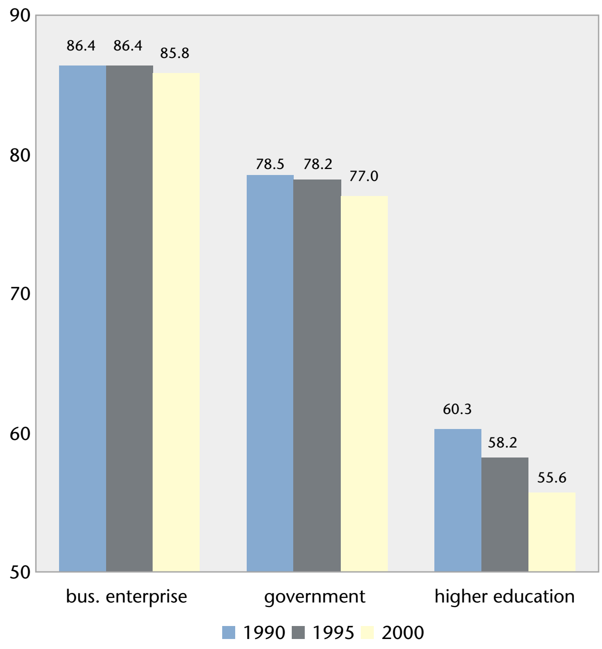
A short-fall in the production of S&E graduates could contribute to the inadequate supply of human resources in S&T. In order to assess the situation, the number of researchers, measured in terms of full-time equivalents (FTEs cf. box "Some statistical features about full-time equivalents and head counts of R&D personnel"), has to be looked at.

Some statistical features about full-time equivalents and head counts of R&D personnel

In general, the data for researchers and R&D personnel refer to the full-time equivalent (FTE) figures. In order to form an idea of how many people are conducting R&D, it is worthwhile to have a look at the head count (HC) data. Given the lack of head count data on researchers, one has to rely on total R&D personnel data. The best way of comparing FTEs with HCs is to calculate the ratio between the two. The ratio resulting from "full-time equivalent divided by head counts" indicates to what extent R&D personnel are deployed in R&D. A ratio of one means personnel are engaged full time in R&D, and a ratio of one half indicates that they are typically performing R&D for half their time or in two different jobs. These statements are of course just statistical averages. Figure 4.1.13 shows the ratio of FTEs to HCs for R&D personnel in three sectors in the EU over the last decade.

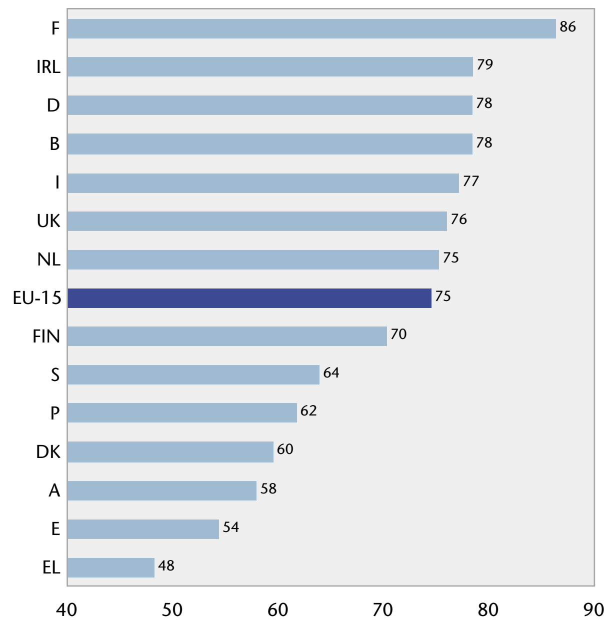
The data for the EU Member States were relatively stable throughout the 1990s, but there are large differences between the three sectors. The highest ratios are in the business sector, stable at around 86%, while the lowest ratios are in the higher education sector, which saw a decline from 60% in 1990 to 56% in 2000. The government sector values fall between those of the other two sectors, with ratios which have remained relatively stable between 79% and 77%. These results are hardly surprising. R&D personnel

Figure 4.1.13 Ratios FTE/HC of R&D personnel in %: EU average



Source: DG Research
Data: Eurostat/NewCronos database
Note: No data for L which is not in the EU average. The EU average is estimated. Estimates: DG Research.
Third European Report on S&T Indicators, 2003

Figure 4.1.14 Ratios FTE/HC of R&D personnel in %: EU Member States 1995



Source: DG Research
Data: Eurostat/NewCronos database
Note: No data for L, US or JP. L is not in the EU-15 average. EU-15 average and data for A and UK are estimated. Estimates: DG Research.
Third European Report on S&T Indicators, 2003

are more commonly employed full-time in private companies than, for example, in universities, where many of the teaching staff, post-doctoral or PhD students, are engaged on a part-time basis and are likely to hold other part-time posts. A closer look at the ratios for the Member States highlights the differences between them (figure 4.1.14).

The differences are striking. In France, the average ratio of all sectors comes to 86%, which signifies that the majority of French R&D personnel is employed full-time. In Greece this ratio is significantly lower at about 48%, which indicates that, on average, Greek R&D personnel are employed less than half time in any given R&D job. Belgium, Germany, Ireland, Italy, the Netherlands and the UK all have above the EU average ratios of 75%. Finland is at about 70%. The others have ratios varying between 55 and 65%. On the one hand, these different ratios could relate to the different size of the sectors in the Member States. On the other hand, and more importantly, they indicate discrepancies in employment conditions relating to working hours in the R&D field.

The discrepancy between head counts and full-time equivalents means that the head count number considerably outstrips the number of full-time employed personnel, especially in higher education, where the ratio between FTE and HC for total R&D personnel amounted to 56% in 2000 for the EU (figure 4.1.13). In the government and business sectors, the ratio is much higher. The gap between FTE and HC effectively increases the number of S&E graduates that are required to form new R&D personnel in FTE. The average ratio for all sectors is around 75%, which means that on average R&D personnel share the equivalent of three full-time posts between four people. Put differently; for every person employed full-time in R&D, there is statistically one person employed on a half-time basis.

Assuming that the ratios for researchers are more or less the same as for total R&D personnel, four S&E graduates are needed to replace three full-time equivalent researchers.[2] This would lower the above calculated replacement factors by 25% and increase the replacement period by one third. In this way, the real replacement need could be calculated for each

[2] *These calculations are purely quantitative and hypothetical. They do not take into account work specific skills, experiences and qualifications of the researchers to be replaced. The "replacement" is just a hypothetical approach – the actual question is not, how many researchers can be replaced, but how many researchers can be employed additional to the existing researchers. Only the researchers who are leaving because of age or new professional orientation have to be "replaced".*

country and for the different sectors. This will not be done here because the data for R&D personnel and researchers are not completely comparable and the ratios are not sufficiently stable.

Another possible mismatch relates to a lack of structural correspondence. Not all S&E graduates have qualifications in the fields of study that are in demand. This is especially true nowadays, as in the case of IT graduates, who are relatively in short supply compared to the demand for them in the emerging information society. Lack of geographical mobility can also keep young graduates away from job opportunities in centres that are geographically remote from their current homes or where they originate from. These factors cannot be analysed with the available indicators, but they do suggest other possible reasons for mismatches in supply and demand.

From the data analysed in this section, it is clear that the EU Member States are turning out substantial numbers of graduates in S&E, but is production sufficient to keep up with the demands of a knowledge-based economy? In order to consider other relevant factors that are influencing the situation in human resources in S&T, and to reflect on possible future developments, the next section analyses data on the general education and employment situation of human resources in S&T.

Section II The growing demand for human resources in S&T

The previous section highlighted that the EU has relatively far fewer researchers than the US or Japan. An inadequate number of highly qualified S&T personnel would be a serious obstacle to the growth and expansion of the EU into a knowledge-based economy. An adequate and sustainable supply of human resources in this field is even more necessary in the light of the goal of the EU to become “the most dynamic and competitive knowledge-based economy in the world”, implying the need to “catch up” with the better performing countries such as the US.

The need to understand the replacement demand for human resources in S&T and to ensure an adequate supply of highly skilled personnel, is a challenge that EU policy and decision-makers share with the US and Japan. For example, not all people with higher education in S&E fields of study enter research careers, because in today’s knowledge-based and transformed economy, people with science and technology skills find that there is considerable demand for their talents from across a number of sectors and therefore enter a wide range of occupations. For example, the IT sector still appears to have an insatiable appetite for engineers and highly trained technical staff, and add to this the human resources needs of enterprises that are moving into e-business (even with the bursting of the e-bubble). Shortages in human resources may also result from inadequate, inefficient and inappropriate education systems. Likewise all EU Member States have to face the problem of ageing populations and in some cases this problem will become quite acute during the next decade.

This section analyses the growing demand for personnel with certain skills. This is a result of the transformation to a knowledge-based economy. It looks at the human resources pipeline in the context of the education system, ageing populations and the problem of making S&T attractive for the population. It ends by looking at the employment situation by tracking the employment and unemployment figures for the highly qualified population in general and the S&T employees in particular.

1. Education situation

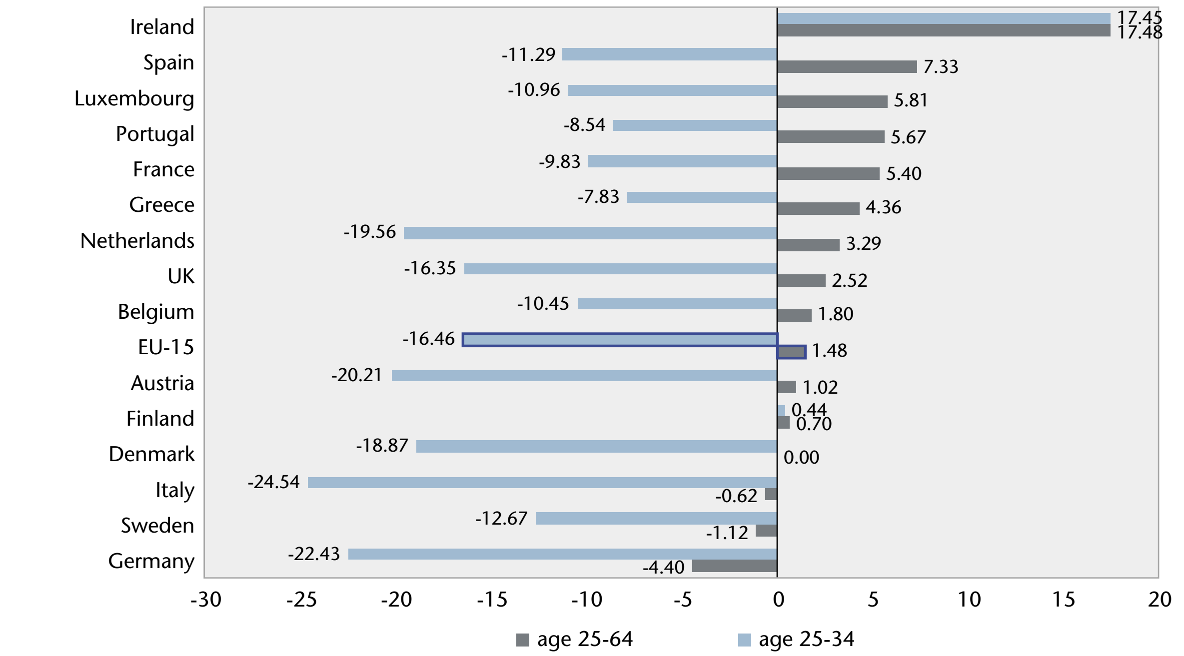
An ageing population and the higher education pipeline

A key input indicator for the supply of human resources in S&T is the size of different age groups or birth cohorts, making up the population. This information can be combined with participation rates to project potential graduate output. Figure 4.2.1 presents the projected growth rates for the two age groups 25-64 and 25-34 from 2000 to 2010.

The age group 25-64, corresponding to the population of working age in S&T, is projected to increase at a low rate averaging 1.5% over the period 2000 to 2010 for the EU. By far the strongest growth is foreseen for Ireland with 17.5%. High growth of between 7 and 5% is also expected in Spain, Luxembourg, Portugal and France. Only Germany is expected to experience a significant decline of 4.4% in its 25-64 year population, while for the other Member States it is anticipated that their 25-64 year populations will change very little.

The 25-34 age group, where one finds the people who will, over the next 10 years, enter the labour market with post-secondary qualifications, some of them in S&T, is expected to decrease in size. In fact, in nearly all of the countries surveyed, the first decade of the 21st century sees the key pool of potential S&E graduates decreasing in size. Apart from Ireland, where the growth of 17% matches that foreseen for the 25-64 age group, and Finland, where there is likely to be no change, other countries should see a decrease in the number of young people. In the EU as a whole, the 25-34 group is likely to shrink by 16%. Among the Member States, the most serious decreases will affect Italy with 25%, followed by Germany (22%), Austria and the Netherlands (both with 20%), and Denmark (19%). In the remaining countries it is anticipated that the age group will decrease in size by between 8 and 16%.

Figure 4.2.1 Population projections: Growth rates in % (from 2000 to 2010)



Source: DG Research
Data: United Nations 2001. World Population Prospects 2000
Note: The data display the medium variant population prospects.

Third European Report on S&T Indicators, 2003

In real numbers, the 25-34 age group in the EU-15 will total 48 million in 2010, a decrease from the 57 million in the year 2000. This drop of nine million people can be mainly attributed to population decreases in just a few countries: Germany (2.8 million), Italy (2.3 million), the UK (1.4 million), France (850 000) and Spain (750 000). The remaining EU Member States are only likely to see their populations decrease by less than half a million each. The gains foreseen for Ireland, the only country showing an increase in this age group, only amounts to 100 000 people, which does little to compensate for the losses across the EU as a whole.

In the previous section it was shown that in 2000 in the 25-34 age group in the EU only around 0.4 per 1 000 people obtained an S&E PhD. Given that there is expected to be a decrease in the population and assuming that the proportion obtaining PhDs and all other parameters remain constant, this implies that in 2010 there are likely to be roughly 3 800 fewer S&E PhDs awarded in the EU than a decade before. Based on the same assumptions, the total number of university graduates in S&E per year will decrease by around 90 000. Furthermore, the total population aged 25-34 with higher education is likely to shrink by 2.25 million, and there are likely to be 1.1 million fewer young researchers.

These estimates are somewhat rudimentary and do not take into consideration a range of external factors such as change in birth/death rates and in the education and science systems, migration and so on. However, the estimates clearly illustrate how an ageing population could have serious consequences for the production of educated people and, of more interest to this report, for the growing reliance the EU may have to develop on external sources for the supply of human resources in S&T.

It could be argued that the problem of an ageing population discussed here will not have any effect before 2010 because the number of people in the S&E relevant age group 25-64 is not shrinking. However, the declining numbers of young researchers and S&E graduates will have an immediate impact on the qualifications and skill levels of the labour force. Scientific, technical and economic knowledge is changing rapidly. Young people are educated taking account of the most recent developments in S&T, and having a high proportion of young, newly educated people is a fundamental necessity for the fast evolving knowledge-based economy. Moreover, given the potential decline in the numbers of young people trained in S&E, the implications for older workers are likely to be important together with the associated need for life-long learning, both for the maintenance of a highly qualified working-age population, and for scientific and technical development and expansion.

Qualification structures of populations

The shrinking size of the younger age groups is likely to affect the qualification structures of the population but if a greater percentage of younger people were more highly qualified and in S&T, the shortages created by demographic changes could potentially be smaller. One of the concrete, quantitative objectives of the Lisbon Council is to reduce by half the number of those at lower secondary level who do not go into advanced education (European Council Lisbon 2000). This would contribute to addressing the goal of transforming Europe into a knowledge-based society and more of its population participating and contributing to such a society.

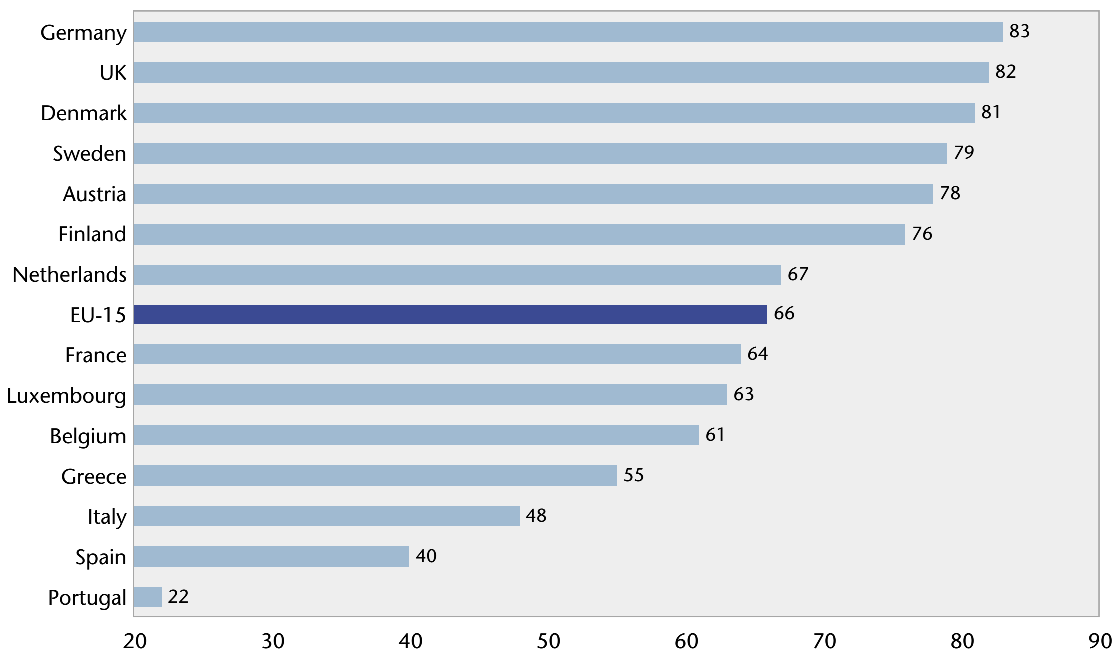
The output of the education pipeline is a key indicator of what is likely to happen to the basic reserves of skilled people in a society. In an ideal world and taking a rather simplistic view this indicator is likely to reflect the short- to medium-term potential of an economy to recruit S&T employees and people with the capacity to acquire S&T related knowledge, who could work as research scientists and engineers. In the EU, currently about 66% of the population in the 25-59 age group have at least an upper secondary education (figure 4.2.2).

The share of the population with upper secondary education varies across the Member States, from a high of 83% to a low of 22%. In Germany, the UK and Denmark, more than 80% of the population has an upper secondary education, with Sweden, Austria and Finland not far behind. In the Benelux countries and France the share is near to the European average. The populations of the southern European countries, Greece, Italy, Spain and Portugal, have the lowest proportions of their populations educated to upper secondary level.

In almost all EU countries, the number of people with post-secondary qualifications increased between 1995 and 1997 (figure 4.2.3). Within three years, this increase pushed up the EU average by around 1%. Spain and Italy experienced the highest increases with 13% and 8%, respectively. Only the Netherlands saw a marked reduction, which was mainly due to an above average percentage of people with secondary education during 1995; the overall trend in the Netherlands shows stagnation.

These results suggest a positive outlook in terms of decreasing numbers of those with only lower qualifications. But, as is often the case, the differences among the EU Member States create specific challenges and needs**.** While the populations of northern European countries have a broad knowledge base, there is considerable potential for its improvement in the southern part of Europe. Such an improvement will take time, but the high growth rates seen in the southern European countries (with the exception of Portugal) give rise to optimism for the future.

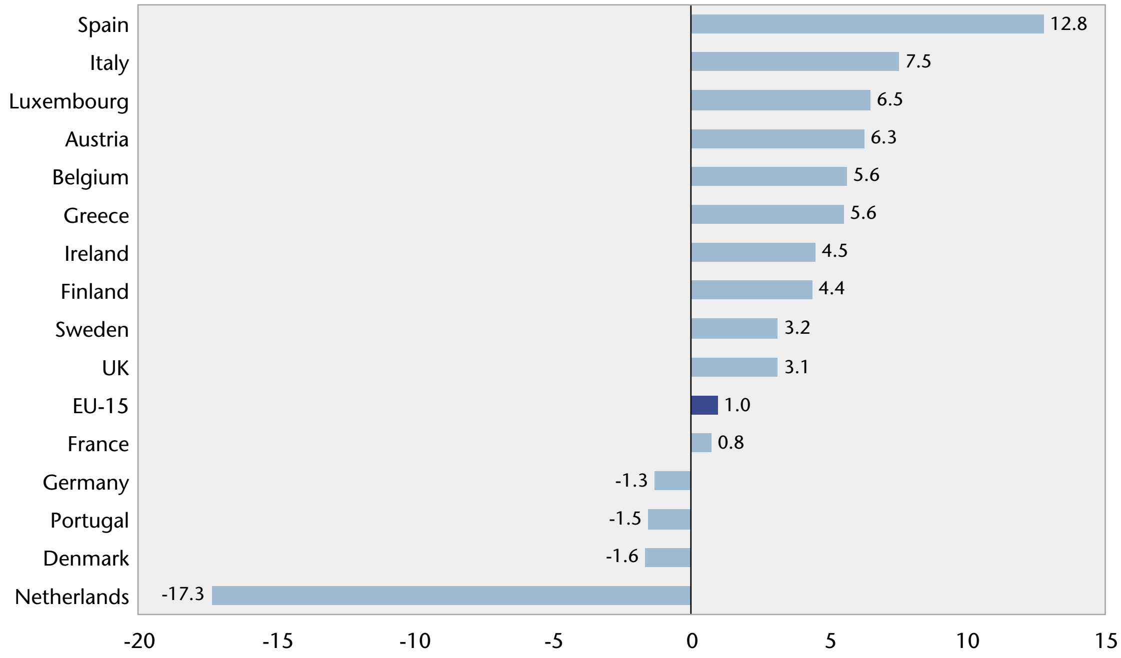
Figure 4.2.2 Share of population aged 25-59 with at least secondary education in % (2000)



Source: DG Research
Data: Eurostat NewCronos database and CLFS 2000
Note: No data for 2000 for IRL, which is not in the EU average.

Third European Report on S&T Indicators, 2003

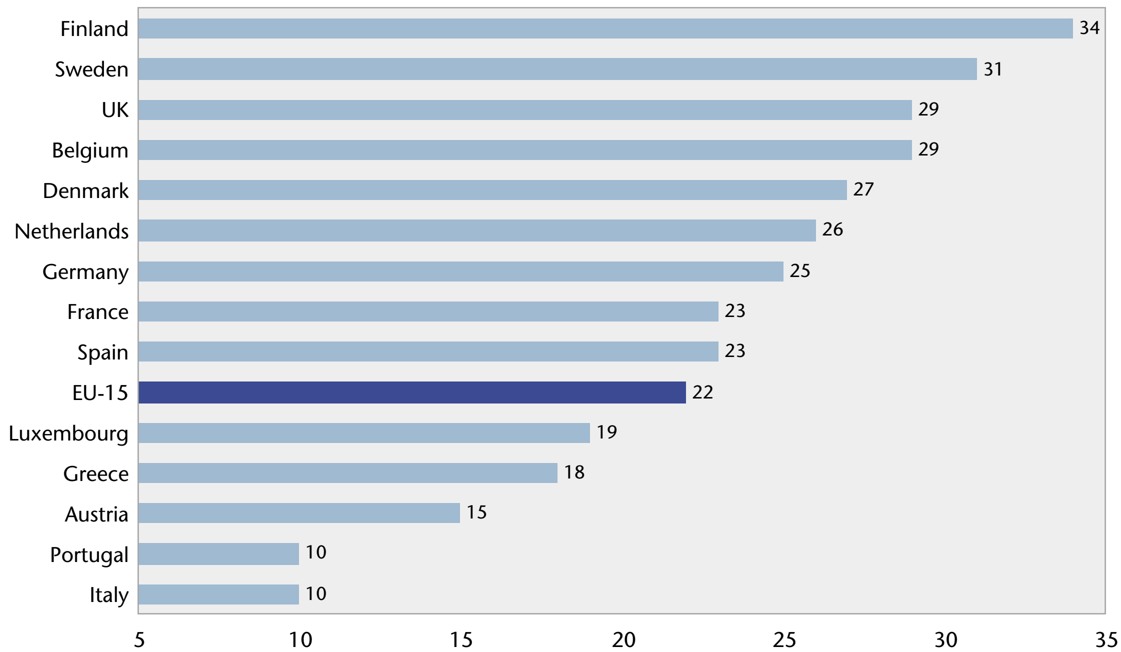
Figure 4.2.3 Share of population aged 25-59 with at least secondary education: total growth in % (1995-1997)



Source: DG Research
Data: Eurostat NewCronos database and CLFS 2000
Note: The data for L are not statistically reliable.

Third European Report on S&T Indicators, 2003

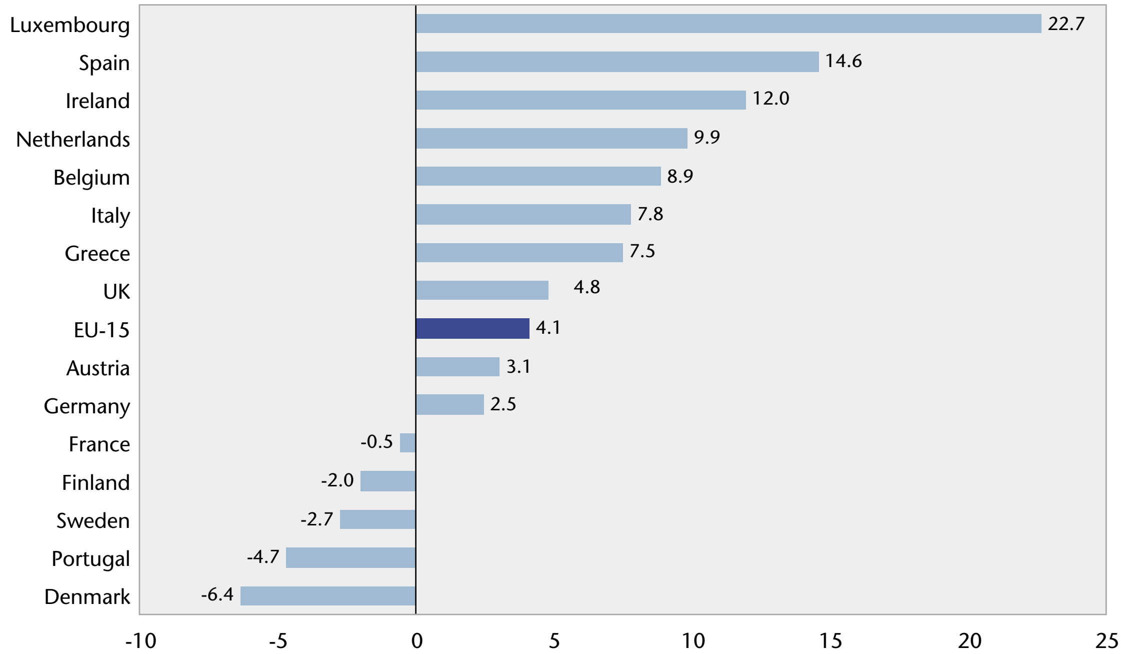
Figure 4.2.4 Share of population aged 25-59 with tertiary education in % (2000)



Source: DG Research
Data: Eurostat NewCronos database and CLFS 2000
Note: No data for IRL for 2000, which is not in the EU average.

Third European Report on S&T Indicators, 2003

Figure 4.2.5 Share of population aged 25-59 with tertiary education: total growth in % (1995-1997)



Source: DG Research
Data: Eurostat NewCronos database and CLFS 2000
Note: The data for L are statistically not reliable.

Third European Report on S&T Indicators, 2003

What share of the population has a post-secondary qualification, and potentially the skills for an occupation in S&T? On average in the EU, about 22% of the population aged 25 to 59 have completed tertiary education (figure 4.2.4). However once again, there are big differences among the countries, and the rankings are slightly different. Finland, Sweden, the UK and Belgium are in the lead, with some 30% of the population having completed higher education. Denmark, the Netherlands, and Germany follow with a quarter of their people having been educated at the tertiary level. Spain, France, Luxembourg and Greece show values near to the average, while Portugal and Italy only have around 10% of their populations with tertiary education. Austria's low of 15% in 2000 is surprising given that in the same year some 80% of the population had secondary education. This means that in Austria less than one fifth of the population progressed to the next level of formal qualification – the EU average rate being one third.

In terms of the growth rates between 1995 and 1997, all countries except France, Portugal and the Nordic countries increased their proportions of people with higher education by on average 4% (figure 4.2.5). The high growth of 23% in Luxembourg may not be statistically significant given the country's small population. Once again, Spain and Ireland are in the lead with 15% and 12% growth respectively.

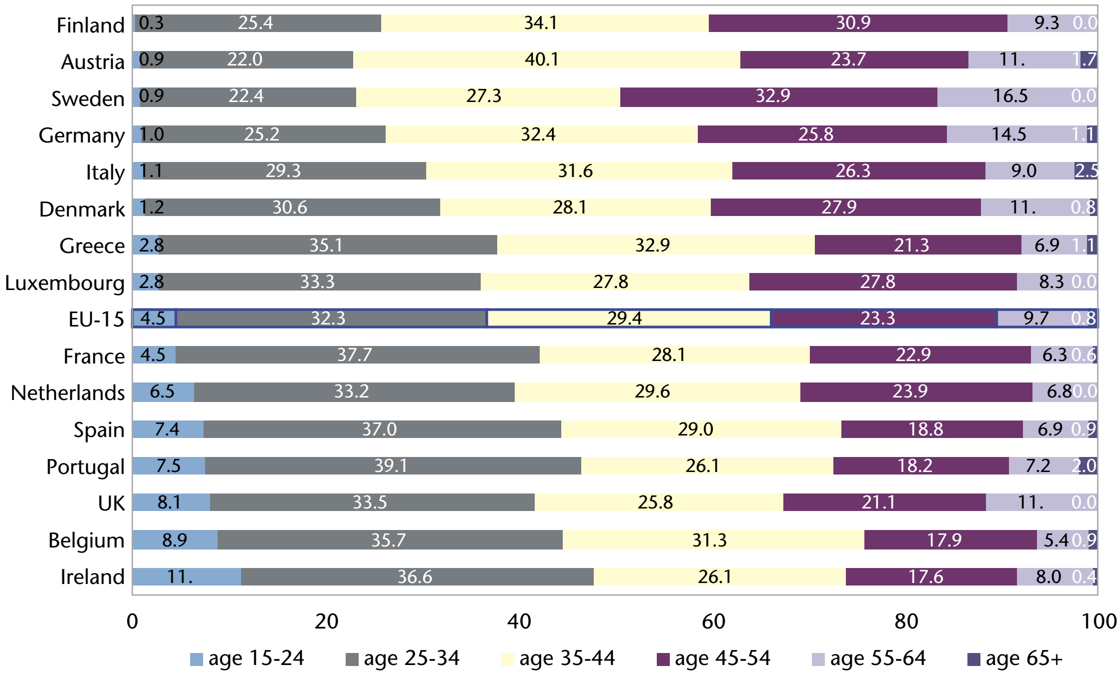
Higher education by age groups

How are these findings likely to affect the labour force in the future which will consist of more old people than young ones? One effect of the rising share of young people with tertiary education could be that there will continue to be more young graduates under 25 who enter the labour force than people aged over 59 with higher education who leave the labour force. In order to understand this phenomenon, it is useful to look at the population with higher education by age group, which is done in figure 4.2.6.

The age profiles of the populations of the EU Member States vary a lot (figure 4.2.6). Across the EU, on average, about 37% of the population with tertiary education is 34 years old or younger. The age group 35-54 includes more than half the number of people with higher education qualifications. Only about 8% of the tertiary educated are 55 years old or older. Ireland and Portugal are the countries with the highest proportion of young people with higher education (about 50%), while the smallest percentages are found in Italy, Germany, Austria and the Nordic countries.

In the EU in 2000, the ratio between the younger age group (15-34 years) and the oldest group (55 years of age and over) of the population with higher education was 3.5 to 1. At the top of the list are Belgium, France, the Netherlands and Ireland with ratios of between 7.1 to 1 and 5.7 to 1. In Sweden,

Figure 4.2.6 Population with tertiary education by age groups (2000) (%)



Source: DG Research
Data: ILO

Third European Report on S&T Indicators, 2003

Germany and Austria, the ratio was with 2 to 1 and below the EU average. Finland, Italy and Denmark were also below the EU average. One explanation may be in the length of the study programmes in these countries, where a significant portion of the population does not complete its studies in tertiary education in its twenties.

The following can be concluded about the problem of the ageing population: On the one hand, there are currently relatively fewer young people than old people in the population aged 25 to 64. On the other hand, more young people than old people have higher education. Depending on specific demographic factors, the overall effect of this could either be a shortage of higher qualified people because of general decreases in the population or an increase in the pool of qualified people because of increasing shares of young people with higher education. Thus the net effect cannot be predicted from the data.

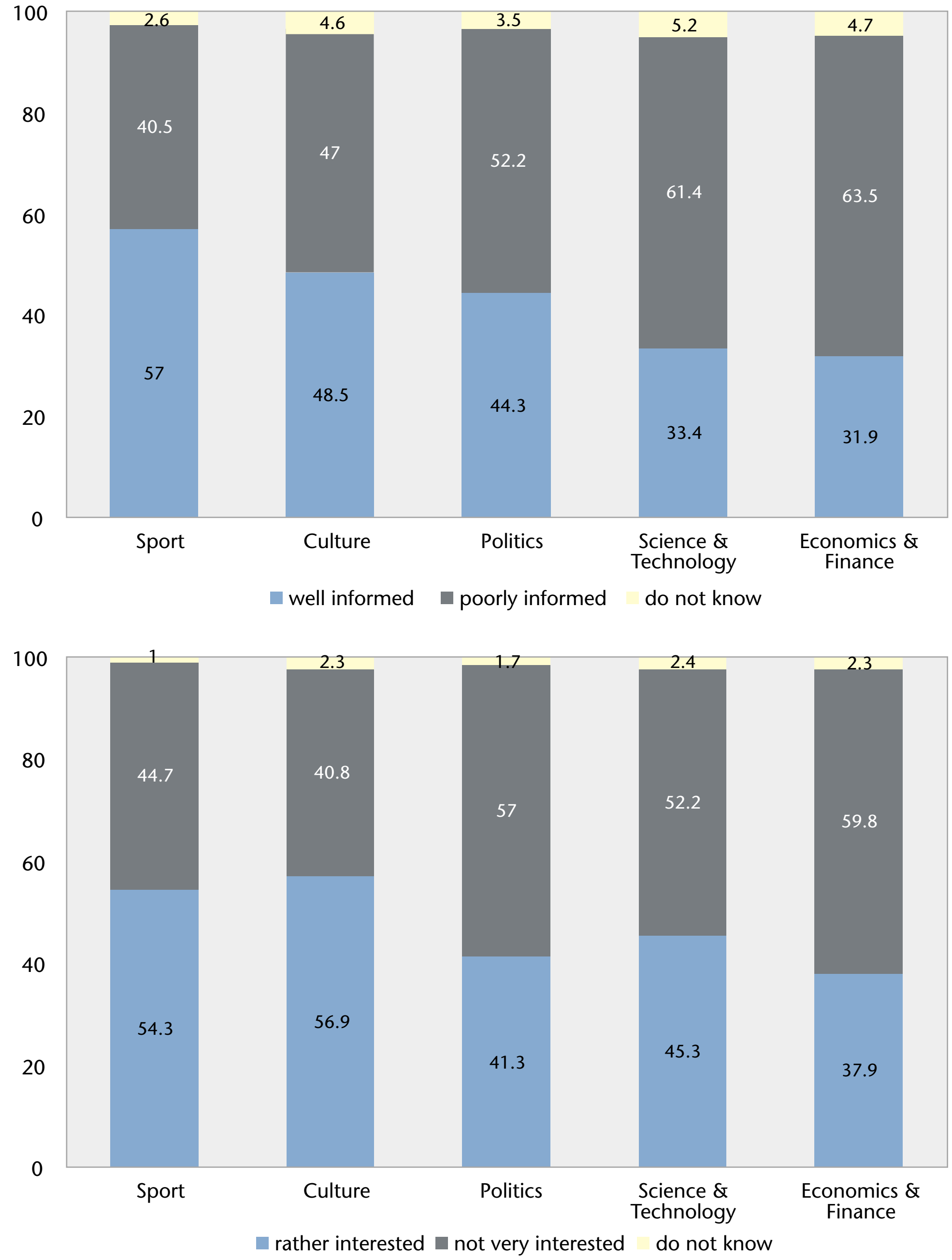
Attractiveness of S&T for the European population

Increasing the attractiveness of S&T is an important prerequisite to increasing young people's interest in and general understanding of science and technology and in making them consider S&T as a career option. The attractiveness of S&T is something rather subjective and not easily measured. One source of information on general perceptions about S&T in the population is provided by the Eurobarometer on Science and Technology, which was carried out in 2001 for the Research Directorate General of the European Commission (2001a). In this study, people in the EU Member States were asked their opinions, perceptions and knowledge of various fields of S&T.

What is the perception of information and interest levels in S&T compared to other areas such as sports, culture, politics, economics and finance? Figure 4.2.7 shows the perceptions of people and to what extent they are informed about and interested in five areas.

Across the EU, 57% of the people asked felt they were best informed about sports, followed by culture and politics at between 44 and 49%. People felt least well informed about S&T or economics and finance, which scored only 33% and 32% respectively. The order changed when they were asked about their interest in these areas. Culture then led with 57%, followed by sports with 54% and S&T with 45%. Politics and economics and finance, with 41% and 48% respectively, seem to be areas where the people gave the impression that they were better informed rather than interested in the subject area.

Figure 4.2.7 Perception of information and interest in different areas: EU averages (%)



Source: DG Research
Data: Eurobarometer 55.2, tables 1 and 2

Third European Report on S&T Indicators, 2003

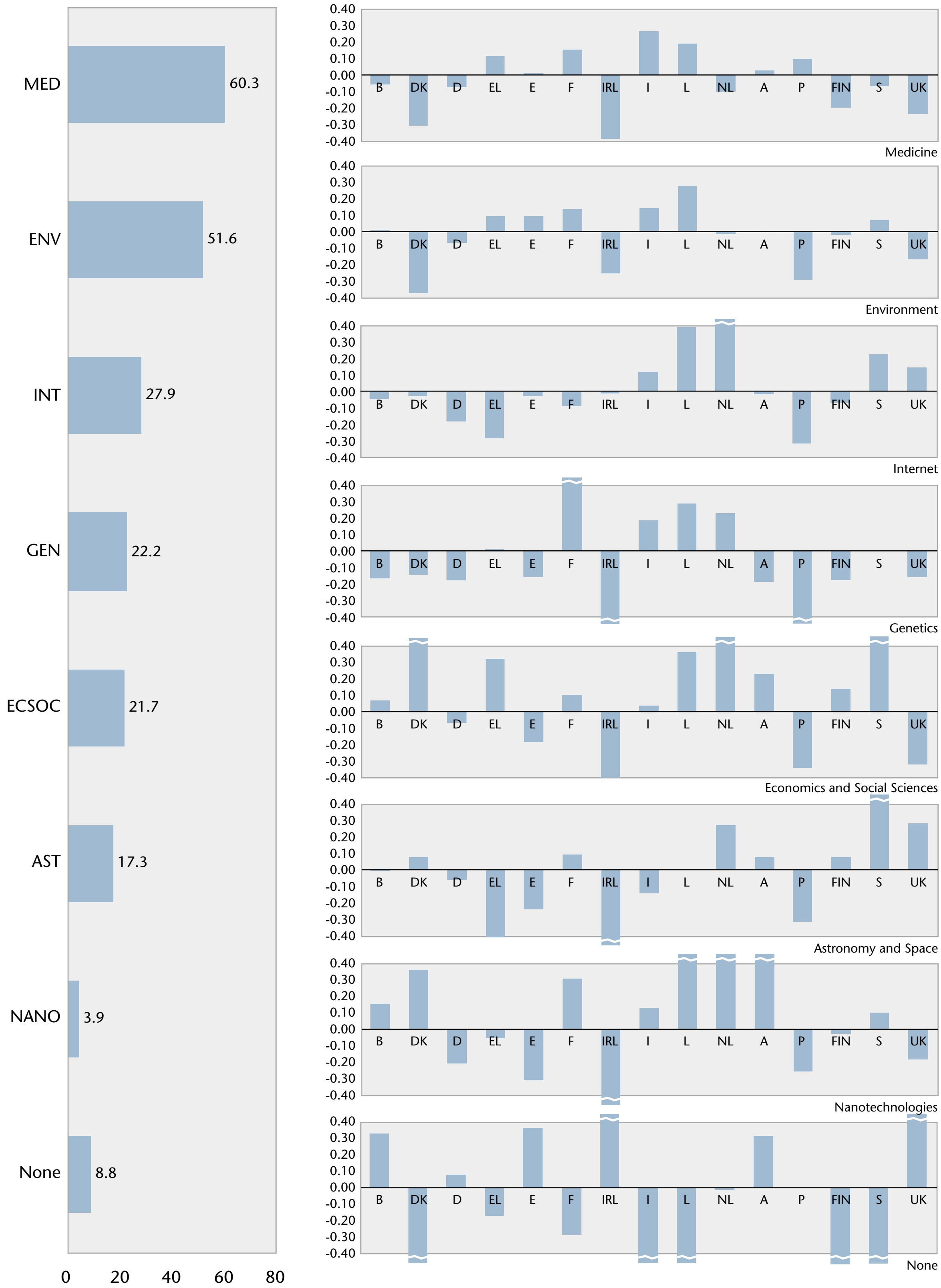
General interest in S&T

With regard to S&T, only 29% of the respondents considered themselves to be both well informed and interested. Another 46% feel neither interested nor well informed, while 15% are interested, but did not feel well informed. These results suggest that S&T is not the most popular area of interest, and that in general the population is not well informed on this subject.

Asked about their particular areas of interest in S&T, 60% of the EU respondents said medicine was of most interest to them, followed by the environment at 52% (figure 4.2.8). Much lower down came interest in the internet (28%), genetics, economics and social sciences (both 22%), and astronomy and space (17%). Only 4% of the people asked were interested in nanotechnology, which probably shows that there is a lack of information about this emerging key technology (section 6.3.2). Almost 9% of the respondents showed no interest in any of the areas.

There are huge differences between the Member States. Of particular interest is the consistently low interest shown in all fields of S&T by the Irish and German populations, compared to the higher interest in most areas shown by the French, Ital-

Figure 4.2.8 Interest in S&T developments by areas: EU average in % and deviation from EU average per country



Source: DG Research
Data: Eurobarometer 55.2, tables 3
Note: The deviation from the EU average is calculated by: (% country- % EU average) / % EU average. Deviations higher than 40% or below -40% are not shown in the figure.

Third European Report on S&T Indicators, 2003

ians, Swedes and Luxembourgers. Italians show the highest interest in medicine, while the Dutch appear to be most interested in the internet and in nanotechnology, the French in genetics, the Danish and the Swedish in economics and social sciences, and the Swedes in astronomy and space.

Social standing of S&T professions

Interest is only one factor in choosing to study or pursue a career in S&T. Other aspects that influence the individual are perceptions of a profession and its reputation in society. The survey asked people in what regard they held a number of professions (table 4.2.1).

In the EU overall, as well as in individual Member States, it is the profession of 'medical doctor' that is held in highest esteem, although the percentage of people who thought this varied from 59% in Denmark to 80% in France. Interestingly, despite the lack of knowledge about S&T, the 'scientist' ranks second highest in terms of esteem in nearly all Member States. In the EU as a whole, 45% place the scientists as the second highest in terms of esteem, with the share ranging from a low of 23% in Ireland to a high of 55% in Sweden. Only in Ireland did 'judges' (with 24%), 'engineers' (with 24%) and 'sportsmen' (with 35%) receive higher ratings than scientists did. 'Engineers', with 30%, were rated third on the esteem scale in the EU average, followed closely by 'judges' (28%). In Denmark, Germany, Greece, Luxembourg, the Netherlands, Austria, Portugal and Sweden, the esteem of 'engineers' changes ranks with that of 'judges'. Among the Member States, 'engineers' received the lowest rating in Austria (17%), while in the UK they are most esteemed (36%).

In these data there is evidence that the occupation of scientist, as well as that of engineer, remains well regarded by the general public in most EU countries. Compared to other professions, an occupation in S&T ought therefore to be desirable. The high regard for doctors corresponds with the high interest scores in the medical sciences mentioned in figure 4.2.8.

Reasons for lack of participation in S&T

The 'esteem scale' does little to explain a lack of participation in education in the fields of science and technology. Figure 4.2.9 gives some explanations as to why the interest of young people in S&T has not grown. Some 60% said science lessons at school were not appealing enough, and 25% gave this as the main reason for the lack of participation. The difficulty of the subject was given as one of the main reasons by 55% of the respondents. About half of the respondents said young people were less interested in working in the scientific field, while unattractive salaries and career prospects were given as reasons by 42%. 40% of the respondents thought that two or fewer of these reasons could explain the declining interest of young people in S&T.

Table 4.2.1 Esteem for different professions (in percentage of answers)

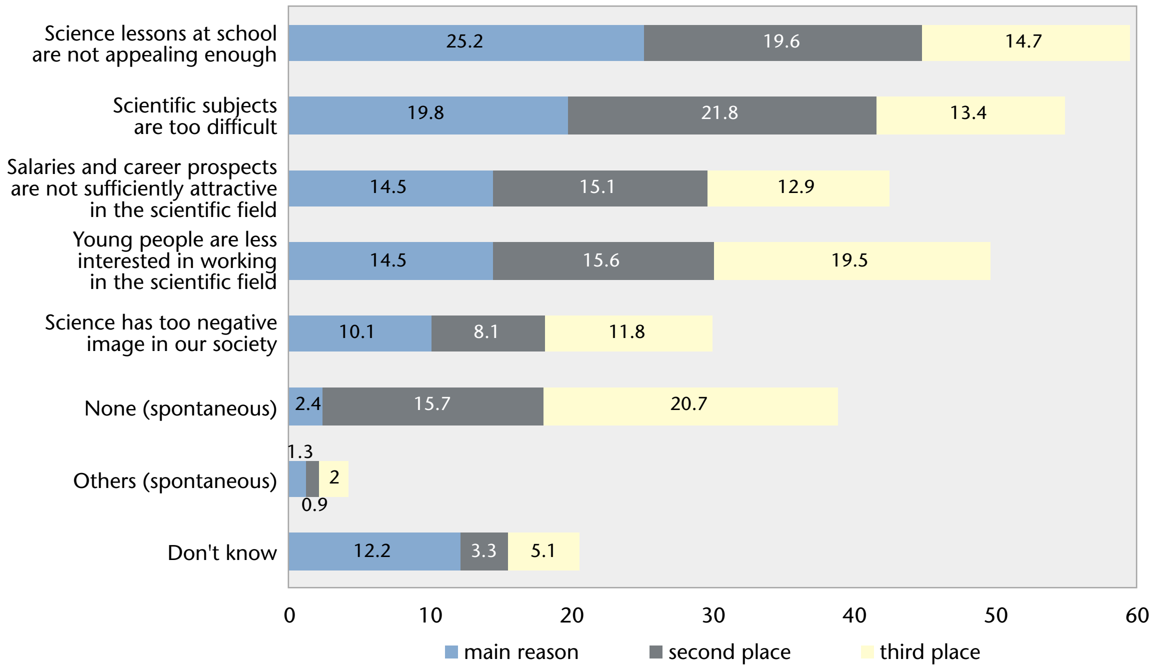
Question: For which of the following professions do you have the most esteem?

	Doctors	Scientists	Engineers	Judges	Sportsmen	Artists	Lawyers	Journalists	Businessmen	Politicians	None of them	Don't know
EU-15	71.1	44.9	29.8	27.6	23.4	23.1	18.1	13.6	13.5	6.6	6.9	3
Belgium	74.3	48.5	31.5	21.3	30.5	32.2	17.4	20.3	17.8	8.7	4.7	2.6
Denmark	58.9	50.1	28.7	41.9	14.7	19.2	21.3	8.8	11.9	13.1	7.9	3
Germany	64.4	42.7	26.6	35.5	16.8	16.4	21.1	8.6	9	7.8	8.9	3.5
Greece	68	53.3	24.7	26	49.1	31.8	17.5	24.4	14.5	5.8	6.5	0.4
Spain	68	47.4	32.1	20.9	32.8	25.8	15.2	26.7	16	6.2	8	4.2
France	80.4	47.9	33.8	20	26.3	30.3	15.4	17.6	10.6	3.2	5.6	1.5
Ireland	69.6	22.9	24.3	24	35	13.4	16.2	14.1	18.4	6.1	6.2	5.5
Italy	67.4	46.4	27.1	23.3	19.3	29.8	12.5	12.3	18.1	4.5	6.7	2.5
Luxembourg	79.2	50.1	31.9	32.5	22.5	26.4	20.3	26.8	17.1	16.8	3.6	2.8
Netherlands	72.2	50	29.2	39.1	27.5	29.6	24.7	15.9	13.7	14.9	7.6	3.4
Austria	65.2	36.2	16.5	29	23.1	13.7	15.6	8.1	16	8.7	9.1	3.4
Portugal	76.5	35.2	26.4	30.4	22.3	24.9	15.5	25.8	15.6	5.9	4.8	3.3
Finland	76	43.5	27.5	26.3	17.1	25.6	14	10	18.6	7.1	4	2
Sweden	73.9	54.8	24.5	37.4	12.9	17.5	20.3	9.3	11.2	9.8	6.9	2.7
UK	78	40.9	36.3	27.2	23.3	14.8	22.8	5	14.6	6.3	5.1	3.6

Source: DG Research
Data: Eurobarometer 55.2, table 26

Third European Report on S&T Indicators, 2003

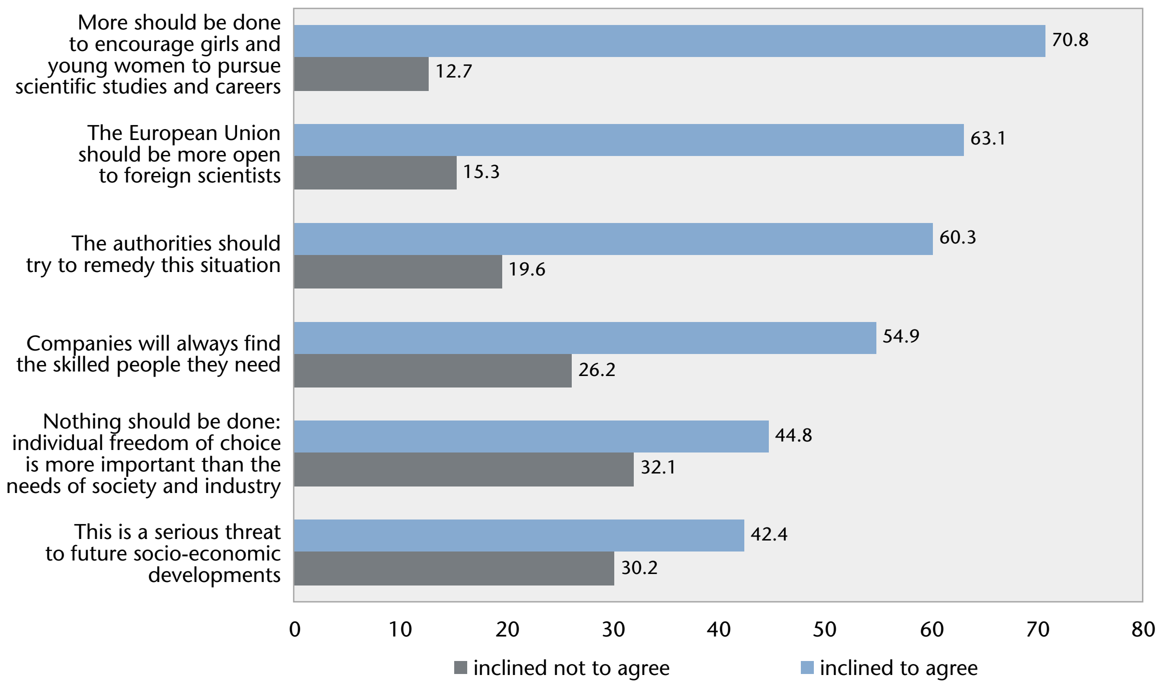
Figure 4.2.9 Reason for falling interest of young people in S&T (EU average in percentage of answers)(Question: What do you think is the main reason for the falling interest of young people in scientific studies and careers?)



Source: DG Research
Data: Eurobarometer 55.2, table 28

Third European Report on S&T Indicators, 2003

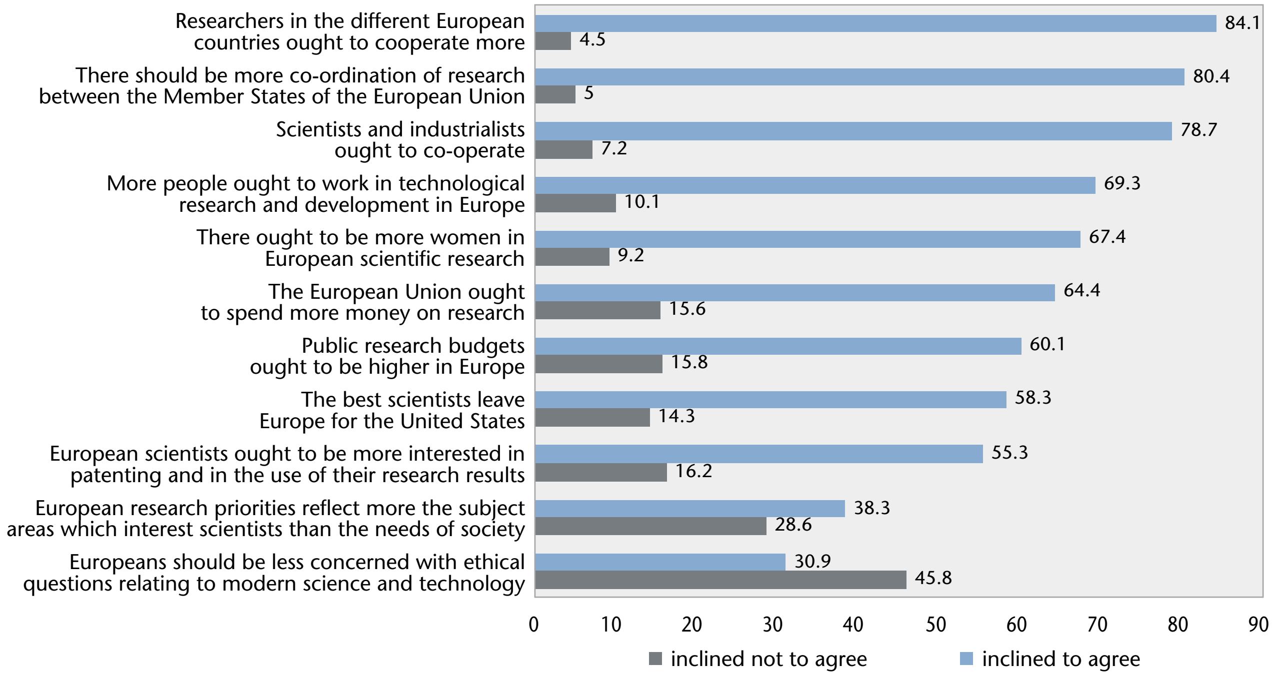
Figure 4.2.10 Attitudes of the general public in the context of falling interest of young people in S&T (EU average in percentage of answers)



Source: DG Research
Data: Eurobarometer 55.2, table 30
Note: Percentage missing to 100 means "Don't know".

Third European Report on S&T Indicators, 2003

Figure 4.2.11 Opinions about research in the European Union (EU average in percentage of answers)



Source: DG Research
Data: Eurobarometer 55.2, table 30
Note: Percentage missing to 100 means "Don't know".

Third European Report on S&T Indicators, 2003

Figure 4.2.10 shows the attitude of the general public in an era when there is a declining number of young people, who choose to study S&E in tertiary education or to consider it as a career, concerning what can be done to encourage young peoples' participation in S&T. The highest support (71%) is given to encouragement for more girls and women to pursue scientific studies and careers. Attracting foreign scientists comes second, with 63% of the support. 60% of the respondents thought that the authorities have to take action to remedy the situation, while 55% assumed that companies would find the skilled people they needed. A high proportion (45%) considers individual freedom to be more important than economic or social needs. Yet some 42% of respondents see the declining interest of young people in S&T as a serious threat to future socio-economic developments.

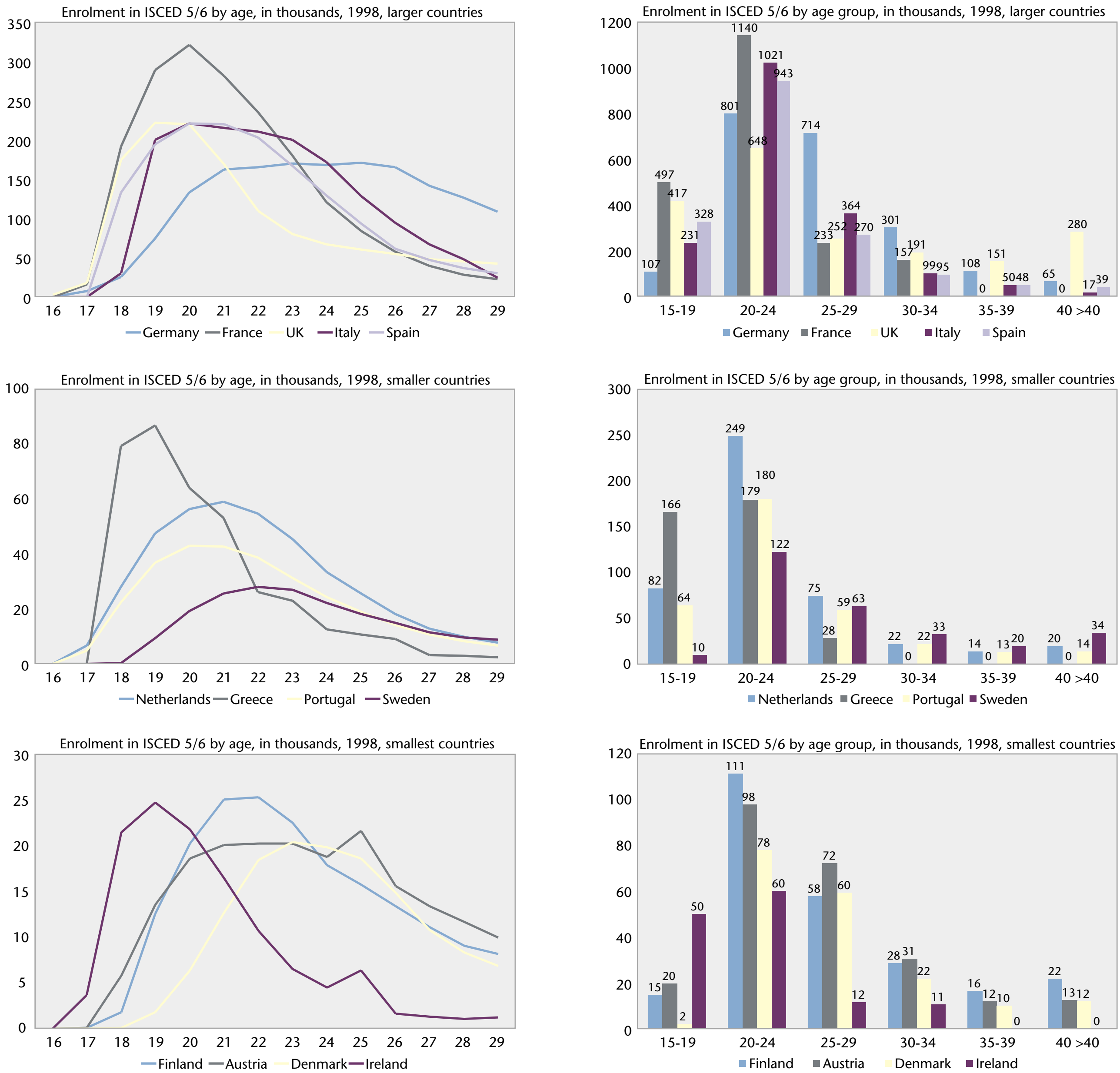
The Eurobarometer study also solicited more general opinions about research in the EU. Most respondents supported the notion that co-operation between scientists, researchers and industrialists in different Member States should increase. However rated low, in fourth position with 69% of support, was the idea that more people should work in technological research and development. The statement that more women should be active in European research was supported by 67% and the statement that the best scientists leave Europe for the US was supported by about 60% of respondents (figure 4.2.11). The last two statements are analysed in sections IV and V of this chapter.

Students' enrolment in higher education and lifelong learning

An important factor influencing the availability of human resources in S&T is the period in the individual's lifetime dedicated to higher education and the age at which studies are completed and people enter the S&T labour market. The numbers of students by age and age groups enrolled for university education leading to PhDs and other university degrees are given in figure 4.2.12 for 13 of the EU Member States in 1998.

The age profiles of students in higher education differ across the EU countries. In the UK, France, Greece and Ireland the majority of students are aged 19-20, in Denmark, Sweden, Germany and Austria the students are often older than 23 when they start higher education. These differences are caused partly by the different duration of secondary school and university programmes, but other aspects such as the requirements of the labour market (training before higher education) and military service also have an impact on the timing and duration of higher education.

Figure 4.2.12 Enrolment in tertiary education by age, 1998, in thousands



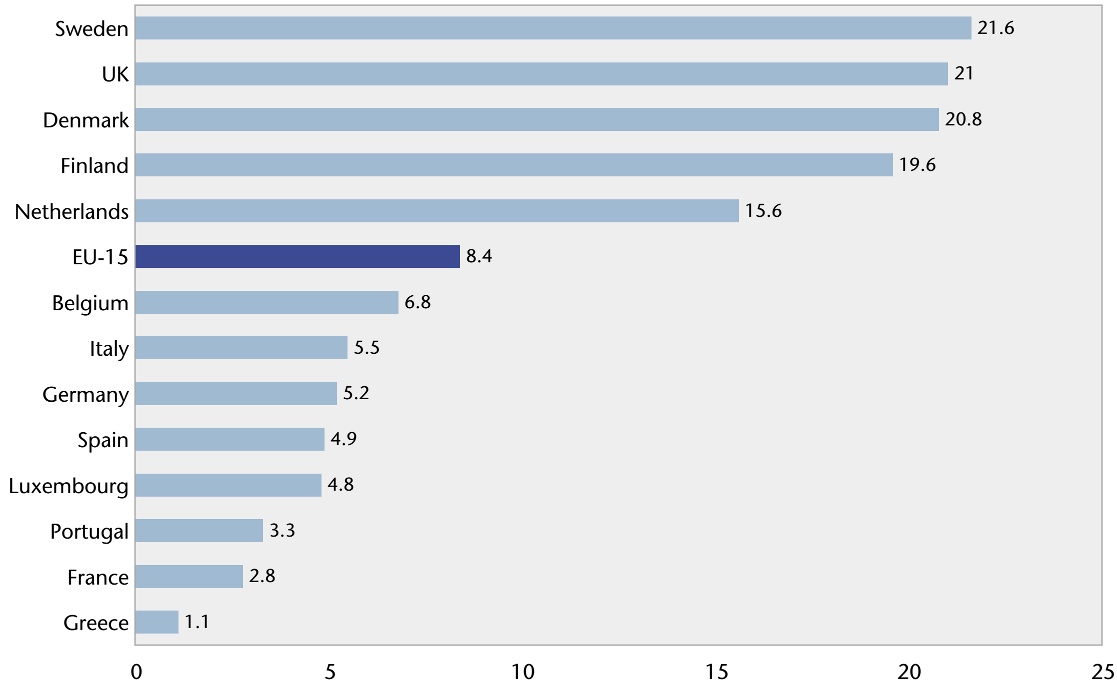
Source: DG Research
Data: Eurostat NewCronos
Note: No data for B or L.

Third European Report on S&T Indicators, 2003

Lifelong learning

Qualification and training do not end at graduation from university. In a time of rapid technological change, investment in knowledge acquisition should be on-going, with adjustments to change in the working and social environment being essential for personal and professional development and success. Researchers who have completed their education in their twenties now constantly find they require new skills. A good example involves the rapid changes introduced by IT: freshly acquired computer skills are regularly overtaken by the rapid emergence of new technologies and software. A knowledge-based economy has to face up to these new requirements by offering opportunities to its knowledge workers to continually enhance their knowledge and skills. Figure 4.2.13 shows the participation rates in continuing professional development education of people aged 25 to 64.

Figure 4.2.13 Participation in lifelong learning as a percentage of population aged 25-64 in 2000



Source: DG Research
Data: Eurostat NewCronos
Note: No data for IRL or A which are not in the EU average. The data for L are statistically not reliable.
Third European Report on S&T Indicators, 2003

Across the EU, 8.4% of the population aged 25 to 64 participates in some form of continuing professional development education or training. Among the EU Member States, the percentages vary from 22% in Sweden down to only 1% in Greece. The UK, Denmark, Finland and the Netherlands follow behind Sweden with participation rates of between 21 and 15%. In the remainder of the Member States, the proportion of the population aged 25-64 who are involved in continuing professional development education and training is much below the EU average, ranging from 7 to 3%. Based on 1996 data, the participation rate in Austria is estimated at about 9%, which is average for the EU.

2. Employment situation

Clearly, one factor influencing the availability of human resources in S&T and the attractiveness of S&E studies is occupation and employment prospects. One problem in the supply situation reflects the lack of interest young university students show in S&E disciplines. However, S&E graduates also choose occupations outside the fields associated with S&T. The choice may be influenced by occupation and income expectations, but there are also softer factors such as the reputation of researchers and the social or cultural acceptance of S&T mentioned earlier in this section.

The source of the data which follows is the Community Labour Force Survey (CLFS), which is undertaken annually in the EU Member States by Eurostat. These data use some OECD definitions (cf. Canberra manual) on human resources in S&T (HRST), which do not fully correspond with the definitions of researchers and R&D personnel used in the first section of this chapter. In order to avoid confusion, it is necessary to clarify that the indicators analysed in the next paragraph are based on the HRST concepts.[3]

Occupation of people with higher education

An occupation in S&T is not the only employment option for people with S&T qualifications. In a knowledge-based economy, there are many jobs that are not directly related to sci-

[3] *The first indicator analysed is the number of persons with higher education or higher qualified – in the Eurostat/OECD wording it is HRST educated. The second indicator is the number of higher qualified people occupied in S&T – an overlap of HRST occupied in S&T and HRST educated - or simply HRST core. The third relevant indicator for the following analyses is the number of higher qualified unemployed people – HRST unemployed. Cf. the methodological annex for details.*

entific and technological development, and there is ever more demand in this area. For example, because of IT and other emerging technologies, there is a still unsatisfied need for highly qualified personnel in the service industries and manufacturing positions that have been transformed through the use of new technologies. This section looks at some of the occupations that draw on human resources in S&T.

Because people with S&T qualifications have a choice of professions outside science and technology, employers in S&T have to compete with employers from across the whole economy for expertise and skilled personnel. Twenty-three million highly qualified people worked in R&D in the EU in 1999. The three largest countries – Germany, the UK and France – host the majority of them (60%), about 14 million people. Italy comes next but was overtaken by Spain in absolute numbers in 1999. The Netherlands, Sweden and Belgium have the next largest level of S&T employment.

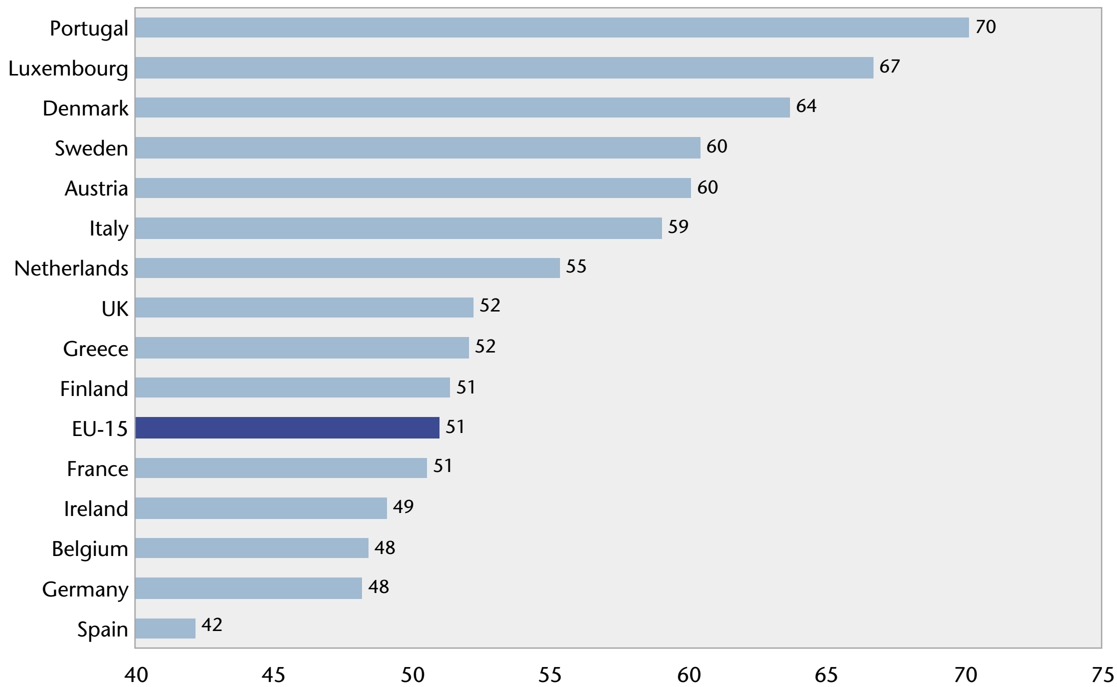
S&T employees among the higher educated

Much more interesting than the total figures, which are similar to the distribution of researchers across the Member States, is the relative number of higher qualified S&T employees compared to the population with higher education. The population with university degrees in S&E is not necessarily engaged in S&T, some work in jobs outside S&T and others are unemployed or inactive. Figures 4.2.14 and 4.2.15 show the proportions of higher qualified S&T employees in the population with higher education[4] for the year 1999 and the growth rates between 1994 and 1999.

In 2001, the highest percentage of S&T employees amongst the higher qualified population was found in Portugal (70%), followed by Luxembourg, Denmark, Sweden, Austria, Italy and the Netherlands, whose shares range between 67 and 55% (figure 4.2.14). The UK, Greece, Finland, France, Ireland, Belgium and Germany are at around the EU average of 50%. Some 42% of the population with higher qualifications in Spain work in S&T.

Most of the Member States have increased their proportions, with countries showing the biggest increases including the Netherlands, Spain, Greece and Ireland with percentage increases of between 4 and 11% per year (figure 4.2.15). Luxembourg's increase of more than 80% in five years is extraordinary, but given the small overall numbers it should not be over-interpreted. France experienced a sharp decrease of 14%, and the shares of Italy, Austria and the UK also declined, but to a much lesser extent.

Figure 4.2.14 Shares of higher qualified S&T employees of higher qualified population in % (2001)

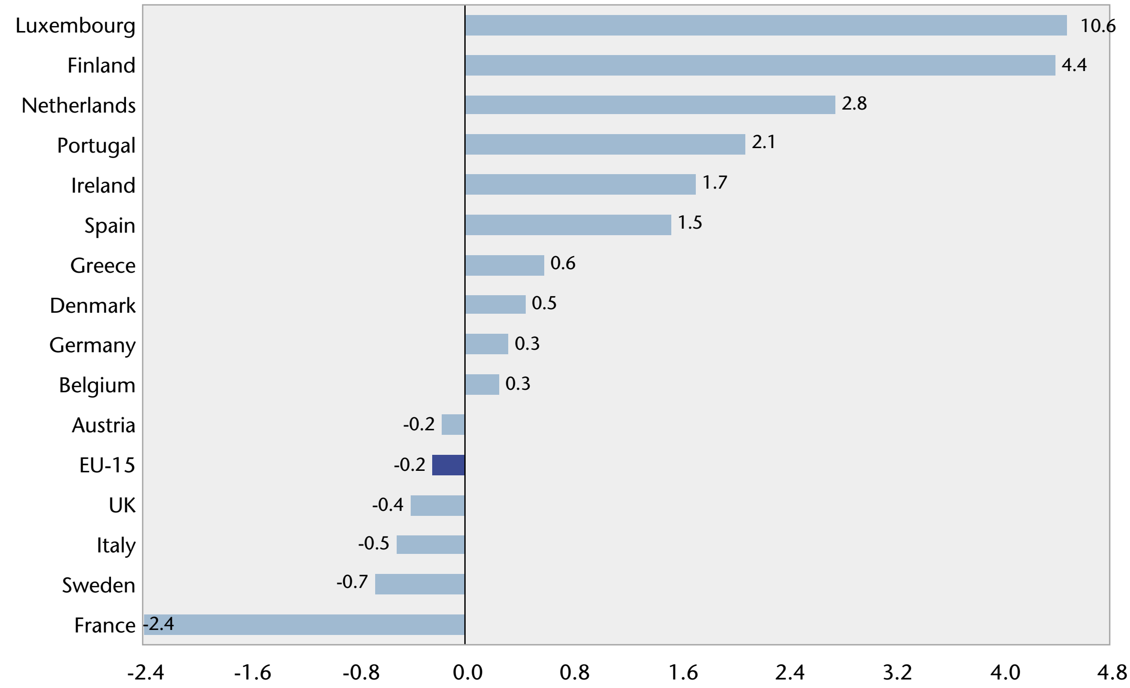


Source: DG Research
Data: Eurostat NewCronos CLFS, HRSTC, HRSTE
Note: A: 1997, S and UK 2000. The data for L are statistically not reliable.

Third European Report on S&T Indicators, 2003

[4] *These shares are derived from the fraction of HRST core divided by HRST educated.*

Figure 4.2.15 Shares of higher qualified S&T employees of higher qualified population: Average annual growth rates in % (1994-1999)



Source: DG Research
Data: Eurostat NewCronos CLFS, HRSTC, HRSTE. The data for L are statistically not reliable
Third European Report on S&T Indicators, 2003

Next, the age of S&T employees with higher qualifications is analysed. The database provides information on four age groups: people aged 25-34, 35-44, 45-64 and the remainder – those older than 64 or younger than 25. Figure 4.2.16 shows the proportions of these age groups as an EU average and for each of the Member States.

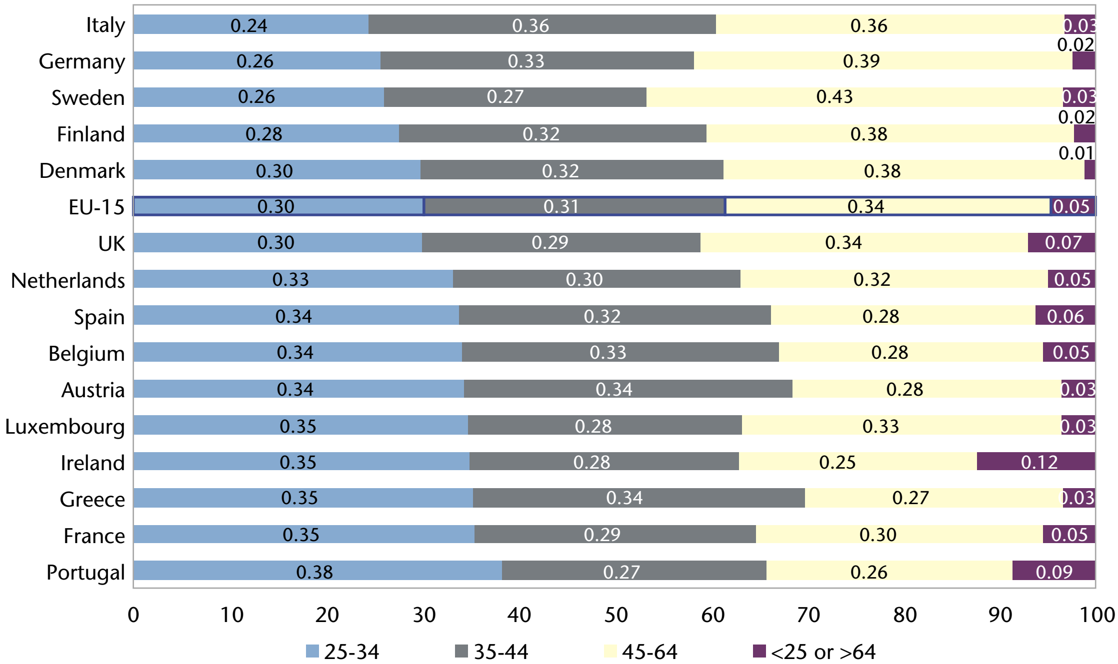
The proportions of higher qualified S&T employees are more or less equally distributed over the first three age groups, although the first two age groups cover only 10 years, while the third one extends over 20 years. In the EU average, 30% of the higher qualified S&T employees are between 25 and 34 years old. This percentage is lower in Italy, Germany, Sweden and Finland. The other Member States are around the average – or slightly above. In Portugal, the percentage is as high as 39%, which means that Portugal has, on average, the youngest higher qualified S&T employees. The second age group, 35-44, has a share similar to the first group with around 31% as the EU average. This proportion is slightly higher in Italy, Austria and Greece and lower in Luxembourg and Ireland.

The 45-64 age group shows an EU average percentage of 34%. It is much lower in Belgium, Greece, Spain, France, Ireland and Austria, and significantly higher in Sweden, Germany, Denmark and Finland. In the latter countries, the higher qualified S&T employees are older than the EU average. The fourth group cannot be described in terms of young or old because it is not possible to distinguish between those younger than 25 years and those older than 64 years among the higher qualified personnel. But it can be stated that in Ireland, Portugal and the UK this group is much larger than the average, which either means that these countries more commonly employ very young personnel, as a result of much younger age at graduation, or that they employ older personnel more or for longer than the other EU Member States.

Regarding shifts in the trends (not shown in figure 4.2.15), the oldest group of 45-64 years has the largest increases. In the EU average, an ageing of the higher qualified S&T employees can be discerned. This applies in most of the Member States, with the exception of Ireland, where it is the share of the youngest employees that has grown.

This section illustrates that there are signs of ageing populations, and particularly of the ageing of higher qualified S&T employees. The scenarios of insufficient young people, as analysed in section 4.2.1, seem applicable also to the highly qualified S&T employees. Without explicitly projecting to future developments concerning S&T employees, it is fair to say that the trend towards an ageing personnel creates an expectation of an increase in the replacement need in the future. This critical development is to be expected, not necessarily in the whole EU, but in the majority of its Member States.

Figure 4.2.16 Higher qualified S&T employees: Proportions by age: EU average and Member States 1999 (%)



Source: DG Research
Data: Eurostat NewCronos, CLFS, HRSTC
Note: EL: 1998, IRL: 1997. The data for L are statistically not reliable.

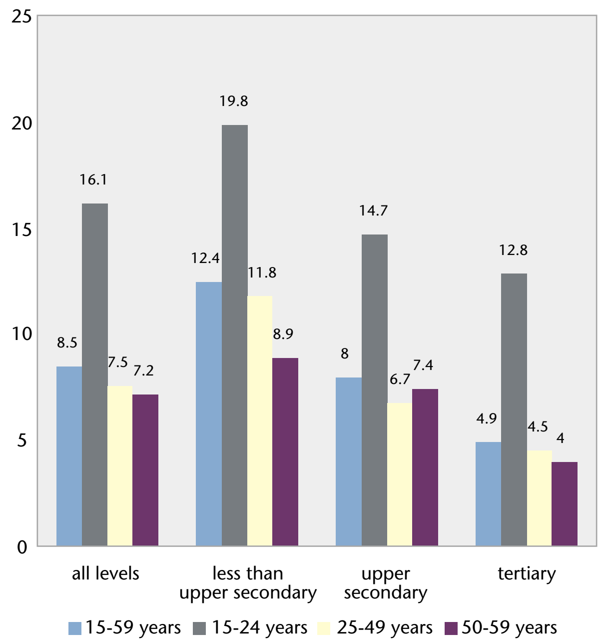
Third European Report on S&T Indicators, 2003

Unemployment of persons with higher education

What is the unemployment situation of people with higher education? A useful indicator from CLFS analyses the unemployment rates for those in the population with higher education (cf. definitions in the methodological annex). It is also revealing to examine the number of unemployed people, specifically those previously employed in S&T related occupations.

Unemployment rates differ significantly across levels of education, especially in the age group 15-24 (figure 4.2.17). For all levels, the unemployment rate is about double that for the average of all age groups and is extremely high, with almost 20% for those people who have less than an upper secondary education. In each age group the unemployment rates decrease with increase in level of education. Even the problematic 15-24 age group has unemployment rates of 12.5%, which is not much higher than the average of the least educated people. Taking into consideration that tertiary education is not usually completed before the age of 23 or 24 (but there are big differences between the Member States), this high rate is not a long-term problem for younger people and could be mainly due to job seeking and frictional problems (short-term mismatches between supply and demand) after finishing studies.

Figure 4.2.17 Unemployment rates by educational attainment level and age group: EU average in % (2000)



Source: DG Research
Data: Eurostat, CLFS 2000

Third European Report on S&T Indicators, 2003

Table 4.2.2 Unemployed HRST by EU Member States

	Unemployed HRST in thousands						Unemployed HRST as a percentage of total HRST						Non-HRST
	1996	1997	1998	1999	2000	2001	1996	1997	1998	1999	2000	2001	1997
Belgium	53	49	50	51	37	44	3.4	3.1	3.1	2.9	2.3	2.5	9.8
Denmark	29	23	23	21	18	24	2.9	2.4	2.3	2.1	1.7	2.2	5.6
Germany	456	515		459	395	381	3.1	3.5		3	2.6	2.4	11.3
Greece	50	50	61	73	66	62	5.5	5.4	5.9	7	6.5	6.1	7.7
Spain	605	605	603	536	494	465	14.6	13.8	13.1	11.1	9.6	8.7	19.4
France	366	392	419	418	348	317	4.8	5	5.1	4.9	4	3.5	12.2
Ireland	19	17	:	:	:	7	4.1	3.5	:	:	:	1.3	11.3
Italy	153	167	176	187	163	157	2.9	3.1	3.2	3.2	2.7	2.4	9.6
Luxembourg	:	:	:	:	:	0.6	:	:	:	:	:	1.1	:
Netherlands	74	68	37	32	33	31	2.6	2.2	1.2	1	1	1	5.3
Austria	9	9	8	:	:	:	1	1	0.8	:	:	:	4.9
Portugal	:	:	11	16	12	13	:	:	1.6	2.1	1.7	1.8	:
Finland	:	:	46	39	44	36	:	:	4.5	3.5	3.8	3.1	
Sweden	:	51	54	49	38	:	:	3	3.1	2.7	2.1	:	10.8
UK	275	233	:	216	185	:	3.1	2.5	:	2.2	1.9	:	7

Source: DG Research
Data: Eurostat, NewCronos database
Notes: The data for L and P are statistically not reliable. The column non-HRST shows the percentages of unemployed non-HRST of total non-HRST labour force

Third European Report on S&T Indicators, 2003

The data for all levels shows similar trends and substantial differences across the Member States. Table 4.2.2 shows the total numbers and the percentages of unemployed people with higher qualifications (unemployed HRST) for each EU Member State and comparative rates for people without higher qualifications (non-HRST).

In recent years in the EU, the total number of unemployed HRSTs has been at around two million, with decreases in most of the countries. In 2001, the largest number of unemployed HRSTs was in Spain (465 000), followed by Germany, France and the UK. In the same year, the percentages of unemployed HRSTs were between 1% in the Netherlands and 8.7% in Spain. Compared to the proportion of unemployed non-HRSTs in the last column, the rates for the unemployed HRST are significantly lower in all the Member States. This suggests that higher education qualifications are the best way to reduce the risk of unemployment.

On the other hand, the low unemployment figures show that the demand for people with higher qualifications is higher than for other people, which may indicate shortages on the supply side. The decreasing percentage of higher qualified people in most of the EU countries during the period 1994 to 1999 could also be a sign of the transition to the knowledge society, which implies labour market advantages for higher qualified people.

A special group among the unemployed is those who have already worked in S&T related occupations, either as a professional or as a technician. As explained in the Methodolog-

Table 4.2.3 Previous occupation of the unemployed 2000

	Unemployed people previously working as a :			
	professional	technician	professional	technician
	(total numbers)		(in % of the unemployed)	
EU-15	577 958	1 168 365	5.1	10.4
Belgium	15 950	21 750	5.5	7.5
Denmark	8 382	17 653	6.6	13.9
Germany	181 134	440 343	5.8	14.1
Greece	27 005	30 442	5.5	6.2
Spain	112 992	150 656	4.8	6.4
Italy	91 620	201 055	3.6	7.9
Austria	6 335	15 566	3.5	8.6
Portugal	6 501	26 201	3.3	13.3
Finland	23 463	29 403	7.9	9.9
UK	104 576	235 296	6.4	14.4

Source: DG Research
Data: Eurostat, CLFS 2000 and own calculations
Note: No data for F, IRL, L, NL or S which are not included in the EU sum and average

Third European Report on S&T Indicators, 2003

ical appendix to this chapter at the end of the report, the group of professionals is comparable with the group of researchers (but does not fully correspond), while the technicians provide the technical and administrative support for the professionals and form the residual of the R&D personnel. It is worthwhile to have a look at the percentages of unemployed (all levels of education) people who worked as professionals or technicians in their last job prior to being unemployed (table 4.2.3). This gives an idea of how many unemployed people would be potentially able to work in S&T related occupations as a result of their previous experience.

Across the EU, about 5% of unemployed people reported that they were last employed as ‘a professional’ while about 10% of the unemployed identified themselves as having had ‘technician’ occupations. This amounts to more than half a million professionals and nearly 1.2 million technicians. Taking into account that these statistics only cover ten of the Member States and that countries, such as France and the Netherlands, are not included, the total number for all the Member States can be estimated to be more than 750 000 professionals and 1.5 million technicians. This adds up to more than 2.2 million unemployed people who formerly worked in S&T. It is reasonable to assume that at least some of these people are potentially competent to fill S&T positions.

While the percentages of unemployed people formerly employed as professionals only range from 3.3% (Portugal) to 7.9% (Finland), the range is much wider for the technicians. In some countries, such as Greece, Spain and Belgium, the percentages do not differ much from the professionals’ percentages and are between 6 and 7.5%. In other countries, the percentages of technicians in the unemployed population are more than double those of the professionals. This can be seen in Denmark, Germany, Italy, Austria and the UK, with percentages between 7.9% (Italy) and 14.4% (UK). Portugal is a very special case with regard to people becoming unemployed after being in an S&T occupation. Former technicians in Portugal (13.3%) form a 10% higher share than former professionals (3.3%) among the unemployed people, which underscores the significantly higher share of unemployed technicians in the EU average and among the other Member States.

So what can be concluded from these unemployment data? Taking into account those formerly employed, both with and without higher education qualifications in S&T, there obviously are substantial S&T human resources, currently unemployed, that are potentially available for employment in S&T. From another perspective, one can conclude that the shortages experienced cannot be too significant if such a reserve of human resources, which could be accessed, is unemployed. However, compared to other occupations and other levels of educational qualification, this unemployment is still very low and probably not so much caused by a lack of opportunity as by other constraints, including deliberate choice of non S&T occupations or voluntary inactivity, which cannot be analysed with the currently available indicators.

Employment scenarios from an EC study

These findings do not tell the whole story about possible future shortages and challenges. In a EC funded study by Marey, de Grip and Cörvers (2001), possible employment scenarios for S&T graduates were developed. Important parameters analysed on the demand side are job openings due to employment growth (expansion demand) and due to outflow (replacement demand). On the supply side, the analysed parameters are S&T graduates in the four disciplines of natural sciences, technology and engineering sciences, medical sciences, and agricultural sciences.

In the study, four scenarios are built, combining the dimensions of economic growth (high/low) and human capital policy (high/low). Ex-post adjustments to distortions are overtime working, reduction of time spent on non-R&D activities and attracting researchers and S&T graduates from abroad and from other disciplines. Country forecasts are presented in the next paragraphs, some are given separately, and countries with similar outlooks are grouped. The results are calculated by adding up the demand and the supply in the Member States.

According to the findings of Marey, de Grip and Cörvers, the first group consisting of Belgium, Greece, Spain, Finland and the UK will have no major problems in employment in the period up to 2002. In France and Portugal, which form a second group, possible job shortages are foreseen for natural science researchers if a strong human capital growth policy is followed that will put pressure on existing jobs. Adjustments can be made to the demand side of labour markets by reducing time spent on non-R&D tasks and, in theory, by increasing working hours. But the problem is not serious and adjustment processes can solve the ex ante shortages.

A third group – including Denmark, Germany, Ireland, Italy, the Netherlands, Austria and Sweden – will experience shortages under all scenarios. In Denmark, there will be a deficit of natural scientists because the number of job openings exceeds the production of new S&T graduates. It will not be possible to address the problem with adjustments to either the supply side or the demand side. R&D tasks will have to be reallocated between natural scientists and engineers. Another possible solution could be to attract researchers from abroad. In Germany shortages of natural science researchers are also expected for the same reasons. The shortfall becomes even bigger in the scenario of a high human capital growth policy and low GDP growth. An oversupply of technology and engineering researchers could reduce the manpower shortage of natural science researchers, but not completely. In the worst case scenario, the number of available jobs even exceeds the total output of S&T graduates.

Ireland, the Netherlands and Italy will experience a shortage of medical science researchers. In Ireland, a reduction in non-R&D tasks of up to 26% is needed to match the inflow of new graduates. Longer working hours or recruiting foreign medical science researchers could be a short-term solution. In the Netherlands, a severe recruitment problem is also expected for natural science researchers. Job openings by far exceed the output of S&E graduates. Here it would not be possible to close the gap by reducing the time spent on non-R&D activities or by introducing overtime or using the excess of technology and engineering researchers. The effect could be rationing of R&D activities or inflow of researchers from abroad. Austria will also have a shortage of medical science and natural science researchers. In the case of natural science researchers, a reduction in the labour demand can solve the mismatch, which can further be corrected by applying the excess of technology and engineering researchers. The shortage of medical sciences researchers, however, should be taken seriously because it cannot be solved by either supply side actions or by demand side adjustments. The only solution again is to attract medical researchers from abroad.

According to Marey, de Grip and Cörvers, the prospects of Sweden are the worst – the country will face shortages in all fields in all scenarios. The situation will require far-reaching, complementary solutions, including a reduction of non-R&D activities, overtime and attracting more S&T graduates into research occupations.

The findings show that the situation with regard to shortages in S&T human resources varies greatly between the different EU Member States. The challenges of the future will be different in each and every country, which means that the individual countries will have to find the solutions that are the most appropriate for their particular conditions. A number of possible solutions have already been identified: shifting from non-S&T to S&T work, extending working hours and improving the appeal of S&T for students and employees. But there are also other solutions that are possible, such as attracting researchers from abroad or the integration of less well represented groups like women into S&T, which are issues covered in sections IV and V of this chapter.

It should be noted that all these possible solutions have to build on a broad base of well-educated individuals. In the next section, data on investment in education are analysed in detail.

Section III Expanding the knowledge base by investing in education

Making science and technology (S&T) more attractive and filling the positions available in S&T have financial implications. The question that has to be answered is whether public and private decision-makers are allocating enough money to the education and training of researchers. Is investment in education and training sufficient to maintain and extend the S&T knowledge base? While no data are available specifically on investment in science and engineering (S&E) fields of study, the expenditure on education as a whole gives some idea of the financial input into human resources and, for example, of the value placed on this by governments.

In the context of developing the knowledge-based economy, investment in efficient and appropriate education and training systems is of crucial importance for several reasons. Firstly, having a large base of well-educated and well-trained people is important to maximise “absorptive capacity”. This is crucial for the dissemination of new knowledge and its transformation into innovations that may create economic growth and welfare. Secondly, well-developed and effective education systems produce the researchers needed to create new knowledge, an essential element for future competitiveness. In an era of greatly increasing globalisation and ever more intensive competition, well-educated people and thus highly educated human resources, with a high level of basic qualifications, are key to facing the challenges of rapidly evolving economies.

The following analysis focuses on this second reason and the section gives an overview of the total expenditure in the EU on education and training, both by private and public sources, on different levels of education, with a specific focus on tertiary education. Expenditure during the 1990s is analysed, with breakdowns by level of education, source of financing, and country. In the figures and subsequent comments, comparisons are made between the efforts of the EU countries and those of the US and Japan. Comparisons of this nature are only possible when reliable data on the different countries are available.

1. Public and private investment in education

This section presents and analyses the evolution of total investment in education in the 1990s in Europe and beyond, using two indicators. The first, educational expenditure as a percentage of Gross Domestic Product (GDP), measures the efforts of countries in relation to the national wealth. It indicates what share of national resources is devoted to the financing of education. The second measures educational spending per capita, taking into account purchasing power parities. The second section examines the relative contribution of the public and private sectors to the financing of education, and its evolution over the past decade.

Educational investment in the EU, US and Japan

Figure 4.3.1 shows the “intensity of total educational expenditure” in the EU-15, Japan and the US in 1990 and 1999. It refers to the “total expenditure on educational institutions” as a percentage of GDP (figure 4.3.1a) and in euro per inhabitant (figure 4.3.1b). The data cover all direct and indirect expenditure on schools, universities and other public and private institutions involved in delivering or supporting educational services. They include all sources of funding – public, private and subsidised private – and all educational levels. Spending on research at the tertiary level can also be significant and is included in this indicator in so far as the research is performed by educational institutions.

As shown in figures 4.3.1 a and b, towards the end of the 1990s all EU countries were spending a significant proportion of their collective wealth on education. In 1999, 5.5% of EU GDP was devoted to the financing of national education systems, which represents, at the EU level, 1 056 euro per year per inhabitant (1995 prices). In absolute amounts and in current terms, European expenditure on education represents, (totals for 1999), about 440 billion euro (396 billion euro in PPS95). Countries with the highest intensity of spending on educational institutions were Denmark, Sweden, Austria and France, which were allocating more than 6% of national resources to education. This amounted to between 1 270 euro per inhabitant in France and more than 1 500 euro per inhabitant in Denmark. On the other hand, countries such as Greece, Ireland, the Netherlands and Italy remain clearly below the EU average with less than 5% of their GDP going to education, and a relatively low level of expenditure per inhabitant. In these countries, efforts to catch up in the years ahead will need to be important [5].

Despite the fact that some EU countries were investing comparable proportions of their wealth in education, the EU-15 as a whole was still lagging behind its main competitors, Japan and the US, at the end of the 1990s. In 1999, the EU invested 1% less of its GDP (5.5%) than the US (6.5%) in education. In terms of expenditure per inhabitant, the US also spent nearly twice as much as the EU. However, there are considerable differences within the EU: the country with the lowest percentage of education expenses in its GDP (Greece) reaches only roughly half of the percentage of the country with the highest value (Denmark). In terms of expenditure per capita, the differences are much more striking: in Greece educational expenditure is only slightly over one third of that in Denmark.

There is, however, some evidence showing that the EU is catching up. Expressed in absolute amounts and in real terms (1995 prices), total educational expenditure has been increasing significantly in all EU countries since 1990. Total educational expenditure rose on average by 2.5% per year between 1990 and 1999 and by 2.7% per year between 1995 and 1999 (PPS1995)[6], going from about 350 billion euro PPS95 in 1995 to 396 billion euro PPS95 in 1999. The highest real growth took place in Portugal, Ireland, Austria and Sweden. In all of these countries, real educational expenditure increased by more than 4% per year (and even by more than 6% in the case of Portugal). These major efforts allowed Portugal to catch up. Compared to other EU Member States for which data are available, Portugal was allocating in 1990 the lowest share of GDP to education. Since 1999, however, it is slightly above the EU average.

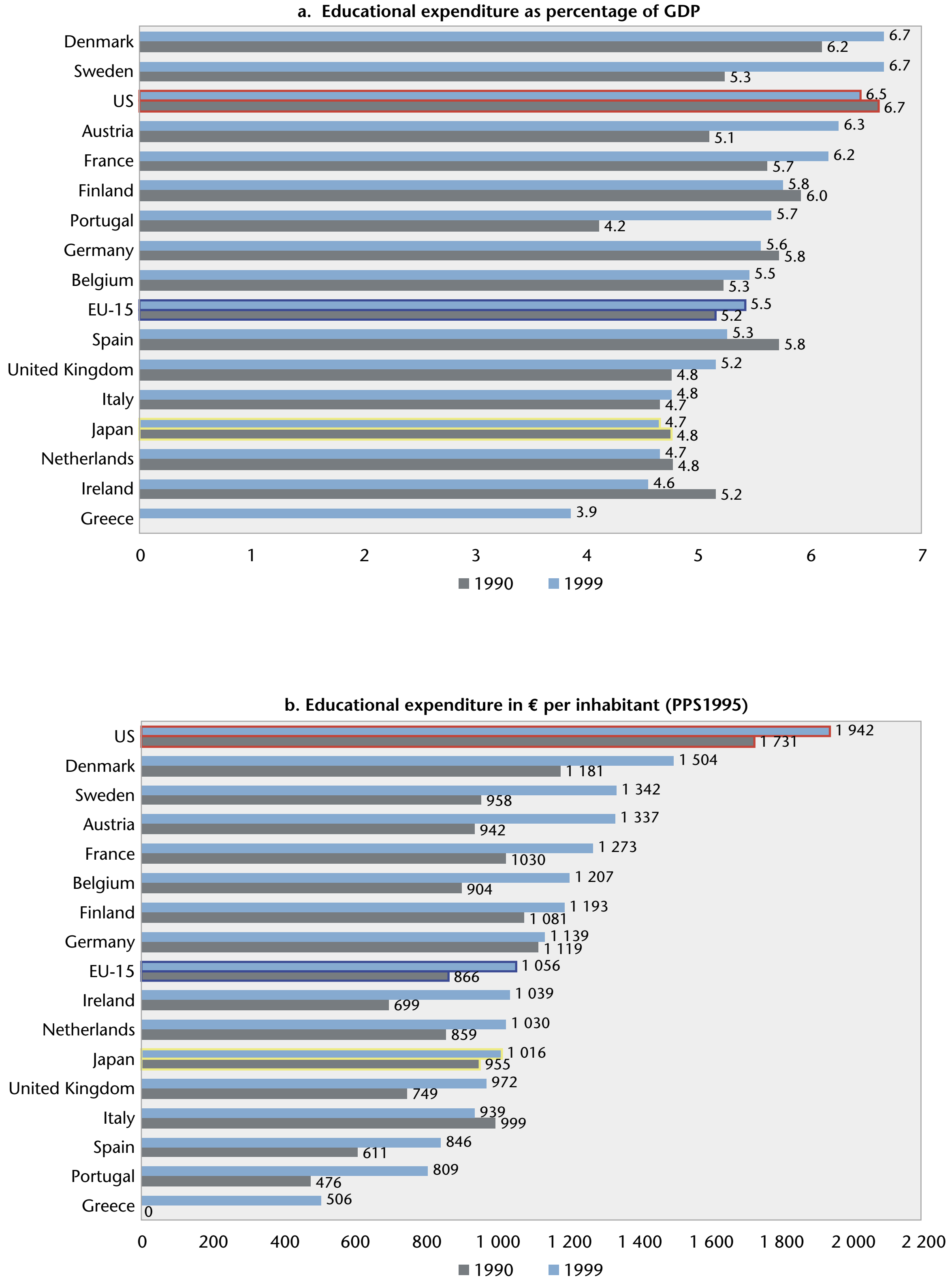
In this context, the real increase of educational expenditure in some Nordic countries, such as Sweden (4.2% per year) and Denmark (3.1% per year), where in 1990 the intensity of education expenditure was already among the highest in the EU, is remarkable. The overall intensity of total educational expenditure in Europe increased from 5.2% of GDP in 1990 to 5.5% in 1999. Therefore, compared to the US and Japan, which both experienced a slight decrease in the intensity of educational expenditure between 1990 and 1999, the EU-15 is catching up.

The increase in educational expenditure in Europe was not constant during the 1990s and slowed down in the second half of the decade. During the first half of the 1990s, educational expenditure grew faster than GDP in almost all the EU countries, with the exception of the Netherlands and Italy, leading

[5] *In the case of Ireland, it must be borne in mind that its relatively low intensity of expenditure in 1999 partly resulted from the exceptional growth in GDP during the 1990s.*

[6] *The figures referring to the period 1990-1999 do not include Greece, Luxembourg and Germany.*

Figure 4.3.1 Intensity of educational expenditure in the EU-15, Japan and the US in 1990 and 1999



Source: DG Research
Data: Expenditure: OECD 2001 and 2002; Population and GDP: Eurostat 2000
Note: Figures per capita are in € per inhabitant, in purchasing power standard of 1995. L: no data available - L is not included in EU average; EL: no data available before 1999; US and D: no data available before 1995, data of 1990 refer to year 1995; B: data refer only to Flemish Community; UK: only public expenditure available before 1995, total educational expenditure of 1990 is estimated; FIN: public expenditure only. Estimates: DG Research.

Third European Report on S&T Indicators, 2003

to an increase in average expenditure from 5.2% in 1990 to 5.5% in 1995. However, the trend began to slow down in the second half of the 1990s. In absolute terms, real educational expenditure did increase between 1995 and 1999, but no faster than real GDP. With the exceptions of Portugal, Sweden, Denmark and the Netherlands, all countries showed a decrease in the proportion of GDP allocated to educational expenditure.

The national resources devoted to the financing of education are influenced by many diverse though inter-related supply and demand factors. How many young people there are and the changes in these numbers, for instance, shape the potential demand for educational services. Enrolment figures, or the number of students and pupils registered at educational institutions as a percentage of the total population in the age group, indicate the level of participation in education, and correlate directly with variations in educational spending. The average duration of studies, which varies significantly between countries, can also influence the share of GDP devoted to education. Lastly, due to the labour intensive character of education, teachers' salaries represent a major part of unit expenditure.

In most EU countries, the increased intensity of educational expenditure during the 1990s is not the consequence of changes in demographic structure, since the ratio of school-age population to total population is decreasing in nearly all Member States. Instead, underlying factors may be found in the longer participation in education, as shown by increasing time in education and rates of enrolment. Indeed, the period of school enrolment grew during the 1990s in almost all the EU countries. In Finland, Greece and the UK, the increase was more than one year over the relatively short period of 1995-1999 (OECD, 2001, p. 123).

Enrolment rates for all levels of education also increased in nearly all EU Member States. Since compulsory schooling in Europe was raised to at least 14 years of age[7], the most significant increases have occurred at the upper secondary and tertiary levels (EC, 2000, p. 100). In most of the EU countries, policies of expanding youth education increased pressure to broaden access to tertiary education. During the 1990s, this pressure more than compensated for the relative decline of the school-age population. Partly, the increase in enrolment and the longer time spent in the education system also reflect critical labour market conditions. In a situation in which it is difficult to find a job, it seems to be a logical conclusion to stay in the education system instead of being unemployed. In this case, more years at university do not automatically express higher levels of skills that are relevant for knowledge creation in the economy.

It should also be mentioned that all figures presented here are referring to input into the education system. This perspective assumes that a similar amount of expenditure on education produces a similar level of qualification in different countries. However, this assumption can be quite problematic. The high cost of an education system is not automatically correlated with high quality; on the contrary, if students spend a long time in universities to finish their degree, this may result in a less efficient use of human resources than shorter degree courses. High costs per student (caused, for example, by high salaries for teaching staff or by inefficient administration) can limit the number of students who qualify per unit of input resources. However, discussion about the quality and appropriateness of the various education systems and the efficiency of education expenditure go beyond the scope of this report.

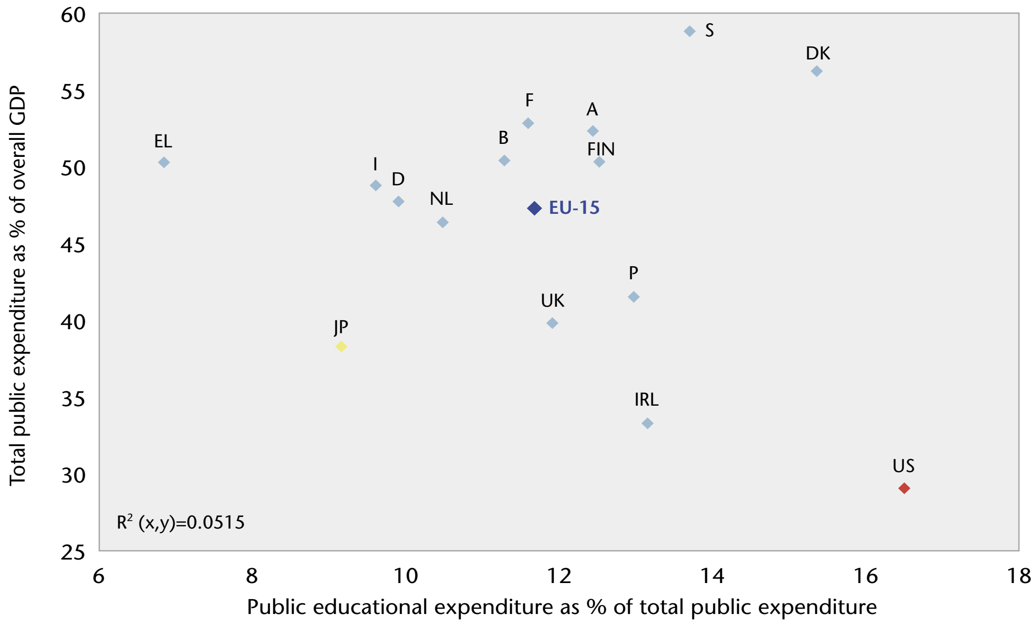
The role of public funding in EU education

Throughout the developed world, the belief of policy-makers that human capital is a key contributor to economic and social development has led to the provision of subsidised education. Theories of growth, competitiveness and development have supported this belief by arguing that education is a key factor for economic growth, and that its social rate of return is likely to exceed its private rate of return. Such insights suggest that not even a well-functioning market economy is likely to invest sufficiently in education to dispense with government subsidies. As there is no guarantee that markets will provide equal access to educational opportunities, government funding of educational services ensures that education is potentially within reach of all members of society.

Within the EU-15, public funding of education is a social priority, even in countries with little public involvement in other areas (figure 4.3.2). Furthermore, even in countries where the share of public spending in overall GDP is low, as in Ireland (33.2% in 1999), the proportion of public expenditure on education may be relatively high (13.5% in 1999). In the remaining EU Member States, where public spending accounts for more than 40% of GDP, there seems to be no systematic relation between the size of public budgets and the level of educational expenditure. Sweden, for instance, the EU country with the highest share of national resources spent by the public sector (58.2% in 1999), allocated the same high proportion of its public budget to education (13.7% in 1999) as Portugal (13.5% in 1999), a country with a relatively small public sector. Finland invests nearly twice as much of its public budget on education, as does Greece (12.4% in Finland and 6.9% in Greece in 1998). In both countries, public spending accounts for 50.5% of overall GDP. In Japan and the US, where welfare state commitments and public involvement are much lower than in Europe, investment in education represents a large part of total public expenditure.

[7] *In the EU, compulsory education ends at 14 years in Italy, 15 years in Luxembourg, Austria, Ireland, Portugal and Greece, 16 years in Denmark, Spain, France, Finland, Sweden and the UK, and at 18 years in Belgium, Germany and the Netherlands (EC, 2000, pp. 100-101).*

Figure 4.3.2 Share of public expenditure on education in total public expenditure, and share of total public expenditure in overall GDP, EU-15 Member States, 1999



Source: DG Research
Data: OECD 2002
Note: No data available for L. Figures for EU-15 is a simple country average calculated across all countries for which data are available. Estimates: DG Research.

Third European Report on S&T Indicators, 2003

The evolution of the share of public educational expenditure in the total public budgets indicates, especially in periods of budgetary constraint, the high perceived value of education compared to other public investments. During the 1990s, in the context of international agreements on macro-economic stability and economic convergence within the EU, most EU countries made serious efforts to consolidate their public budgets. All Member State governments looked very carefully at their public finances and the portfolio of activities in which they are engaged. Education had to compete for public financial support with other areas financed from government budgets.

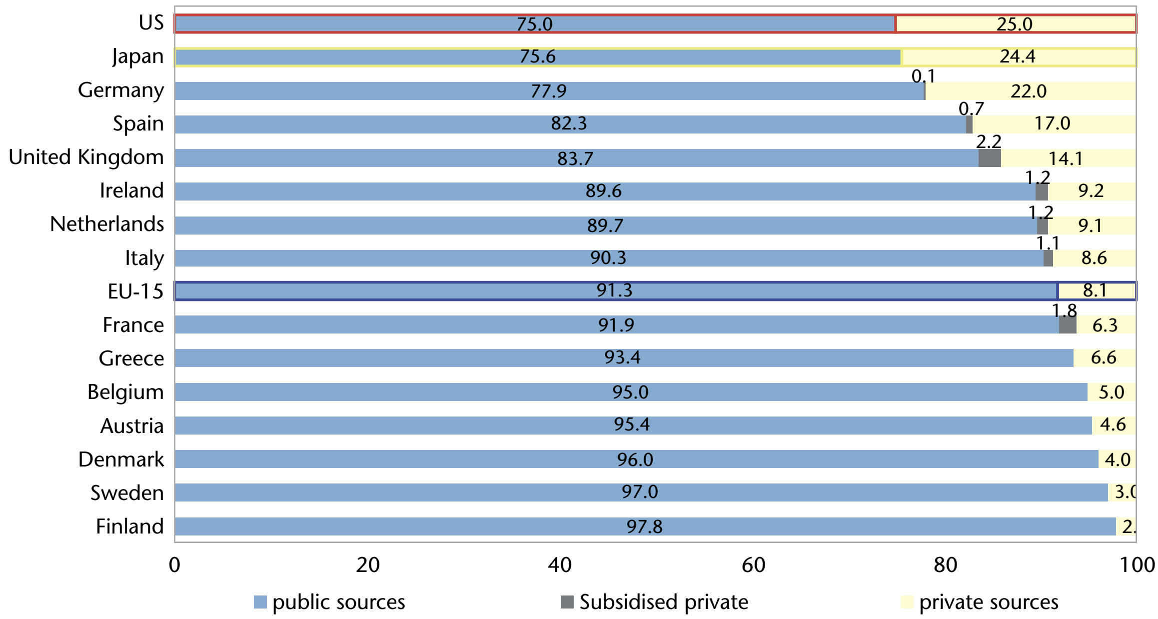
Despite the pressure that this budget consolidation process was putting on education and on other activities, it is remarkable that educational expenditure grew faster than total public expenditure in all EU countries during the 1990s. On average, in the latter part of the 1990s the proportion of public educational expenditure in total public budgets in Europe grew by about 1%: from 10.7% in 1995 up to 11.5% in 1999[8]. Countries with the highest growth rate in these areas were Sweden, Greece, Denmark and the Netherlands. In Sweden, the education share of public spending increased from 11.6% in 1995 to 13.6% in 1999, in Denmark from 13.1% to 14.9%, in Greece from 5.2% to 7%, and in the Netherlands from 9.1% to 10.4% (OECD, 2001, p. 100). Obviously, within Europe, processes of catching up go along with a continuous strong emphasis on education in the lead countries.

Public funds include subsidies to private entities for the purpose of education. Thus, private agents can engage in education either with financial support from public funds or they can rely entirely on private sources of finance. The level of government control in private education institutions will be higher in the first case and lower in the second, although recognition of qualifications through public certification imposes a certain level of control over standards through public bodies. Alternatively, governments can play a restricted role and leave private agents a broader manoeuvring space in which to organise unsubsidised education. Figure 4.3.3 shows the extent to which governments and private entities are involved in the financing of national education systems in Europe, the US and Japan.

The figure indicates the distribution of public and private funds to educational institutions. It includes the following for all levels of education: share of direct public expenditure on educational institutions, financial transfers to the private sector (subsidies to households and other private entities[9])

[8] *Calculated as the simple average across all countries for which data is available.*
[9] *Excluding the public subsidies for students' living costs, which are not part of the expenditure on educational institutions.*

Figure 4.3.3 Distribution of public and private expenditure on educational institutions, 1999
Distribution of public and private sources of funds for public and private educational institutions (after transfer from public sources), for all levels of education



Source: DG Research
Data: OECD 2002
Note: No data available for L. B, EL and UK: year of reference is 1998. Figures for EU-15 is a simple country average calculated across all countries for which data are available. Estimates: DG Research.

Third European Report on S&T Indicators, 2003

and the share of private payments to educational institutions (e.g. household spending on tuition fees, excluding public subsidies). To gauge the level of total public contribution to the financing of education, the first two categories must be combined.

Generally, schools, universities and other educational institutions are for the most part still publicly funded. In the EU-15, as well as in Japan and the US, at least 75% of financing is of public origin. Nevertheless, the EU-15 clearly differ from Japan and the US in the higher level of public funding. An average of more than 91% of the financial resources of EU education systems consist of direct public expenditure. This average is even higher if public subsidies to private entities are taken into account. In all EU countries, public funds represent more than 90% of financing, with the exception of Germany, Spain, the UK, Ireland and the Netherlands. With more than 95% of financing originating from public funds, the Nordic countries, Austria and Belgium have the highest levels of public contribution. Japan and the US, on the other hand, rely far more heavily on private sources for the financing of their education systems.

In all EU countries, and in the US and Japan as well, there are substantial differences between the way education is financed at the primary, secondary and tertiary levels. Tertiary level institutions mobilise far higher proportions of their funds from private sources (cf. next section about the financing of tertiary education). Primary and secondary education, usually perceived as a public good with mainly public returns, has a far higher recourse to public funding. In most EU countries, publicly funded primary and secondary education is also largely organised and delivered by public institutions. In some countries part of the public expenditure is transferred to private entities for an independent organisation of education. In these cases, governments pay a large share of the costs of primary and secondary education, but leave the management of educational institutions to the private sector. In Belgium and the Netherlands, for instance, most primary and secondary students are enrolled in government-dependent private institutions (58.3% and 76.3% respectively). In Spain and the UK, these proportions remain higher than 20%. Through this indirect public contribution, Member State governments seek to provide a wider range of learning opportunities including for students from low-income families.

Indeed, at the primary and secondary levels of education, private educational institutions that are mainly financed by household payments are often seen as discriminating against students from lower-income families, as these institutions are thought to provide education of a higher quality than public schools. In this context there is, once again, a clear difference between the EU-15 and Japan and the US. In Europe, private institutions that are predominantly financed through unsubsidised household payments represent only 4.6% of pupils and students, compared to more than 10% in the US and Japan.

Nevertheless, although public funds still represent by far the largest part of financing, the scale of private-sector funding of education increased in many EU countries during the second half of the 1990s. In the Netherlands real private expenditure increased by more than 60% between 1995 and 1999. In Portugal and Sweden it more than doubled during the same period, while public sector expenditure on education increased by about 20% only. At the European level, real private expenditure on education rose between 1995 and 1999 by nearly 50%, real public expenditure by less than 15% (OECD 2002, table B2.2)[10]. Although in most EU countries the sharp increase of private funding has not led to a decrease in public sector spending, cost sharing between public and private participants in the education system has become an issue for debate. The debate about the private or public financing and organisation of education is based on a set of diverse arguments. Some promoters of larger private involvement argue that private education yields superior results because of the financial incentives to improve performance. The introduction of competition (between public and private service providers and among private providers themselves) is supposed to raise the overall level of quality. Increasing choice for parents is another argument in favour of a mixed system. Finally, a general reduction of public engagement in all spheres of the economy and society is seen as a positive trend. It is especially relevant at the post-secondary stage of the educational cycle, where full or nearly full public funding is less common. This development, which concerns all the EU countries, is discussed in more detail in the next section.

2. Investment in tertiary education[11]

As shown in the previous sections of this chapter, the increased need for researchers in the knowledge-based economy has created an important additional demand for highly skilled graduates. In general, the demand increased most significantly in the fastest growing sectors of the economy, such as in IT and in business services.[12] However, it is also prevalent in manufacturing more generally due to structural changes in the skills content of jobs, as production has shifted to more high-tech manufacturing processes (EC, 2002, pp. 46-47).

Because of the permanent character of these changes, a drastic slowdown in the demand for highly educated people is unlikely in the near future.[13] This results in a strong emphasis on the allocation of sufficient, or increased, financial resources to tertiary education. More generally, this situation and the discrepancies it has created between the supply of and demand for human capital, shed new light on the role of tertiary education – especially that of universities, as providers of potentially highly skilled individuals – as well as on possible new forms of involvement of private agents in its financing.

This section starts by looking at the evolution of overall spending on tertiary education in the EU, Japan and the US during the 1990s. Then, it examines the contribution of the private and public sectors during the 1990s.

Tertiary education investment in the EU and US

High overall spending on education does not necessarily mean a high level of spending at all levels of education. Figure 4.3.4 shows the expenditure on tertiary education as a percentage of GDP in 1999. The data cover all expenditure (direct and indirect, public and private) on universities and other public and private institutions involved in delivering or supporting tertiary educational services.

This figure shows quite clearly how the US puts more emphasis than the EU on investing in tertiary education. In fact, the EU figure stands at only 1.3% of GDP spent on tertiay education, while the US percentage is 2.3%. Much can be said about regional disparities in these data, but it remains true that no single country in the EU spends as large a share of its GDP on tertiary education as the US. The EU country with the highest public expenditure per GDP on tertiary education are the Nordic countries Finland, Sweden and Denmark, all above 1.5% of GDP, followed by Austria with 1.5%.

In the EU and throughout the developed world, primary and lower secondary education is characterised by largely universal enrolment. Together with upper secondary education, which is also characterised by very high enrolment rates, these levels represent the bulk of educational expenditure. At the same time, higher spending per student at the tertiary level of education compensates for lower enrolment rates and causes the overall investment at that level to be higher than at the secondary level. In the EU, educational expenditure at pre-primary, primary, sec-

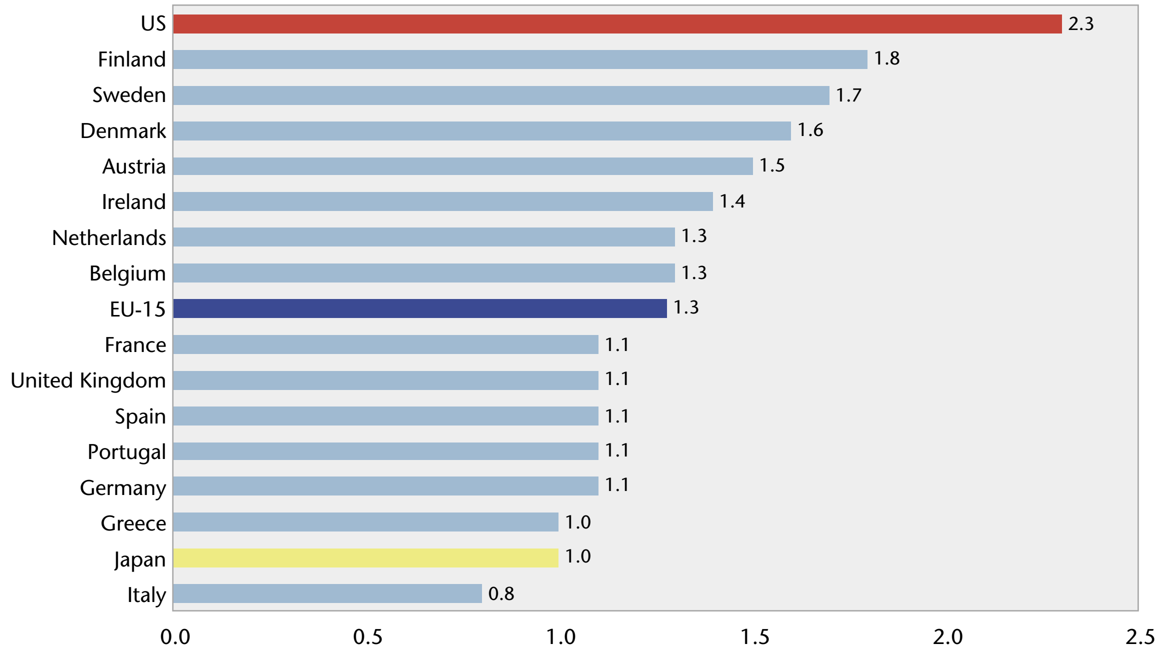
[10] *Calculated as the simple average across all countries for which data is available.*

[11] *Tertiary education is treated globally in this section. The International Standard Classification of Education (ISCED 1997), defines tertiary education as the sum of ISCED 5B, 5A and 6 (for more detail, cf. the methodological annex to Chapter 4 at the end of this report).*

[12] *The demand for university qualification does not refer to all disciplines. It is most acute in natural sciences (biology, biotechnology), engineering and information technology (IT). Very important new disciplines with a high level of demand are (1) the combination of mechanics (qualifying engineers for machine construction) and electronics, as well as (2) the combination of IT qualifications with knowledge about business processes and management.*

[13] *However, the insecurity in markets following the end of the excitement about what has been called the New Economy, has led to a decline in the demand for consultancy services and also to a slowdown in the realisation of internet applications. The related qualifications are still scarce, but the situation is less dramatic than a few years ago.*

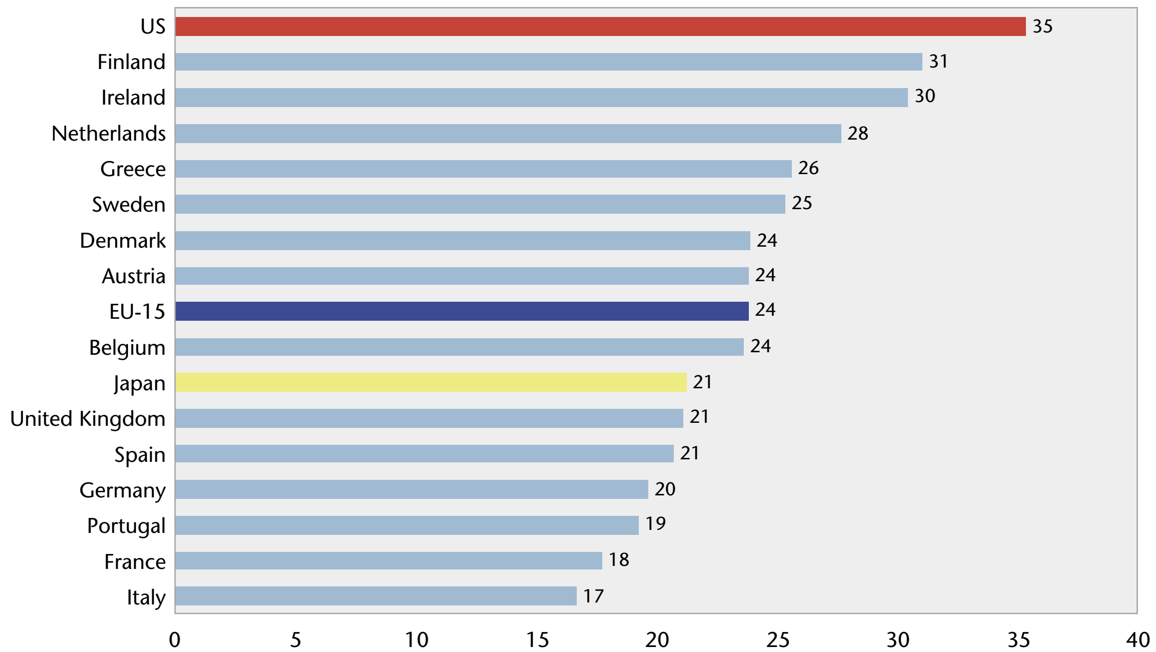
Figure 4.3.4 Expenditure on tertiary education as percentage of GDP 1999



Source: DG Research
Data: OECD 2001 and 2002
Note: No data available for L. B: public expenditure only. EU-15 figure is a simple country average calculated across all countries for which data are available. Estimates: DG Research.

Third European Report on S&T Indicators, 2003

Figure 4.3.5 Share of tertiary level expenditure in total educational expenditure, 1999 (%)



Source: DG Research
Data: OECD 2001 and 2002
Note: Countries are ranked in descending order of the proportion of educational expenditure at tertiary level in total educational expenditure. This figure does not include pre-primary expenditure. No data available for L. B: public expenditure only. EU-15 figure is a simple country average calculated across all countries for which data are available. Estimates: DG Research.

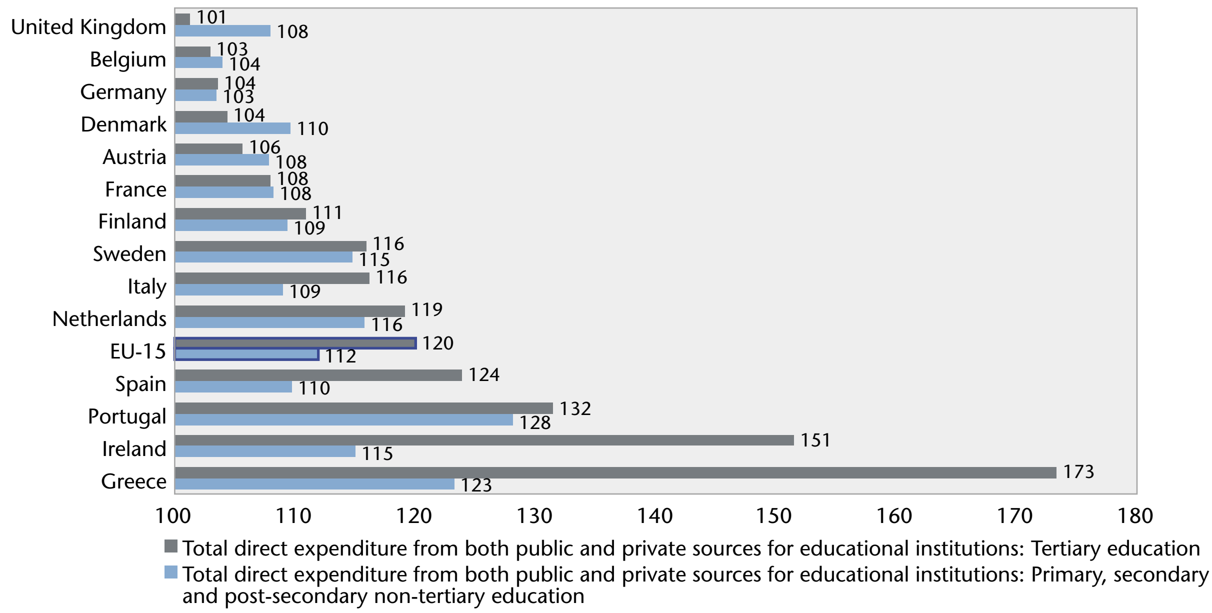
Third European Report on S&T Indicators, 2003

ondary and post-secondary non-tertiary levels in 1999 accounted for 76% of the total educational expenditure. Expenditure at tertiary level in 1999, on average in the EU, represented nearly one-quarter of the total expenditure on education (figure 4.3.5). When examining these data one should take into account that students at tertiary education level in Europe represent about 15% of the total student population enrolled in the entire education system (EC, 2000, p. 103).

The percentage of educational expenditure going to tertiary education varies significantly from one Member State to another. Countries such as Finland or Ireland invest 30% or more of their educational expenditure in tertiary education. Italy, France and Portugal, on the other hand, allocate a smaller share (less than 20%) of their educational expenditure to the tertiary level. Compared to the US, where tertiary education represented 35% of total expenditure on education in 1999, Europe allocates a much smaller proportion. It has to be borne in mind that these figures depend on enrolment rates and on demographic constellations. However, they also express differences in the approach to education and in educational structures and systems in different countries. Higher investment in tertiary education leads to the generation of highly qualified experts that can develop new technologies and create new knowledge. Intensive investment in lower levels of the education system, on the contrary, produces a broader diffusion within the population of less high ranking qualification levels. This second strategy is likely to facilitate the absorption and implementation of new technologies. These differences between the EU and the US are also reflected in different innovation styles.

Expressed in absolute amounts and in real terms (PPS1995), all Member States experienced increases in total educational expenditure during the 1990s (figure 4.3.6). Whereas in some of the Member States of the EU, such as Germany, Belgium, France, Finland and Sweden, the additional resources were allocated more or less equally across the different levels of education, in other countries the levels at which spending on education has increased vary. The UK, Denmark and Austria increased their spending on primary and secondary education at a higher rate than on tertiary education. In contrast, Greece, Ireland, Portugal, Spain, the Netherlands and Italy allocated far more of their additional resources to tertiary education than to primary and secondary education. At the European level, real expenditure on tertiary education rose between 1995 and 1999 nearly 10% faster than on secondary and primary education[14].

Figure 4.3.6 Index of change of educational expenditure 1995-1999 (in € PPS1995, 1995=100). Tertiary expenditure compared to expenditure at primary, secondary and post-secondary non-tertiary levels



Source: DG Research
Data: OECD 2001 and 2002
Note: No data available for L. B: no data available for 1999, change refers to period 1995-1998. I and UK: no data available for 1999 for non-tertiary expenditure, change in tertiary expenditure refers to period 1995-1999, change in non-tertiary expenditure covers years 1995-1998. DK: data for post-secondary non-tertiary are missing. Figures for EU-15 are a simple country averages calculated across all countries for which data are available. Estimates: DG Research.

Third European Report on S&T Indicators, 2003

[14] *Calculated as the simple average across all countries for which data is available.*

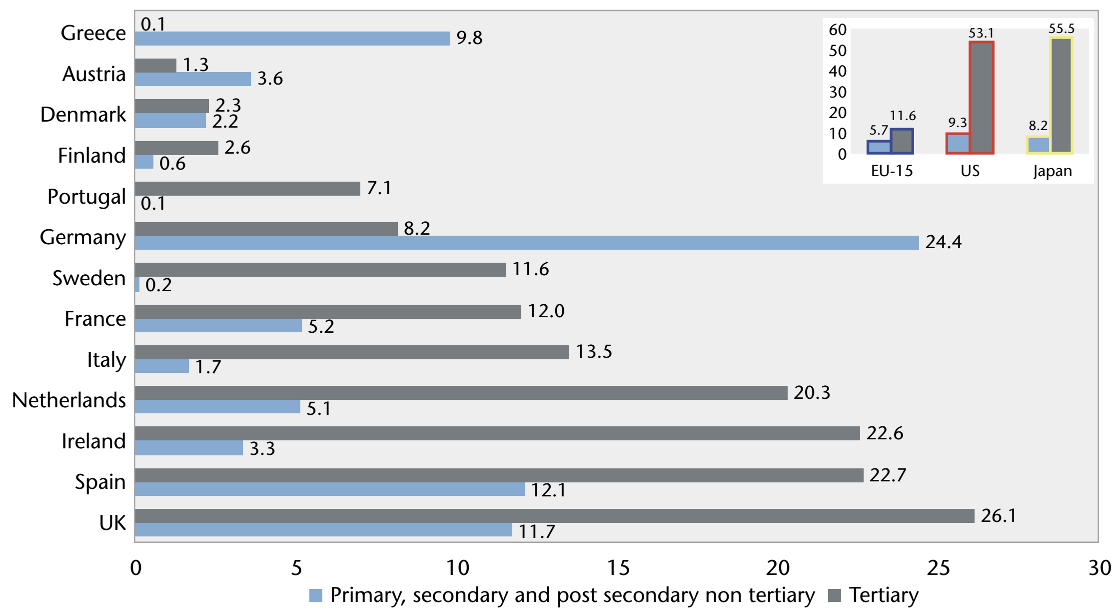
Expenditure on tertiary education during the 1990s grew slightly faster than overall GDP. In 1995 1.1% of European GDP was devoted to the financing of tertiary education; in 1999 it was increased up to 1.3% of GDP. In Finland and the UK, there was a slight decrease of the share of national wealth allocated to tertiary education (from 1.9% of GDP in 1995 to 1.8% in 1999 in Finland, from 1.2% of GDP in 1995 to 1.1% in 1998 in the UK). Conversely, at the end of the 1990s, Greece, Ireland, Portugal and Spain devoted a higher share of their GDP to tertiary education funding (from 0.70% in 1995 to 1.0% in 1999 in Greece, 1.3% to 1.4% in Ireland, 0.9% to 1.1% in Portugal, and 1.0% to 1.1% in Spain). The overall EU education gain on the US during the 1990s, previously seen in terms of growth of the total educational expenditure, has been primarily at the secondary, intermediate level, and much less so at the tertiary level.

Private funding of tertiary education

Full or nearly full public funding is less common at tertiary level. Figure 4.3.7 shows the contribution in 1999 of private sources to the financing of education in Europe, the EU Member States, Japan and the US, by level of education. In most countries, tertiary education relies far more heavily on private resources than do lower levels of education. On average, nearly 12% of the total funds for tertiary education in Europe originated from private sources, whereas such sources accounted for only 6% of the expenditure on primary, secondary and post- secondary non-tertiary education[15]. This phenomenon is present in nearly all EU countries; only Germany, Austria and Greece are exceptions. For Germany and Austria this arises undoubtedly from the organisation of the post-secondary non-university education in these countries, which is characterised by a high involvement of industry.[16]

Private sources seem to play a significant role in the financing of tertiary education in Europe. However, their contribution varies significantly from country to country, from less than 10% of total expenditure in Germany, Portugal, Finland, Denmark Austria and Greece, to more than 20% in the Netherlands, Ireland, Spain and the UK. Moreover, the involvement of private sources at tertiary level is much lower in Europe than in Japan or the US, where private sources represent more than 50% of total expenditure.

Figure 4.3.7 Contribution of private sources to financing of education. Share of private expenditure in total educational expenditure, by level of education, 1999



Source: DG Research
Data: OECD 2001 and 2002
Note: The 'share of private sources' does not include public allowances and subsidies to households and students. No data available for L or B. Denmark and US: Post-secondary non-tertiary included in tertiary education or missing. Japan: post-secondary non-tertiary included in both upper secondary and tertiary education. Figures for EU-15 are a simple country average calculated across all countries for which data are available. Estimates: DG Research.

Third European Report on S&T Indicators, 2003

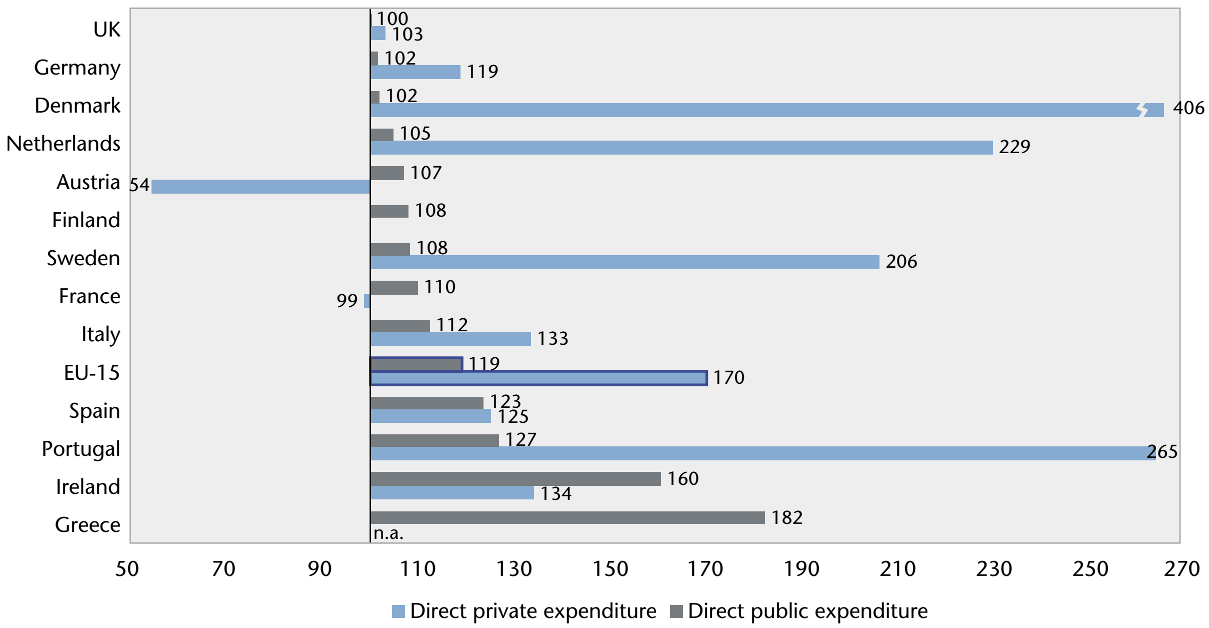
[15] *The figures are a simple country average calculated across all the countries for which data is available.*
[16] *Cf. for instance the concepts of Berufsschulen, Fachhochschulen and Berufsakademien in Germany, where the companies are involved essentially in training, traineeship and funding.*

The involvement of private agents in the financing and organisation of tertiary education is a matter of debate in many EU countries. Indeed, considering supply and demand discrepancies regarding highly skilled graduates, the question has been raised whether (increased) private funding of tertiary education would contribute to balancing skills and jobs, as market incentives would probably guide decisions and thus curricula to market needs. Private agents would be capable of changing curricula and qualification programmes with more flexibility than public universities. Various financing models exist, mainly based on sponsorship by large firms and foundations or on paying student fees. Quality control for private institutions is either left to the market or to certification by public bodies.

Figure 4.3.8 displays the overall growth between 1995 and 1999 of both private and public educational expenditure at tertiary level (in PPS1995 euro). It shows that private financing increased at a faster pace than public expenditure during the second half of the 1990s. In 7 out of 10 EU countries for which data are available, private funding clearly grew at a faster rate than public financing. In some countries, such as Portugal and Denmark, where the initial contribution from private sources was still very low in the middle of the 1990s, the overall growth between 1995 and 1999 was exceptional. However, in countries where private sources already by 1995 played a significant role in the financing of tertiary education, such as Sweden or the Netherlands, private financing followed the same trend. In other words, by the end of the 1990s, tertiary education relied increasingly on private sources for its finance. This is a result of deliberate decisions counting on private agents for more market responsiveness and greater flexibility, but also a consequence of the cutting back of public expenditure at the same time as being in a situation of growing needs for investment in the education system. However, it is interesting to note that there is no systematic relationship between changes in private and in public expenditure for tertiary education in the EU-15 Member States.

It appears that in most EU countries, public funding is seen increasingly as providing only a part – albeit a very important part – of investment in tertiary education. Private sources are playing an increasingly significant role in the financing of tertiary education. This arises from the increasing demand for tertiary education by new client groups and a demand for new types of qualification which are often acquired after an employment career has already started or is well advanced. Indeed, universities are no longer the monopoly of older adolescents. The number of adults aged 30 years or more who, already having obtained a tertiary level degree, are enrolled

Figure 4.3.8 Index of change between 1995 and 1999 of educational expenditure at tertiary level, by source of financing (in € PPS1995, 1995=100)



Source: DG Research
Data: OECD 2001 and 2002
Note: Countries are ranked in descending order, following the growth of direct public expenditure between 1995 and 1999. No data available for L and B. EL and FIN: only data on direct public expenditure are available. Figures for EU-15 are a simple country average calculated across all countries for which data are available. Estimations: DG Research.

Third European Report on S&T Indicators, 2003

[17] *According to a recent OECD survey, 18% of the interviewed adults aged 30 to 64 with a tertiary level degree, embarked on a complementary degree at a tertiary level institution in the year before the survey (OECD, 1999).*

for a complementary degree, is no longer negligible and is in fact increasing.[17]

With the increased participation of new client groups, and a wider range of educational opportunities, programmes and providers, governments are forging new partnerships to mobilise the resources necessary to pay for tertiary education. New policies are designed to allow the different players and stakeholders to participate more fully and to share the costs and benefits more equitably.

It is clear that tertiary education faces significant challenges, not only to increase the availability of educational services in order to meet a growing demand, but also to re-orient educational programmes towards changing needs.

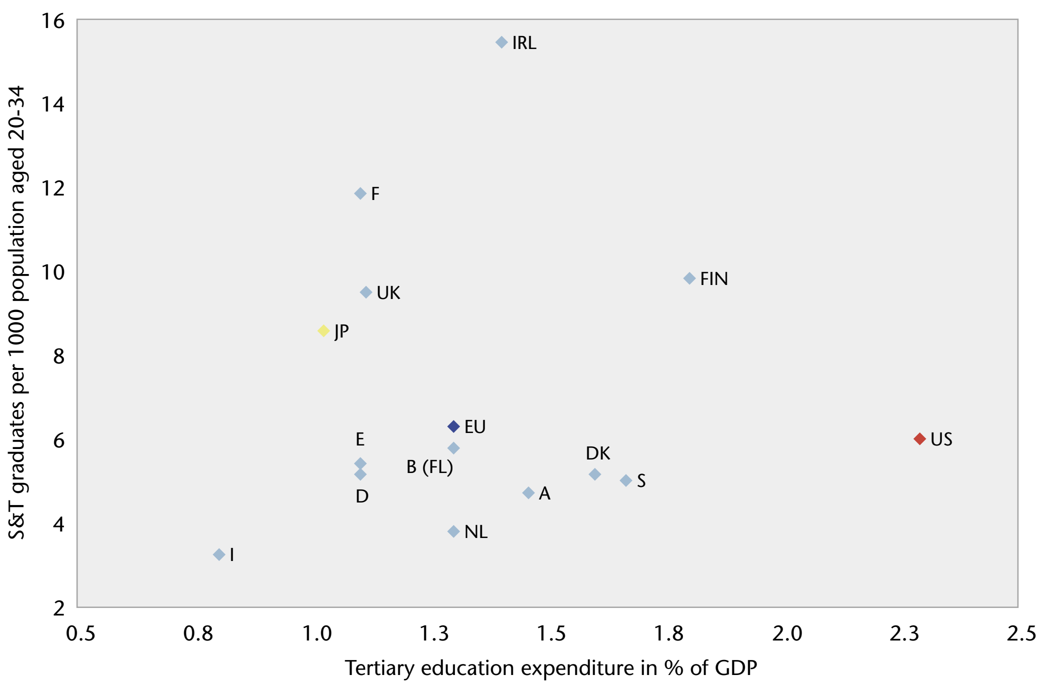
Investment in tertiary education and number of graduates compared

What is known about the relationship between financial investment in tertiary education and output in terms of S&E graduates? Figure 4.3.9 suggests that there is no direct correlation between the amount of money spent on tertiary education and the number of S&E graduates. Countries like Sweden, Denmark, Austria and the Netherlands spend more than the EU average on higher education, yet have a below average output of S&E graduates. The same applies to the US ratio, which is not very favourable – the US spends more than double the amount the EU spends on tertiary education (as a share of GDP), yet has a slightly smaller output of S&E graduates (among the younger population). In contrast, the UK, France and Japan are spending the same or less than the average on education, but have a much higher output of S&E graduates.

Looking at the number of all graduates, the links are not any clearer. There seems to be no direct connection between the input and output of higher education, and about the only thing the data show is that some countries are more productive than others. Clearly, there are other factors influencing the education supply line beyond financial contributions. In view of the differences in the organisation of education systems in the EU countries and Japan and the US, there is not necessarily a linear relationship between educational expenditure and the output or performance of the education system.

So, what can be concluded from these findings? Although a direct, immediate connection between monetary input into tertiary education and output in terms of number of graduates cannot be observed, it is quite clear that the investment in tertiary education is an important parameter for the quality of the higher education system. The maintenance of high level education both in terms of quality and quantity cannot be done without sufficient financial input. The effects are long-term rather than short-term, the EU still benefits from its past efforts in education. In order to make sure that the European

Figure 4.3.9 S&E graduates and tertiary education expenditure: Comparison 1998



Source: DG Research
Data: Eurostat/OECD 2001 and 2002
Note: EU average for 12 Member States. No data for EL, L or P.

Third European Report on S&T Indicators, 2003

tradition of both excellent and widespread education and therefore a broad base of highly qualified human resources will still be available in the future, a high level of investment in education is indispensable. Thus it is one obviously important element among others and if it is not achieved it will neither be possible to maintain the stock of human resources in S&T nor to increase it.

Section IV Attraction of researchers from abroad: Beyond brain gain and brain drain

The demand for employees with S&T qualifications is increasing with the growth of the knowledge-based economy. Shortages of research personnel in any country can be a serious obstacle to R&D activities, technological progress and economic growth. As the previous sections show there is a need for an increased supply of people with formal qualifications in S&T. One of the challenges of the knowledge-based economy is that people will have to upgrade their skills and knowledge as they progress along their career paths. The demand for people with good general basic knowledge as well as specific S&T skills will grow as the economy and society in general learn how to make better use of knowledge and skills.

Europe has for many years been, and continues to be, a wellspring from which countries such as the US, and to a lesser extent Australia and Canada, have been drawing personnel with S&T skills. The reasons for the exodus of European researchers are manifold and complex. What is clear, however, is that the US is the leading research country in many disciplines and technologies. US funding structures are generous and – which should not be under-estimated – most European researchers are able to overcome the cultural and linguistic barriers they encounter in US society.

What does this mean for the knowledge-based economy of Europe? The loss of human resources to the US may put a strain on national education systems and place EU employers in a position where there is severe competition with their US counterparts for S&T personnel. A more serious consequence could be that the drain of EU based talent and skills leads to a further relative strengthening and growth of knowledge-intensive industries in the US. Such observations are not new. The EU continues to struggle with the issue of how to participate in the global knowledge-based economy and support the exchange of knowledge and ideas, while maintaining a supply of highly qualified S&T personnel for its own economic and social needs. How can the EU make progress towards becoming “the most competitive and dynamic knowledge-based economy in the world” (European Council 2000)?

This section focuses on the migration of skilled human resources: in terms of skill loss from the EU and also from the point of view of skill gain through immigration into the EU. Immigration of skilled human resources constitutes a promising source from which expertise may be drawn to address probably daunting future shortages of S&T human resources in the EU. Studying and working in the European Union must be made more attractive to students, teachers and researchers from abroad, in order to be able to draw them into the EU’s human resource pool. Data on the migration[18] of S&E students and researchers between world regions suggest that the EU is attractive to foreign students. This appeal is generally based on educational motivations and considerations such as language, cultural and historical linkages. The factors and policies that facilitate the mobility and settlement of highly skilled people are summarised in the box below.

Supportive factors in the mobility of highly skilled workers, researchers and students

In advanced economies, ever-increasing attention has been paid particularly to attracting foreign researchers and talent. With the help of foreign talent, these countries hope to improve, for example, the balance between the growing need for competent professionals in various areas of the knowledge-based economy and the insufficient supply of graduates with relevant skills from their own universities. The following factors that influence the mobility of researchers and students, as well as highly skilled workers in general, can be identified.

Regulatory conditions and bureaucracy

- Immigration procedures can be a negative element if they are particularly complex, strict and slow. For instance, in the case of work permits for non-EU citizens, the administrative procedures required to get a permit vary considerably across the EU. It is important to simplify the processes of authorising work permits.
- Raising or abolishing the limits of entry quotas would balance the possible gap between supply and demand in

[18] *It is important to distinguish between migration and mobility. Geographical mobility is a tendency to frequently change one’s place of study, work and residence. Migration, however, also refers to movements that occurred long ago and to situations where there are no plans to move again in the future, i.e. the so-called ‘temporary’ migration. The data analysed hereafter does not necessarily cover the question of mobility. Aspects considered are place of birth, country of origin and nationality or citizenship. Thus, in this sub-section on the mobility of researchers, it is probably better to refer to migration rather than mobility.*

relation to visas. Easy availability of visas allowing spouses to work can be important for families.

- The availability of support, and assistance with immigration procedures facilitates the process of settling into a new environment.
- Faster, less bureaucratic systems are needed for obtaining ID cards.
- Practical arrangements, such as finding decent accommodation or social security programmes, should not pose problems. Accommodation can create a major bottleneck in attracting foreigners, particularly in regions with a high cost of living.

Institutional factors

- Institutional proximity (belonging to an area of regional integration, e.g. EU, NAFTA) or the existence of a common tradition of educational institutions and systems, are positive factors.
- Formal agreements between universities or funding organisations on accommodation and grants are an advantage. Mobility should be backed up by material advantages.
- Requirements to complete parts of the study programme abroad.

Economic factors

- High salaries (compared to those in other countries or countries of origin) attract skilled workers and salaries should be sufficiently related to the cost of living.
- The availability of tax breaks for expatriate specialists are an incentive for moving, especially in countries with high levels of taxation.

Availability of information

- Sufficient and transparent information on job opportunities, career prospects, possible grants, immigration rules, taxation and housing options, should be easily available. It should be easy to find relevant information in major languages and it should not be necessary to deal with a range of administrations whose activities are not co-ordinated.

Visibility, reputation of universities and availability of centres of expertise

- General appeal of the research and the education systems.
- The prospect of working with internationally renowned academics, research groups and universities, is a great draw for people leaving their home countries.

Cultural and language factors

- Cultural and language proximity promotes transnational mobility. The local language may be a barrier to foreigners if it is little used internationally. Good command of the language used in a host country is often a prerequisite for entering the labour market.

General lifestyle appeal of the host country

- Quality of life, safety, generous family support, cleanliness of the urban environment and proximity to nature, are all factors considered by highly skilled foreigners who are contemplating relocation.

Geographical location

- Distances to European centres, or to the immigrant's country of origin, impact on decisions to move.

Most European countries realise that in order to compete with the global frontrunners, they need to improve the international reputation and performance of their best research groups and centres. Policy measures to reduce obstacles and increase the appeal of the European Research Area receive additional government funding and support, and have been adopted in most European countries.

Sources: Boekholt, et al. (2001); European Commission (2001b, 2002); OECD 2002; Swedish Open (2001).

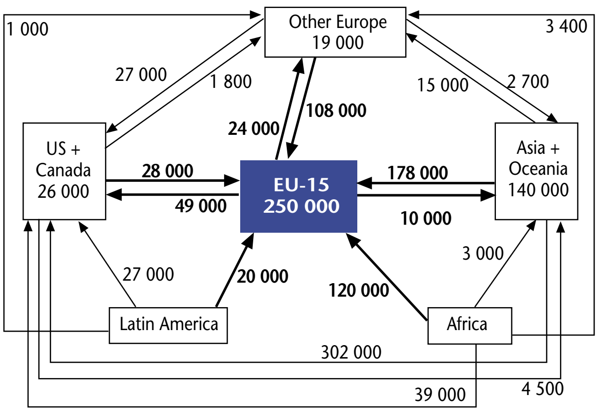
1. Migration between the world regions

It is useful to distinguish between two groups when analysing the movement of human resources in S&T: foreign students enrolled in the higher education system of specific countries (who are potential additions to the skills pool of that country) and foreign researchers and other personnel employed in S&T (ebbs and flows in the existing talent pool). This parallels the distinction drawn in the previous sections.

Migration of students

The OECD maintains a database on student enrolment by nationality for all its member countries. Unfortunately, the data exclude host regions such as Asia, Africa and Latin America, as well as some of the countries of Europe. Figure 4.4.12a shows the number of students enrolled in tertiary education in 1999 by region of origin, including permanent and non-permanent residents. The EU is a net recipient of students from Asia, Oceania and other European countries, and most probably also from Africa and Latin America. The only world region hosting more EU students than the numbers it is sending to the EU, is the US and Canada, which has a net balance in its favour of more than 20 000 students. The largest migration streams are some 300 000 students from Asia into the US system and the migration between EU countries (intra-EU) of 250 000. In the EU, the largest groups of non-EU students come from Asia and Oceania, numbering about 180 000 in total, followed by African students (120 000) and those from other European countries (110 000). EU students in the US and Canada (some 50 000 in total) form the largest group of EU students abroad, followed by 24 000 students in the US and Canada from other European countries. Although no data are available, it is fairly safe to assume that neither Africa nor Latin America play a major role in hosting EU students. Asia and Oceania host around 10 000 students which for the most part are based in Australia.

Figure 4.4.1 Migration between the world regions: foreign students enrolled in tertiary education 1999



Source: DG Research
Data: OECD
Note: The value inside the box represents the migration figure within the particular world region. The EU figures do not include EL and P. The host regions only include the OECD member states. "Asia + Oceania" is Japan, South Korea, Australia (1998) and New Zealand. "Other Europe" is Hungary, Poland, the Czech Republic, Norway, Switzerland, Iceland, and Turkey. Africa has no OECD member states. Latin America has Mexico. For the latter two world regions, the numbers of students they are hosting are not given. The regions of origin are complete.

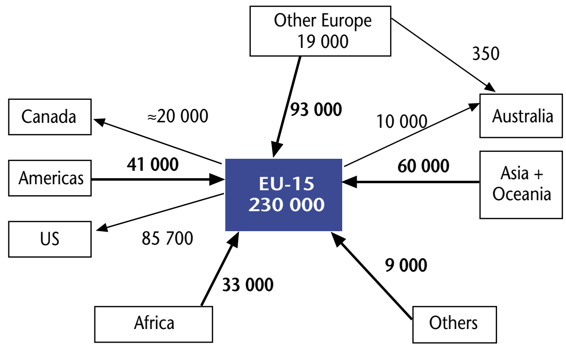
Third European Report on S&T Indicators, 2003

The data show that EU students going to the US form the most significant outward stream from the EU. The student influx into the EU from the US and Canada remains low compared to the influx from other world regions into the EU. The EU is the net recipient of 380 000 students from all other world regions, while the US and Canada are net recipients of 400 000 students. All other regions are net senders. The EU is noted as a popular destination for students from around the world. The large number of Asian students in the EU holds great potential for skilled human resources, not only in S&T.

Migration of S&T employees

Employment figures paint the following picture: In 2000, about 230 000 of those employed in S&T in the EU came from an EU member state other than their country of residence. Another 93 000 came from other European countries such as those in the European Free Trade Association (EFTA) and the Eastern European countries. 60 000 came from Asia and Oceania, and 41 000 have American (Latin America, US, Canada) origins. The number of S&T employees of African origin was 33 000 and 9 000 S&T employees were from other countries. These figures add up to a total of 466 000 foreign S&T employees in the different EU Member States, of which half are from outside the EU. This means that around 4% of all S&T employees in the EU Member States are from other countries and 2% are of them from outside the EU.

Figure 4.4.2 Migration between the world regions: Origin of non-nationals occupied in S&T in 2000



Source: DG Research
Data: EU: Eurostat: CLFS, NewCronos; US: NSF; Australia: Monash University; Canada: Statistics Canada
Note: Emigrants to Australia include the arrival of residents, visitors and settlers from 1997 to 2000 (see also Table 4.4.3). The number of emigrants to Canada is estimated by using the number of all EU residents with university education in S&T fields of study 1996 (see also Fig. 4.4.6). The value inside the EU box shows the intra-EU migration.

Third European Report on S&T Indicators, 2003

These figures have to be compared to the number of Europeans employed in S&T outside the EU. Only limited data are available from national databases allowing only rather tenuous comparisons to be made and conclusions drawn. Figure 4.4.2 only presents a general picture of the more important migration streams of EU-born S&T employees to the different world regions. Large numbers of people have gone to the US (85 700), Canada (20 000) and to Australia (10 000). This implies that it is very likely that the EU is a net recipient of students from all world regions, excluding the US and Canada. The employment patterns, therefore, do not differ greatly from the student patterns. The emigration streams are analysed and discussed in more detail below.

2. Emigration of students and researchers

In discussions on the mobility of researchers, it is common to present the emigration of European students and researchers as a threat to Europe's competitiveness in scientific fields and applied research. The exodus of highly qualified scientists and engineers, often described as 'brain drain', may weaken the field of research in Europe, while strengthening the continent's main competitor, the US. The long list of Nobel laureates with European roots (cf. the dossier on Nobel prizes) comes to mind. Yet, it may no longer be as appropriate to set the alarms bells ringing as it was in the past. Today, both the public and private sectors operate in a global marketplace of policy, trade and human resources. Researchers are mobile and encouraged to be mobile in order to increase the flow of knowledge and exchange of ideas.

It should not be forgotten that the best researchers nearly always have been mobile right from the time that medieval monks, who held the scientific secrets of all types of knowledge at that point in history, were sent from one seat of learning to another across the whole of what was their world. And many of these medieval monastic seats of learning have developed into the top universities of modern times.

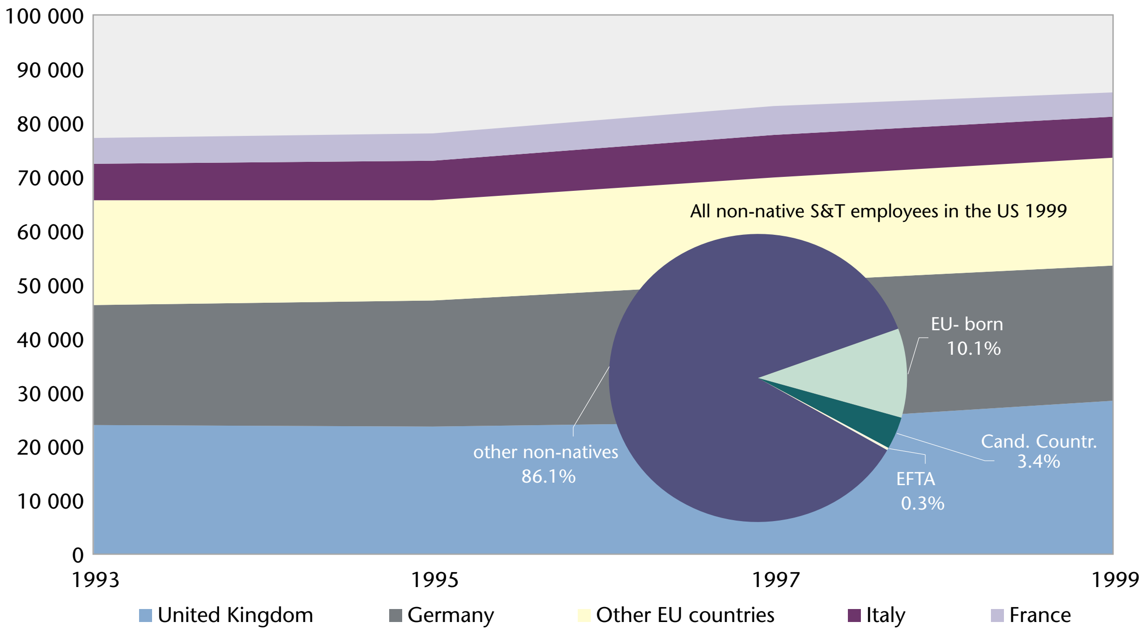
The drivers of growth that underlie the knowledge-based economy are exchange of ideas, knowledge creation and innovation. Knowledge creation and transfer lead to further knowledge creation. Researchers are the bearers of knowledge and they drive the transfer of knowledge, which ranges from regular work activities in one geographic area to extensive networking around the world. The knowledge creation process itself produces further embodied knowledge, i.e. experience and skills for personnel involved in the work.

The mobility of researchers, which may or may not lead to emigration, has certain positive effects on knowledge creation. A timely, even if limited stint abroad by (national) researchers is a valuable way of increasing the knowledge base at home in the long run, presuming that the researcher returns, or at least shares the knowledge in his or her home country. International mobility enhances the knowledge base of any society or country, but the danger of temporary international mobility becoming a permanent loss through emigration, is ever present.

Foreign-born S&T employees in the US

As mentioned earlier, one of the key streams of EU-born researchers goes to the Canada and especially to the US. In

Figure 4.4.3 Foreign born S&T employees in the US: total numbers 1993-1999, and shares of all non-nationals in % in 1999



Source NSF, treatment: DG Research
Data: NSF
Note: S&T, besides the very narrow definition used in this report, also includes social and behavioural sciences and agricultural sciences, according to the NSF definition of S&T. See the methodological annex.

Third European Report on S&T Indicators, 2003

1999, there were 85 700 EU-born persons employed in S&T in the US.[19] Most of them had come from the UK (28 400), followed by Germany (25 200) and Italy (7 700) (figure 4.4.3). This means that one in ten non-nationals employed in S&T in the US are EU-born. S&T personnel employed in the US from other European countries, such as the EFTA region and the Candidate Countries, account for another 4%. This indicates that the contribution of Europe in terms of volume does not make it the most important supplier region of S&T employees in the US.

Foreign-born higher educated people in the US

The number of people working as researchers abroad tells only part of the story of the movement of human resources in S&T. It is useful to examine the total numbers of higher educated people, which includes those with potential to work as researchers.

Table 4.4.1 Foreign born residents in the US with S&T degrees and PhDs in S&T in 1999

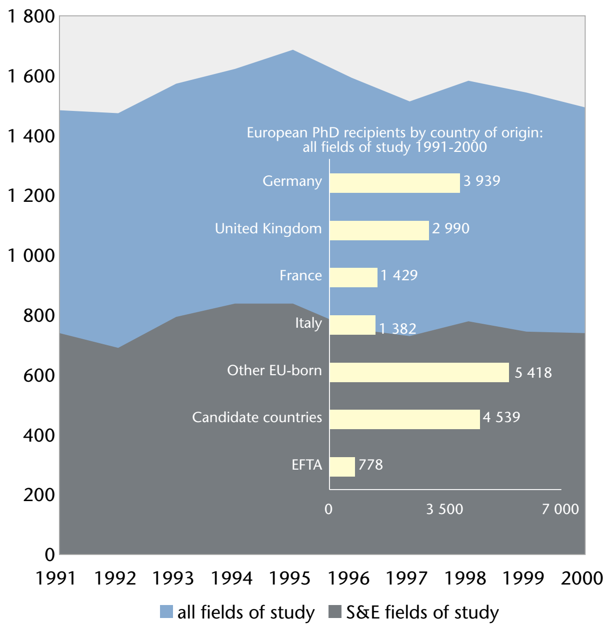
Place of birth	S&T degree	PhDs in S&T
India	164 600	30 100
China	135 300	37 900
Germany	69 800	7 200
Philippines	67 000	3 400
UK	65 400	13 100
Taiwan	64 800	10 900
Canada	59 400	8 400
Korea	46 700	4 500
Vietnam	44 300	:
Iran	39 900	4 800
Former Soviet Union	38 000	4 600
Mexico	31 700	:
Japan	30 700	2 800
Poland	:	3 200
Argentina	:	2 700
Other foreign-born	431 800	58 400

Source: NSF 2002
Data: NSF/SRS: Scientists and Engineers Statistical Data
Notes: Data does not include individuals with only foreign degrees who were not in the US in 1990. S&T means, beside the definition of S&E used in this report, social and behavioural sciences and agricultural sciences, according to the NSF definition of S&T. See the methodological annex.
Third European Report on S&T Indicators, 2003

Table 4.4.1 shows that people from Germany and the UK are not the largest groups of foreign-born, with the highest S&T degrees or PhDs. With around 70 000 people, all holding highest S&T degrees, both countries are far behind India and China, but at the same level as the Philippines and Taiwan. Where numbers of S&T PhDs are concerned, Germany also, and not surprisingly, comes below Canada. It is not possible to estimate the totals for the EU as a whole on the basis of these numbers, but it can be concluded that the overall number of S&T- educated people in the US that come from the EU, is no more than 400 000. This number is quite small when compared to the total number of tertiary educated people in the EU (40 million), which includes an estimated 11 million in S&T disciplines. Considering the increased need in the future for S&T human resources in the EU, the 400 000 people in the US could potentially be an important component of the required supply. It is important though, to distinguish carefully between those who are in the US temporarily and plan to return to their home countries, and those who are planning to stay permanently.

Between 1991 and 2000, a total of 15 158 US doctoral degrees were awarded to EU-born students. Among them

Figure 4.4.4 EU born PhD recipients in the US: 1991 to 2000



Source: DG Research/NSF
Data: NSF/SRS: Survey of Earned Doctorates
Note: S&E is science and engineering, according to the definition used in this report (see the methodological annex).
Third European Report on S&T Indicators, 2003

[19] *The 1999 figure includes EU-born persons who went to the US with a degree and EU-born persons who earned their degree in the US prior to taking up the S&T employment. The 1993 data set is the 'cleanest', after which accurate recording of EU-born persons arriving with degrees and entering employment directly without earning a degree in the US dominates. It is assumed that the 1999 figure undercounts EU-born persons who did not earn a degree in the US before entering S&T employment.*

were 4 000 German, 3 000 British, 1 400 French and just under 800 Italian students. Another 4 500 students from Candidate Countries and 800 students from the EFTA countries complete the number of European students studying in the US (figure 4.4.4).

On average, at least half of the degrees awarded each year were in S&E fields of study. Between 1991 and 2000, more than 7 500 EU-born students received US doctoral degrees in S&E. Annually, some 700 to 850 US doctorates in S&E are awarded to EU-born persons. The figure peaked at 838 in 1995 and dropped to below 750 by 2000. The trend in all fields of study is of a similar nature, and is an important indicator. It could signal a trend of declining numbers of EU-born doctorates emerging, or simply a short-term phenomenon.

The activities of EU-born students in the US after graduation

The National Science Foundation (NSF) tracks information on recipients of doctoral degrees with firm plans to pursue postdoctoral studies. An examination of the activities of EU born students upon graduation is interesting:

- Do they stay and pursue careers in the host country?
- Do they return home or do they relocate to a third country to work?
- How much of the success of the US in attracting foreign researchers is based on their being able to keep the foreign-born graduates?
- How did the plans of EU-born US doctoral recipients change over the period of a decade, in a global knowledge-intensive labour market?

In the first half of the decade, from 1991-1995, 69% of the 7 568 EU-born US doctoral recipients were located in the US (table 4.4.2). Among those who attained degrees in S&E, a lower share of 64% reported a US location. Over these five years, about half of those with doctoral degrees in an S&E field located in the US (1 690 of 2 393) reported firm employment plans. Among those who were already employed (703), about two thirds were in R&D and one sixth in teaching. By the second half of the decade, the share of the 7 590 EU-born US doctoral recipients located in the US had risen to 74%,

Table 4.4.2 EU born PhD recipients in the US with firm plans, by location of plans and primary activity

	1996-2000		1991-1995	
	all fields	S&E	all fields	S&E
Total, all locations	7 590	3 673	7 568	3 742
U.S. LOCATION				
Total	5 614	2 645	5 216	2 393
With firm employment plans	3 942	1 941	3 524	1 690
Post-doctoral study	1 352	1 102	1 235	987
Total employment	2 590	839	2 289	703
R&D	868	506	820	461
Teaching	1 098	134	849	119
Other	503	153	323	59
Unknown	121	46	297	64
FOREIGN LOCATION				
Total	1 976	1 028	2 352	1 349
With firm employment plans	1 241	613	1 432	829
Post-doctoral study	421	314	537	432
Total employment	820	299	895	397
R&D	359	150	395	225
Teaching	231	40	247	54
Other	175	83	126	56
Unknown	55	26	127	62

Source: DG Research / NSF
Data: NSF / SRS: Survey of Earned Doctorates
Notes: S&E is science and engineering, according to the definition used in this report (see the methodological annex)
Third European Report on S&T Indicators, 2003

and the share of those with degrees in S&E, had risen to 72%. During the second half of the decade, three quarters of the S&E doctoral degree recipients located in the US (1 941 of 2 645) reported firm employment plans. Of those already employed, 60% were in R&D and only 16% in teaching.

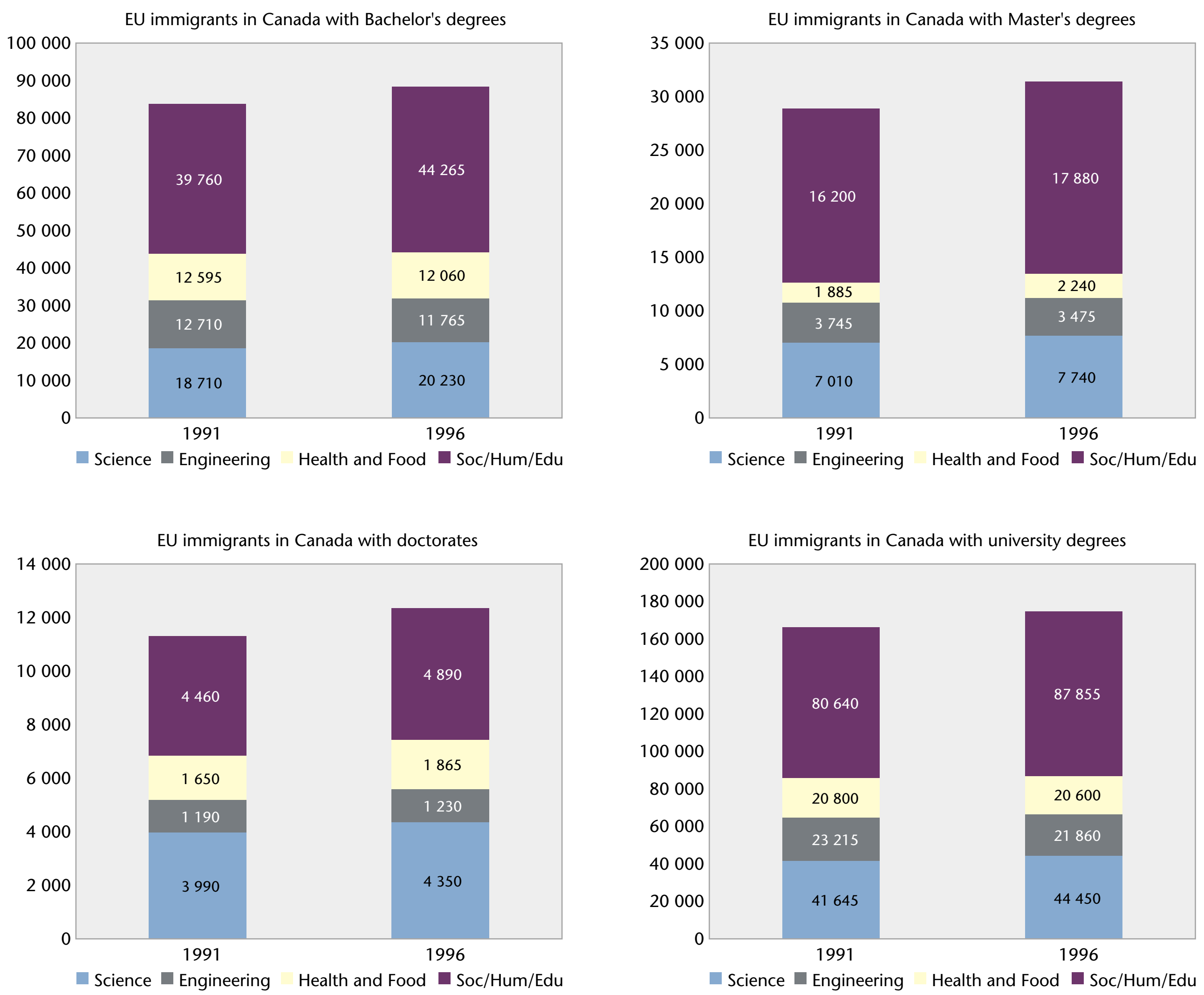
The locations of the EU-born US doctoral recipients outside the US are not known. They may have returned to their home countries in the EU or moved on to another country in the EU, or indeed anywhere in the world, to pursue studies or a career. Nevertheless, it is interesting to examine their plans as compared to those of their colleagues who stayed on in the US. Focusing on those with a degree in S&E, the 1991-1995 time frame saw 36% of the EU-born US doctorate degree holders located outside the US. Of the total of 1 349, 61% had firm plans – almost half of them for employment in the US. Of the employment offers, 57% were in R&D and 14% in teaching.

Between 1996 and 2000, the number of EU-born US S&E doctoral recipients located outside the US had dropped to 1 028, or 28% of the total S&E doctoral degrees awarded to EU-born persons. Among them, 60% reported firm plans – again more than half for employment in the US. One half were in R&D and 13% in teaching.

EU-born higher qualified people in Canada

Historically, Canada has also relied on the EU for skilled personnel. Although the data do not identify where degrees were obtained, an examination of Canada's labour force shows that the number of EU-born people with a bachelor degree rose by 12% between 1986 and 1996. An increase of 23% in the number of EU born people with master's degrees, and a 12% increase in doctorates were recorded. In 1996, there were

Figure 4.4.5 EU immigrants in Canada by level of education and fields of study



Source: DG Research
Data: Statistics Canada
Note: Non-permanent residents are included.

Third European Report on S&T Indicators, 2003

almost 89 000 EU-born people in the Canadian labour force with a bachelor degree, most of them in social sciences (19%), followed by education (14%) and engineering/applied sciences (13%). At the PhD level, the number of EU-born people rose from 11 025 in 1986 to 12 335 in 1996, and the predominance of people with mathematics and physical science specialisations continued. In 1986, 28% of EU-born persons in the Canadian labour force holding a PhD, specialised in mathematics/physical sciences, and in 1996 there were still 25% with similar specialisations. The second most popular field for those holding doctorates, was social sciences (figure 4.4.5).

EU-born S&T professionals in Australia

Australian data provide further information on the movement of EU-born S&T professionals. Table 4.4.3 shows the arrival and departure of S&T professionals from EU Member States and Candidate Countries in the periods 1997-1998 and 1999-2000.

The table gives a detailed overview of the permanent and long-term movement of employed people between Australia and the EU countries. A negative net migration characterises the flow of residents, while more visitors arrive from the EU than depart for the EU. The flows within the EU account for 52% of resident immigration and 50% of resident emigration.

Table 4.4.3 Australia: Permanent and long-term arrivals and departures for selected occupations by residence status and by last/next residence country (1997-98 to 1999-2000) sorted by total net (incl. settlers)

Last/Next	PLT Arrivals			PLT Departures		Net			
Residence	Residency status			Residency status					
	Resident arriving	Visitor arriving	Settler arriving	Resident departing	Visitor departing	Resident	Visitor	Total net (excl. settlers)	Total net (incl. settlers)
UK	3 083	3 385	1 411	5 241	1 319	-2 158	2 066	-92	1 319
Ireland	96	544	162	192	236	-96	308	212	374
Germany	169	423	156	236	140	-67	283	216	372
Netherlands	78	235	105	161	63	-83	172	89	194
France	95	285	55	170	113	-75	166	97	152
Italy	54	67	17	67	21	-13	46	33	50
Austria	29	47	21	31	17	-2	30	28	49
Belgium	61	62	19	64	33	-3	29	26	45
Denmark	12	56	17	30	29	-18	27	9	26
Finland	25	55	5	53	10	-28	45	17	22
Greece	39	11	10	48	8	-9	3	-6	4
Spain	29	25	4	45	11	-16	14	-2	2
Portugal	11	11	0	22	2	-11	9	-2	-2
Sweden	648	502	487	1 023	230	-375	272	-103	-37
EU total	4 429	5 708	2 469	7 383	2 232	-2 954	3 470	522	2 570
% EU of TOTAL	5 1.9	44.3	21.6	50.1	43.1				
Romania	5	7	125	5	7	0	0	0	125
Turkey	54	13	69	36	27	18	-14	4	73
Czech Republic	10	25	23	10	16	0	9	9	32
Poland	26	7	39	26	14	1	-7	-7	32
Malta	5	0	1	5	5	0	-5	-5	-4
Candidates total	100	52	257	82	69	19	-17	1	258
% candid. of TOTAL	1.2	0.4	2.2	0.6	1.3				
TOTAL	8 539	12 872	11 453	14 729	5 180	-6 190	7 692	1 502	12 955

Source: Birrell, B., Dobson, I.R., Rapson, V. and Smith, T.F. (2001), Skilled Labour: Gains and Losses, Centre for Population and Urban Research Monash University, Canberra.
Notes: EU is excluding Luxembourg.
Candidate contries only includes Malta, Czech Republic, Poland, Romania and Turkey.
Third European Report on S&T Indicators, 2003

For visitors, the figures are 44% and 43%, respectively. Settler arrivals are slightly lower than the other two components (22% of all settlers arriving). The data suggest several points for consideration, including the following:

- Europeans are more prevalent among residents categorised as computer professionals, and university professors and lecturers and all groups of non-S&T employees;
- Europeans prevail among the visitors who are chemists (for the arrivals), geologists and geophysicists, life scientists and engineers; and
- Europeans and residents are on an equal footing when it comes to finance managers, technology managers, chemists (for the departure side) and environmental and agricultural science professionals.

The comparative concentration of skills among EU expatriates in the last example, underscores that EU Member States should be proactive, both in retaining local talent and in attracting foreign skilled people. The insert below outlines some of the recent policy measures adopted by EU countries to improve their appeal as destinations for S&T skilled persons.

International mobility of human resources: Government policies to attract highly skilled foreign workers

All advanced economies find it problematic to maintain a self-sufficient supply of competence or specific skills in all fields of employment. That is certainly the case in situations where the demand for special skills increases rapidly as for example in the field of information and communication technologies (ICTs).

Traditionally, this kind of problem is considered to be typical of smaller economies where the markets and human resources might be too limited to provide a sufficient supply of essential skills. Currently, the problems of insufficient supply of highly skilled workers or lack of critical mass in a given field of economic activity apply to all economies irrespective of the size of a country, the number of university graduates turned out annually or the quality of the education system. In general terms, because of these problems, "immigration policies in a number of countries have become more selective and skills based, while shortages of certain specialists … have led to more relaxed immigration policies for skilled workers" (OECD 2002: 72).

The growing importance of human competence and the increasing mobility of such individuals are creating an emerging global market for skills (Swedish Open 2001, see also footnote 1). Scientists, academics, and senior executives have been functioning in a global market for a long time, but now there are whole classes of jobs characterised by a huge gap between the demand and supply of human resources. This means that certain skills or competencies are so specialised or in such short supply that they are tracked on a global basis. For instance, the Information Technology Association of America has estimated that employers created a demand for 1.7 million IT workers in 2001 but that only half of these positions were filled. The London based International Data Corporation estimates that by 2003 the number of unfilled technology posts will rise by 300 000 in the UK and 1.7 million across Europe. As a result, concerted efforts are under way in many developed countries to attract highly skilled foreigners.

In the United Kingdom, it has been made easier for firms to bring in foreign IT specialists. IT skills have been added to the list of official shortages at the Overseas Labour Service so that companies can obtain work permits for recruits more quickly and efficiently. A new work permit system will help meet present and future demands for highly skilled workers. Foreign graduates with skills currently in short supply in the UK will no longer have to demonstrate two years of post-graduate work experience before they can apply for work permit. One of the unusual measures is a pilot scheme involving multinational employers who are authorised to issue their own permits for workers currently employed abroad and who wish to transfer to the UK.

Ireland has realised the need to act quickly to lure skilled workers from overseas. The Irish government has calculated that it will have to bring in 30 000 overseas workers annually, for the next three years, to fill all vacancies and sustain its economic boom. In 2000, Ireland launched a world-wide promotion to attract 200 000 foreign workers to Ireland over five years. Recruitment campaigns were launched in the UK, France, Germany, Canada, Australia, New Zealand, the Czech Republic, Latvia, Russia, South Africa and India. Early results show that the drive may well exceed its targets. To complement this, immigration rules have been eased. In the sectors of the labour market where skill shortages are particularly acute, a working visa and work authorisation scheme has been introduced. This makes it possible for prospective employees with job offers from employers in Ireland, to obtain immigration and work clearance in advance.

In order to meet the demand for 50 000 additional skilled workers, Italy introduced new and simplified rules in 2000 to attract about 1 000 Indian software professionals. In addition, the government announced that immigrants who arrived before March 1998 and have a job and an address, could apply for residence permits.

Germany has also recognised that the speedy processing of work permits is a key competitive advantage in attracting skilled workers. In 2000, a law was passed in Germany issuing "Green Cards" for computer specialists from non-EU countries. The processing time for an application is expected to be a week. A "Blue Card" is also available to simplify and expedite the recruitment of experts in various professions from foreign countries. This card targets those professions in which vacancies would lead to a harsh competitive disadvantage for Germany. The Federal Government and the IT sector have agreed on an immediate programme to alleviate the shortage of specialist staff. Up to 20 000 foreigners with university degrees and resident in countries outside the EU, may obtain work permits for a maximum of five years. This also applies to foreign students at German universities upon successful completion of a study course with a main subject in an ICT field.

Finland has also simplified and speeded up its work visa procedures. Immigration can be arranged relatively easily with the backing of an employer organisation. Generous social security programmes are freely available to work permit holders. As a result, Finland is attracting technology experts from India, China and from less developed countries.

Swedish policies regarding highly skilled foreign workers are neutral at best. Immigration policy is geared toward asylum seekers and family (re)unification, with the result that workers from countries outside the EU encounter significant entry obstacles unless companies sponsor them (5% of immigrants were workers in 1998). In terms of specific initiatives, the decision to allow foreign workers to earn the first 25% of their salaries free of taxation is a positive step, but only gives Sweden parity with other leading European countries. While countries are now actively seeking out foreign IT professionals, Sweden has not made any visible attempts to do the same. However, the recent report by the Invest in Sweden Agency contains numerous recommendations to government, corporations and universities to improve Sweden's appeal to highly skilled workers. The recommendations include, for instance, changes in overall policy on immigration (less bureaucracy in work permit authorisation and residency processes, more international marketing and information on job opportunities in Sweden). The need is also recognised to bring foreign employees of multinationals to Sweden, to develop non-Swedish talent (businesses should be responsible for this) and to allow foreign students to work in Sweden after graduation.

In the US, a bill to increase the number of visas for highly skilled foreign workers was passed in the Senate in 2000. This measure will increase the number of skilled foreign workers (mostly from China and India) allowed into the US. Steps have also been taken to allow faster visa application and issuing procedures via the Internet. Using an online application form, officials are aiming for decisions on 98% of applicants within three months. Thus, in addition to obtaining more highly qualified workers through immigration, more attention has been paid to simplifying the entire work permit authorisation process, to the speed of administrative processes and to other formalities of settling into the country. In many other countries, similar issues have become more prominent on the political agenda.

The above policy measures also apply to a degree to attracting researchers from abroad. Some measures apply specifically to researchers, such as those adopted in France. (Boekholt et al, 2001, see also footnote 2) France recently developed a package of measures to make the research system more open and attractive for foreign researchers. One of the motivations behind these measures is the fear of "brain drain". In order to attract foreign researchers, a number of budget lines are reserved for this purpose. Firstly there is "Les chercheurs de haut niveau – high level researchers" in terms of which around 80 high-level researchers are financed to stay in France for between one and five months. Postes PAST: "Les professeurs associés pour une séjour temporaire - temporary visiting professors" is a programme which funds visiting research professors in universities for one to three years, with openings for 60 professors per year. They are employed under the same conditions and rules as French professors. Lastly, a new post-doctoral programme started in 1999 allows young researchers to obtain positions in French laboratories.

However, attracting foreign researchers is not sufficient to meet the demand for scientists in the French R&D system. For example, a problem has been experienced with the emigration of highly skilled researchers (e.g. computer scientists) to the US. French researchers have been attracted to the US by the flexible structure of career paths and salaries, as opposed to the more regulated environment in their home country. Brain drain in ICT-related R&D, as well as in fields such as chemistry and biology, seems to happen mostly with researchers who have four to five years of experience in France, or experience at the post-doctoral level. Partly because of the difficulty of finding an appropriate job after attaining a PhD in some disciplines, around 30% of post-doctoral studies are pursued abroad. Young researchers who have not been integrated into a research laboratory in France before leaving have great difficulties upon returning.

In order to reduce the drain phenomenon, particularly in high-tech fields, a high-level working group has made two recommendations:

- there should be incentive systems and schemes that offer researchers tempting contracts in France; and
- measures such as subsidised employment contracts promoting the return of French researchers – especially those with PhDs – should be launched.

There are some hints that France is becoming less attractive (again in favour of the US) for researchers, especially those at PhD level. The share of foreigners who completed their doctoral theses in France decreased from a third in 1992 to less than a quarter in 1997.

Sources: Boekholt et al. (2001), Swedish Open (2001), OECD 2002.

Notes: (1) The following text is based on the report by Invest in Sweden Agency (Swedish Open , 2001).
(2) The text below is derived from the report prepared by Technolopolis (Bakholt et al., 2001).

3. Foreign students in the EU: A starting point for attracting researchers

It is clear that international mobility is not necessarily a drain on human resources, as it may provide benefits for both supplier and recipient countries. What needs to be examined, is whether this also holds true in the case of students, who often leave their host countries after their studies and return to their country of origin, or move on to a third country.

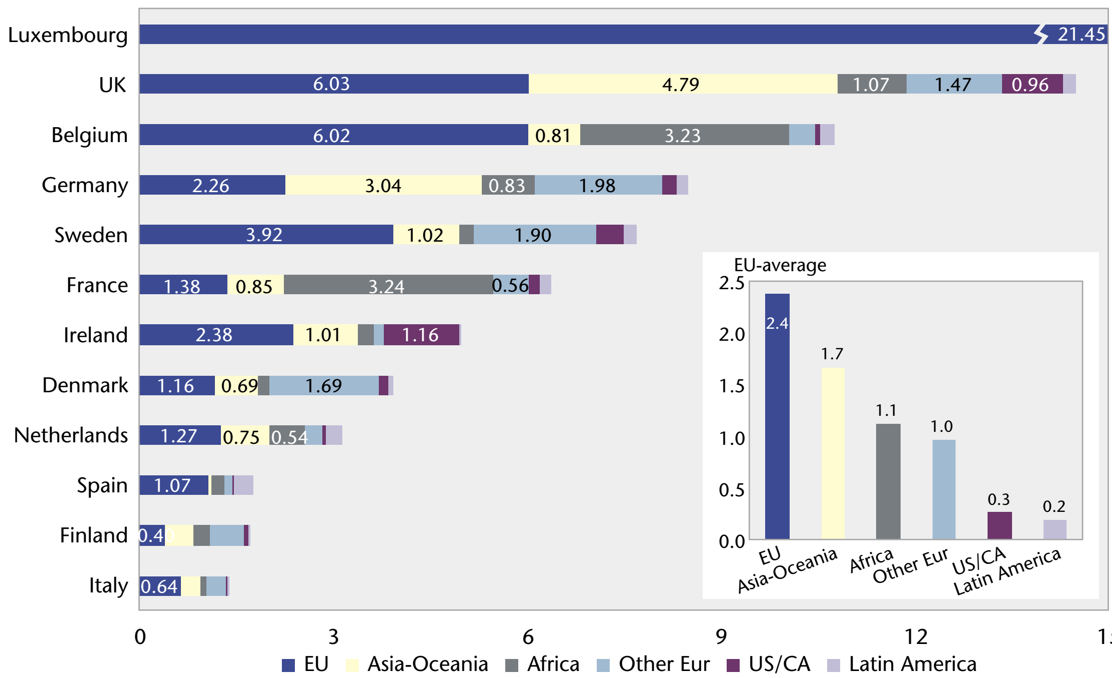
It could be argued that students are not yet active in knowledge creation and transfer and as such are neither a loss to the supplier country nor a gain to the host country. Yet, the creation of knowledge relies to a large extent on the exchange of people carrying different knowledge and experiences. The transfer and absorption of knowledge play a crucial role in this process. Students undeniably do already possess knowledge. This increases the underlying knowledge base of a society and its (knowledge) absorptive capability. The loss of students is not to be underestimated. People who study abroad also show a tendency towards mobility in future careers but, at the same time, a preference for the host country may develop while they are studying there. Furthermore, they have already learned to overcome obstacles of international mobility, be they administrative, linguistic, cultural or family-related. Finally, they are more likely to find an S&T job in their host country, having established contacts and acquired knowledge about its science and labour systems. It is useful, therefore, to analyse the numbers of foreign students, to form a picture of people's potential for staying on in host countries upon completion of their studies, and so adding to the human resource base of that country.

Foreign students in the EU

In the EU as a whole, the largest share of foreign students enrolled in tertiary education (2.4%) comes from other EU member states. This number is higher than the 1.7% of foreign students hailing from Asia and Oceania, 1.1% from Africa, 1% from other European countries, and less than 1% from the Americas. In total 6.6% of students in the EU, are foreigners (Figure 4.4.6).

Differences between the countries are significant. The UK has the highest share of foreign students enrolled (15%), if Luxembourg with its small absolute values is excluded. Belgium follows with 11%. The smallest share of foreign students is reported in Italy, (1.4%). Apart from students from the EU, which is the largest group in most countries, students from Asia and Oceania comprise the largest shares in the UK and Germany. The presence of Africans is strong in Belgium, France and the Netherlands, and other European students are well represented in Sweden, Denmark and Finland. In Ireland, most of the foreign students are from the US and

Figure 4.4.6 Percentages of foreigners among all students enrolled in tertiary education by region of origin (1999)



Source: DG Research
Data: OECD database
Note: No data for P, EL or A, they are not in the EU average. L foreign students only from EU countries. The data for L are statistically not reliable.

Third European Report on S&T Indicators, 2003

Canada, while in Spain, the largest group comes from Latin America.

These findings are not unexpected, given the historical, cultural, linguistic and political histories that influence students' choices of a host country for their studies. Many are permanent residents in their host countries due to the earlier migration of their parents. Table 4.4.4 shows the top five countries of citizenship for foreign students in the EU Member States and the EU totals for the year 1999.

By far the largest group of foreign students is that of Greeks in the UK, followed by Turks in Germany, and Moroccans in France. These three groups, together with the French and the Germans, also constitute the top five groups in the EU as a whole period.

Table 4.4.4 Foreign students enrolled in tertiary education in the EU Member States Top 5 countries of citizenship 1999

EU host country	Country of citizenship	Number of students	EU host country	Country of citizenship	Number of students
Belgium	France	8226	**Denmark**	Norway	1326
	Morocco	4527		Iceland	671
	Italy	3379		Germany	622
	Netherlands	2781		Sweden	523
	D.R. Congo	2495		Bosnia and Herzegovina	425
Germany	Turkey	26583	**Spain**	France	4130
	Greece	8317		Italy	3553
	Iran	8213		Germany	3370
	Poland	7840		Morocco	2258
	Italy	7136		UK	2231
France	Morocco	18849	**Ireland**	UK	1689
	Algeria	14559		United States	1479
	Niger	5582		Malaysia	673
	Germany	5162		Germany	409
	Italy	3777		France	403
Italy	Greece	8916	**Luxembourg**	France	301
	Albania	1539		Belgium	136
	Switzerland	1251		Portugal	47
	Croatia	876		Italy	43
	Germany	707		Germany	34
Netherlands	Germany	2059	**Austria**	Italy	6785
	Morocco	1829		Germany	5679
	Turkey	1501		Bulgaria	1232
	Belgium	1183		Turkey	1126
	Suriname	901		Hungary	967
Finland	China	583	**Sweden**	Finland	3214
	Russia	509		Germany	1715
	Sweden	403		Norway	1226
	Estonia	400		United States	854
	Germany	171		UK	822
UK	Greece	30186	**EU total**	Greece	51825
	Ireland	16192		France	35364
	Germany	14146		Germany	34621
	France	13795		Turkey	34263
	Malaysia	12924		Morocco	33463

Source: DG Research
Data: OECD database
Note: No data for P or EL.

Third European Report on S&T indicators, 2003

Interesting, yet expected, is the presence of students from former colonies in their respective colonial host countries: Algeria and Morocco in France, the Democratic Republic of the Congo in Belgium and Suriname students in the Netherlands. Geographic proximity is a factor in most of the countries, as seen clearly in the case of the Nordic countries and Italy and Austria. Overall, language proximity seems crucial, as confirmed by the French students in Belgium, Norwegian students in Denmark, German students in Austria or the Belgians in the Netherlands.

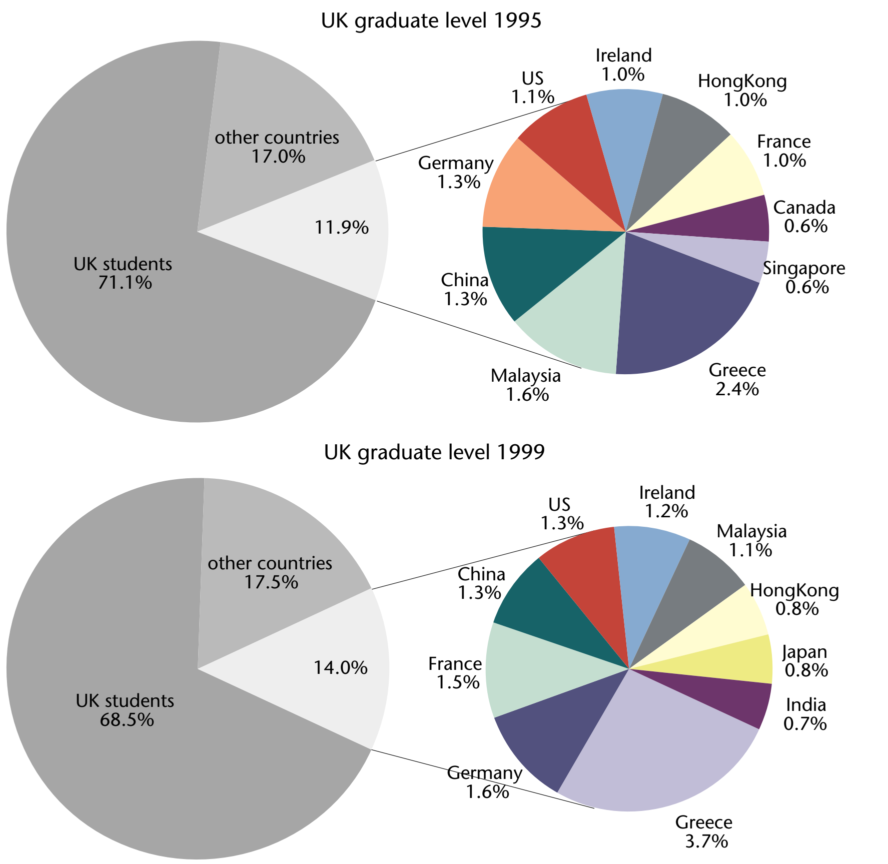
Foreign S&T students in the EU

Data on students enrolled in S&T fields of study are available only for the UK and France, and are provided by the NSF. It is important to compare such data with general data on students' enrolment, analysed above, in order to detect S&T specific differences. Furthermore, the data allow for analyses of changes in the UK over a period of time and of differences in levels of education for France. Figure 4.4.7 shows the number of foreign students in the UK enrolled in S&T fields of study at graduate levels as a percentage of all S&T students for the years 1995 and 1999.

In 1999, the total share of non-native S&T students was 32%, more than double the share of all other fields of study, as shown in the previous figure 4.4.6. The top five countries are Greece, Germany, France, China and the US, followed closely by Ireland and Malaysia. This is similar to the data shown in table 4.4.4, although ranked differently. The order of the countries changed slightly between 1995 and 1999. The share of non-native students decreased by 3%, as the shares of France and Germany increased while that of Malaysia fell. This shows that shares of foreign students and their countries of origin are stable but prone to change over time.

Level of study is another aspect to consider when measuring the contribution of foreign students, as illustrated in figure 4.4.8 with 1999 data for France. At the master's level, the share of foreign students in S&T is only 5%. As seen from table 4.4.4, Morocco and Algeria are again the top suppliers, but are now followed by the Cameroon, Spain, Senegal and Tunisia, ahead of Germany and Italy. At the PhD level, Tunisia's position rises

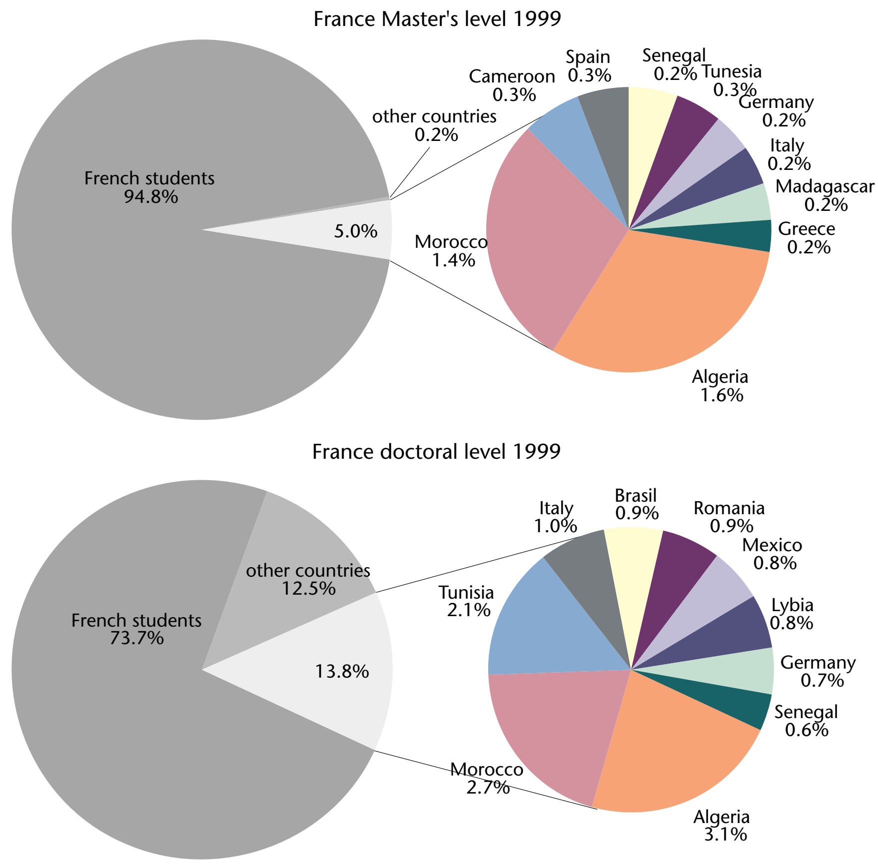
Figure 4.4.7 Students enrolment in S&T fields of study in the UK at graduate level: 1995 and 1999



Source: DG Research
Data: NSF 2002
Note: S&T, next to the definition of S&E used in this report, also includes social and behavioural sciences and agricultural sciences, according to the NSF definition of S&T. See methodological annex.

Third European Report on S&T Indicators, 2003

Figure 4.4.8 Students enrolment in S&T fields of study in France 1999: Master's degree and Doctor's degree



Source: DG Research
Data: NSF 2002
Note: S&T, next to the definition of S&E used in this report, also includes social and behavioural sciences and agricultural sciences, according to the NSF definition of S&T. See methodological annex.

Third European Report on S&T Indicators, 2003

and Brazil, Romania and Mexico feature on the list. Here the percentage of foreign S&T students is as high as 26%, about five times higher than at the master's level. This shows a tendency for foreign students to be concentrated at higher study levels. France conforms to the trend in other countries with higher education systems drawing foreign-born students from countries with less developed and/or not highly valued education systems.

4. Foreign-born S&T employees in the EU

The Community Labour Force Survey (CLFS) provides data which make it possible to look at the number of non-nationals working in a European host country. The survey covers the whole of the working population, those with university level education and those in senior scientific or technical posts. When comparing data for different years, trends begin to emerge. The mobility between EU Member States can be analysed by way of a closer look at S&T employees in the EU who come from other EU Member States. Such an examination also means that an analysis of foreign-born workers' activities can be undertaken, including looking at their duration of stay and rates of return.

Foreign-born S&T employees in the EU: Overall comparisons

When drawing a comparison between qualified people and those in scientific and technological posts (scientists, engineers or technicians, including teachers in higher education), as is done in table 4.4.5, there is very little difference in the rank order of the countries. Luxembourg is always in the lead, but its data should not be over-interpreted due to the small numbers involved. In terms of share of foreign S&T employees, Ireland is in the lead, followed by Belgium, Austria and Germany. In the total population, and among higher qualified people, Austria has the highest shares, followed by Belgium and Germany.

Table 4.4.5 People occupied in S&T; higher qualified people and total working population; Percentages of non-natives 2000

Country	Total working population	Higher qualified people	People occupied in S&T
Luxembourg	41.3	45.1	33.5
Ireland	3.6	-	7.6
Belgium	7.6	5.9	6.6
Austria	9.4	8.7	6.1
Germany	8.2	4.7	5.7
UK	4	4.2	5.4
Sweden	4.3	4.7	4.4
EU average	4.6	3.7	4.1
Netherlands	3.9	3.4	4
France	5.3	3.4	3.4
Denmark	2.6	2	2.3
Portugal	2	2.5	1.7
Finland	1	0.8	1.3
Greece	3.7	3.3	1.1
Spain	1.3	1.3	0.7
Italy	1	1	0.6

Source: DG Research
Data: Eurostat, NewCronos, CLFS
Notes: Data on non-native higher educated people in IRL are not available, IRL is not in the EU average. The data for L are statistically not reliable

Third European Report on S&T Indicators, 2003

The results for people working in S&T and the population as a whole are reasonably comparable, although a few differences emerge. It should be taken into account that the proportion of the population represented in the survey by nationality may differ sharply from one country to the next. The proportion of expatriates in the comparable population is close to this number, although often a little higher. The greatest positive difference is seen in Ireland, where the share of S&T employees is 4% higher. The UK, Finland, Sweden and the Netherlands also show slightly positive differences. Negative differences are found in Austria, Germany, Greece, France, Belgium, Spain, Italy, Denmark and Portugal, with shares of between 3.3 and 0.3% lower.

The significance of this finding is that people in S&T professions appear to be more inclined to move abroad if they feel their careers will benefit. An examination is necessary of which countries are most open, or closed, to immigration. Such data do not reveal who comes to work in European countries and why they come, but as regards the countries or regions of origin, a comparison between European countries is illuminating. In the next section, individual EU member states are analysed according to the numbers of foreigners from different regions of origin working in them.

Non-EU nationals in EU member states by region of origin

The CLFS information is limited to people with a destination in the EU. In 2000, 1.3 million Eastern European nationals and 1 million people from other European countries worked in EU Member States. Some 600 000 Italians worked in other EU countries, and more than 500 000 North Africans, 400 000 South or South-East Asians and 400 000 Africans (other than North Africans) worked in the EU. At the time, the total working population in the EU was around 160 million people.

The shares of foreign nationals in the different EU Member States are given in figure 4.4.9. Apart from Luxembourg with 41% foreign nationalities, coming mainly from the EU, the countries that host most foreigners are Austria (9%, mainly from Central and Eastern Europe), Germany (8%, mostly from Central and Eastern Europe, Italy and Greece), Belgium (8%, mainly Europeans – Italians, French and Dutch, but also North Africans) and France (5%, some Europeans, mainly Portuguese, Italians and Spanish; North Africans and a few Eastern Europeans).

The numbers of foreign-born nationals with higher qualifications as shown in figure 4.4.10, lead to questions such as: How many highly qualified persons are working in the country? Where do they come from? Does a country attract more qualified or more unqualified foreigners?

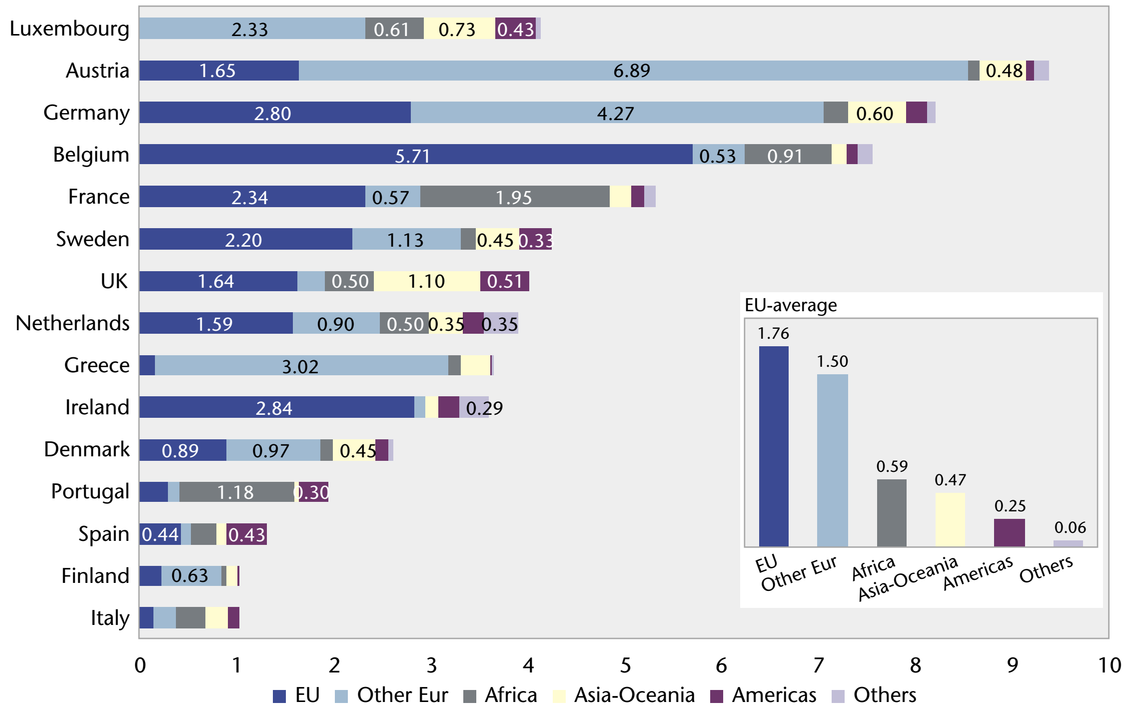
There are around 7.4 million foreign people working in the European Union (excluding Ireland) with university or equivalent education. Figure 4.4.10 presents the higher educated non-native employees by region of origin. Luxembourg houses 45% of foreign well educated nationals within its territory. In other countries the proportion of immigrants varies. The numbers are much smaller in the case of Germany, Belgium, Finland and France, and larger in Portugal and Sweden. The geographical distribution of immigrants also differs greatly.

Across the EU and for most of the EU Member States, the shares from other European countries decrease significantly compared to the total working population. The high 2% share of Africans in France shrinks to 1% in the higher educated population. Similar changes can be observed in Belgium and Portugal. Interestingly, the percentage of higher qualified Asians remains the same.

Relevant to the question of the influence of international mobility on human resources in S&T, is the relationship between the numbers of higher educated foreigners and S&T employment figures. It is necessary to examine whether a close correlation exists between the number of foreign nationals in responsible scientific or technical posts and the number of foreign nationals with higher education.

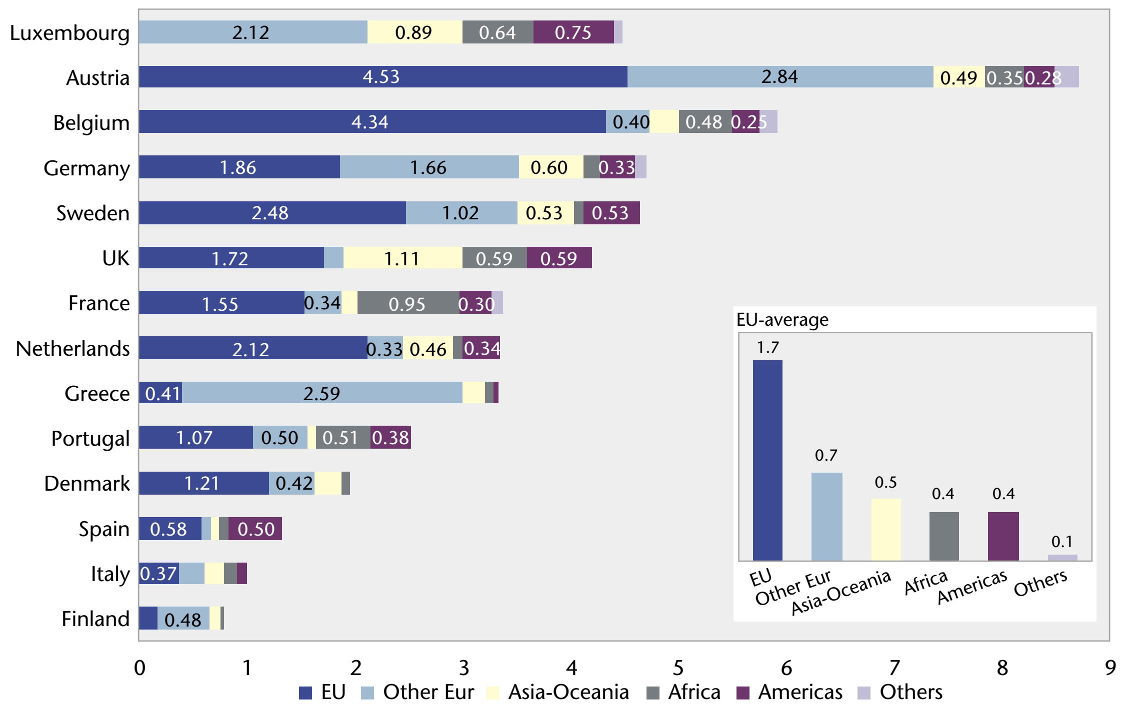
As seen in figure 4.4.11, there are far fewer people employed in S&T than there are people with higher education qualifications. The ratio is around three to ten (two million compared

Figure 4.4.9 Non-native nationalities by region of origin, as shares of totals in %, 2000



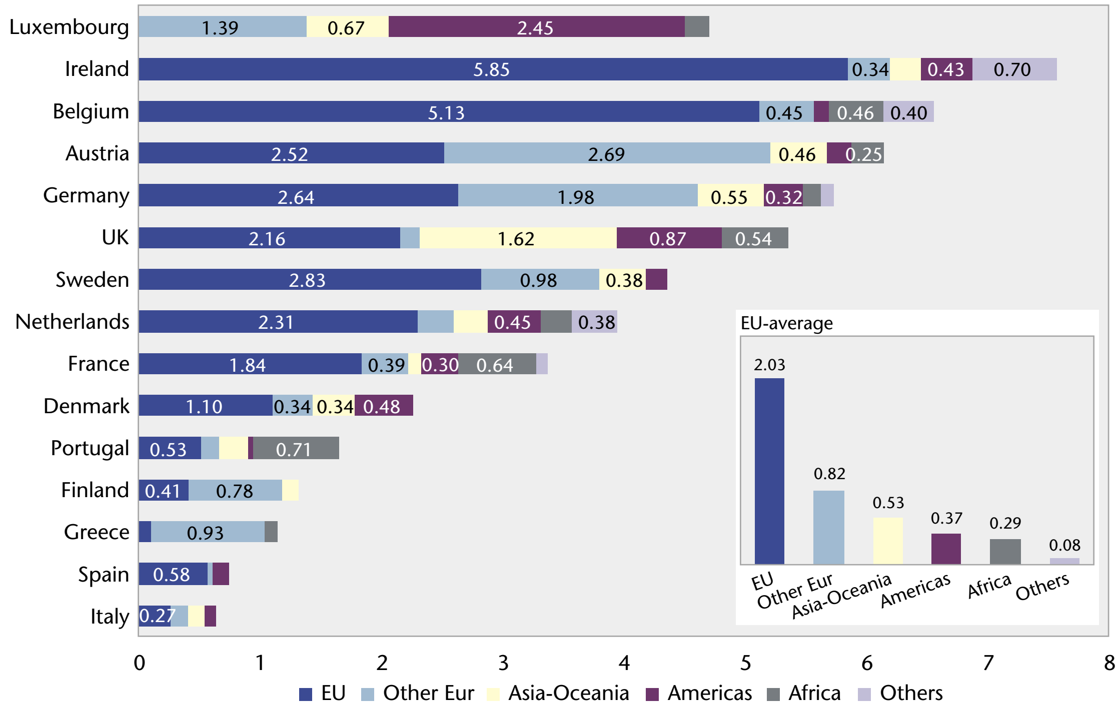
Source: DG Research
Data: Eurostat, NewCronos, CLFS
Note: L: Non-natives from the EU (37.2 %) are not included in the picture. The data for L are statistically not reliable.
Third European Report on S&T Indicators, 2003

Figure 4.4.10 Non-native higher qualified employees categorised by regions of origin in %, 2000



Source: DG Research
Data: Eurostat, NewCronos, CLFS
Note: No data for IRL, which is not included. L: The high share of non-native residents from EU (41%) is not included in the picture. The data for L are statistically not reliable.
Third European Report on S&T Indicators, 2003

Figure 4.4.11 Non-native employees in S&T by regions of origin in %, 2000



Source: DG Research
Data: Eurostat
Note: L: The high shares of non-native residents from EU (29%) are not included in the figure. The data for L are statistically not reliable.

Third European Report on S&T Indicators, 2003

to 7.4 million). Although these two categories are not identical, it is reasonable to assume that many scientific and technical posts are occupied by people with higher education qualifications.

Excluding the special case of Luxembourg, Ireland leads with 7.6% of the population in question, of which up to 6% are from the EU. Substantial numbers of foreign S&T employees in Austria come from European countries other than EU Member States. This is also the case in Germany, Sweden and Greece. The highest shares of foreign employees in the UK are from Asia and Oceania, but also American S&T employees are represented in the UK in higher numbers than in most other EU Member States. France, Portugal, the UK and Belgium have relatively high shares of African immigrants amongst the S&T employees, although these shares are lower than the other two populations regarded (except for France's highly educated population, where the shares are similar).

It can be concluded that in most of the countries examined, the region of origin of foreign employees changes with increased qualification and employment in S&T. For the whole working population, regions of origin that present an important share of the total population can be explained by political, social or geographic factors such as former colonies, refugees, neighbouring countries etc. In S&T, other factors weigh more heavily, for example quality of the research system and working conditions for S&T employees.

Mobility of S&T employees within the EU

Regarding intra-EU mobility (mobility between the EU Member States), the highest numbers of expatriates among the working population in absolute terms are Italians in Germany (360 000), Portuguese in France (320 000), Irish in the UK (210 000) and Greeks in Germany (180 000). The countries with proportionally the most nationals in other European countries are Ireland (12%, mainly in the UK), Portugal (9%, mainly in France but also in Germany and the Netherlands), Luxembourg (6%, in Belgium and Germany) and Greece (5%, mainly in Germany).

In the higher education population, the largest numbers of expatriates in other European countries are from Austria (34 000), Britain (30 000) and Italy (22 000), all of them in Germany. British expatriates have also settled in France (19 000) and the Netherlands (14 000), and French expatriates in Germany (17 000), the Germans in France (15 000) and the Greeks in Germany (15 000). Finally, there are 14 000 highly qualified Finns in Sweden and 12 000 higher educated Belgians in France.

For EU expatriates employed in S&T, data show that those who have moved to another EU country tend to have the same destinations in the EU as people with higher education qualifications. For example, Germany is the most popular destination for Austrians, Italians, Brits, Greeks and Spaniards.

Table 4.4.6 Mobility within the EU: Foreign S&T employees (in 1000) by country of origin, 2000

country of residence	country of origin															
	EU-15	B	DK	D	EL	E	F	IRL	I	L	NL	A	P	FIN	S	UK
EU-15	230	10.7	5.9	25.4	12	16.9	26	16.2	34.4	1	14.9	17.6	8.9	5.7	2.9	30.9
Belgium	17.7			1.3	0.5	1.1	5.8		5.4	0.2	2.2		0.3			0.9
Denmark	2.6			1.7					0.4						0.4	0.1
Germany	84.5	1.9	1.7		9	6.5	7.6	2.7	15.7	0.7	6.2	16.6	2.2	1		12.6
Greece	0.2															0.2
Spain	3.5	0.1		1.1			0.6		0.7		0.2				0.3	0.5
France	32.7	6.2		4.6		3.7		0.7	5.5		1.1		5.1	0.5	0.7	4.7
Ireland	4.8			0.6			0.9		0.1							3.1
Italy	3.3			1		0.5	1.1				0.6				0.1	
Luxembourg	3.1	0.8		0.4	0		0.7	0.1	0.2		0.1		0.4	0.1	0.0	0.2
Netherlands	14.7	1		2.6		0.3	3.1		1.3			0.3			0.3	5.8
Austria	5.3			3.9				0.6	0.6		0.3					
Portugal	1					1										
Finland	0.9			0.3		0.1						0.1			0.3	
Sweden	11.7		2.4	1.4			1		0.2		0.1			3.8		2.7
UK	43.4	0.5	1.8	6.5	2.5	3.7	5.3	12.2	4.2		4	0.6	0.8	0.5	0.7	

Source: DG Research
Data: Eurostat
Notes: Grey number: country of residence is net receiver, blue number: country of residence is net sender. Blanks: no significant migration streams

Third European Report on S&T Indicators, 2003

Many Irish people move to the United Kingdom, Brits to the Netherlands and France, the French to Germany and vice versa, and Belgians to France and vice versa.

Using these figures, it is interesting to calculate the net figures for S&T employees in individual countries. Table 4.4.6 shows the total numbers and the dominant direction of migration. Grey numbers indicate that the country of residence is a net recipient of S&T workers and blue indicates that the country of residence is a net sender of S&T workers.

In terms of total numbers of immigrants from EU Member States, Germany, the UK, Sweden, Belgium, France and Luxembourg are net recipients with total positive balances of between 59 100 (Germany) and 2 100 (Luxembourg) immigrants from EU Member States. The net sender countries are Italy, Spain, Austria, Greece, Ireland, Portugal, Finland, Denmark, and the Netherlands, with net numbers of emigrants of between 31 100 (Italy) and 200 (the Netherlands).

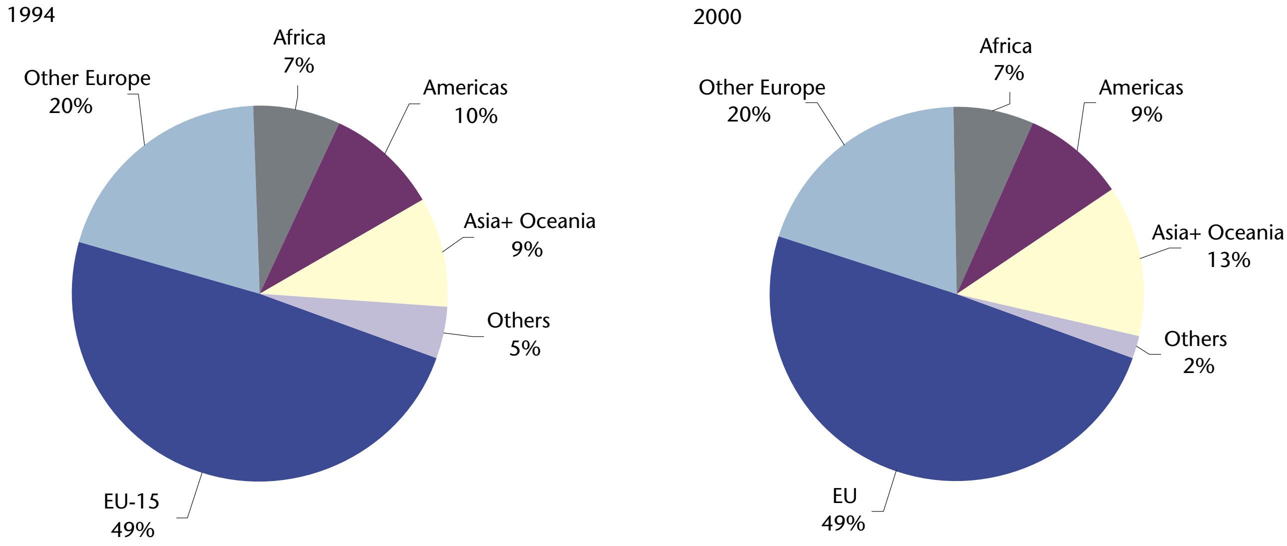
This means that the net recipient countries profit most from the inter-EU migration. The reasons for this could include a higher demand for S&T employees due to the size of the country and the strength of its economy, but also other attractive factors such as the quality of life, language, historical or geographical proximity. Another important factor is the presence of supranational organisations that give preference to employing researchers from EU Member States, e. g. the European Commission services in Brussels and Luxembourg and the Joint Research Centres in Belgium, Germany, Spain, Italy and the Netherlands.

Changes during the 1990s

So far, only the data for 2000 – the most recent available year – have been analysed in this section. To observe the changes during the 1990s, it is interesting to compare the results of the CLFS for 1994 with the data of 2000. Figure 4.4.12 shows the shares of non-native S&T employees in the EU, by their region of origin.

The shares of non-EU national S&T employees only changed slightly during the 1990s. The sole region of origin to increase its share was Asia and Oceania (from 9% to 13%). The other changes are marginal and within the range, due to a slight reduction in the "others" group. However, the absolute numbers of non-EU national S&T employees grew by an EU average of about 40% between 1994 and 2000, as shown in Figure 4.4.13.

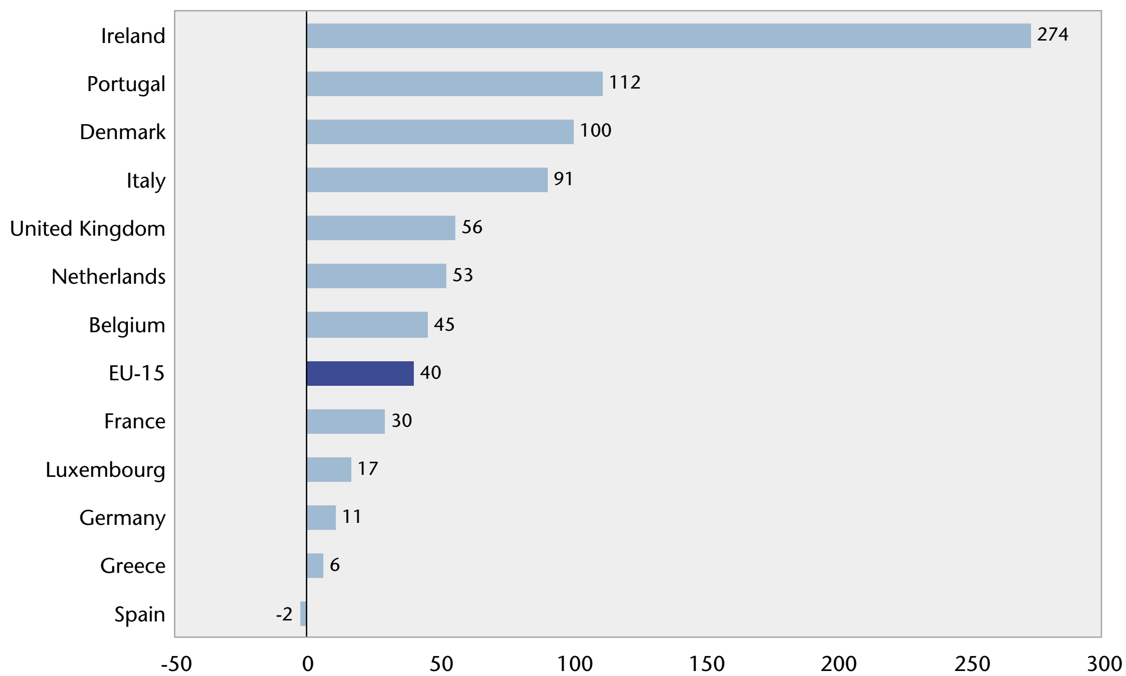
Figure 4.4.12 Regions of origin of non-national S&T employees: EU average



Source: DG Research
Data: Eurostat, CLFS
Note: No data for A, FIN or S for 1994. They are not in the EU average for 1994. The region "others" contains mainly blank answers.

Third European Report on S&T Indicators, 2003

Figure 4.4.13 Non-native S&T employees: total growth in %, 1994-2000



Source: DG Research
Data: Eurostat, CLFS
Note: No data for A, FIN or S for 1994. They are not in the EU average.

Third European Report on S&T Indicators, 2003

This average increase in the absolute numbers hides a very wide range of growth of between 274% in Ireland, and -2% in Spain. Remarkable increases in the numbers of non-native S&T employees can also be observed in Portugal, Denmark and Italy (around 100%) and in the UK, the Netherlands and Belgium (around 50%), which are all above the EU average. Minor increases below the EU average (between 6% and 30%) were recorded in Greece, Germany, Luxembourg and France.

Duration of stay

The study of the activities of foreign born employees is important, and presents one of the big challenges in measuring and understanding the international mobility of people with S&T expertise. For example, it is extremely difficult and often impossible to tell new immigrants from people exercising mobility opportunities. Some people will stay on, some will return to their home countries and others will move on to work in yet other countries. While there are statistics on duration of stay from the immigration services, little or no information is available on the 'types' of persons visiting, in terms of their educational levels, field of training and duration of stay. Some immigration services also record skills, while others focus on the applicants' planned occupations, with the result that comparative information is scarce.

To ensure the 'renewal' of the foreign-born working population in a country, every year an inflow equivalent to about one quarter of the foreign population would have to take place. Over a period of three years, this amounts to around 7.5%. Only two countries – France and Finland – are below this threshold. Are these two countries not attractive enough, are the language barriers too tough to overcome, or do strict rules prevent the entry of new immigrants? In contrast to the situation in other countries, Finland has very few working immigrants (1%) but France has almost 6% of working immigrants.

The countries that do attain this renewal (between 7%-12% of immigrants) are Germany (Eastern Europe, Asia, North America, Italy, the UK and Netherlands), Sweden (various countries in Northern or Eastern Europe), the Netherlands (Eastern Europe, South America, South or South-East Asia, France, the UK), Austria (Germany or Eastern Europe), Belgium (France, Netherlands or North Africa) and Luxembourg, which scores highest overall with the latest arrivals coming mainly from France.

One group of countries appears more attractive as hosts for foreigners, receiving between 22% and 28% of newly arrived immigrants: Greece (Eastern Europe), Denmark (Norway, Germany and the Netherlands, as well as Asia), Italy (Eastern Europe, South and South-East Asia, South America, Africa excluding North Africa), Portugal (Central and Eastern Europe, South America and Spain), the United Kingdom (French, Irish, Germans, Spaniards and many others from the EU, but also from Oceania), America (particularly North America) and Spain (North Africa, Eastern Europe, United Kingdom, Italy, Belgium, France, Germany, Portugal and Finland). Their characteristics are very different, however, in terms of geographical position, size and living standards.

Ireland, with almost 50% of the new arrivals of all foreigners within its territory, is a most attractive host country (for the UK, France and various European countries, but also North America and Oceania). Is Ireland becoming so attractive that people are settling there today, or are new foreign corporations temporarily bringing in managers or employees who probably will not stay?

Rates of return

The survey also shows whether nationals eventually return to their countries of origin. In the last three years, almost 100 000 Germans returned to their country, as did some 50 000 Portuguese and more than 20 000 British. This figure is also significant for Sweden (10 000), the Netherlands (7 000) and the Irish (6 000). Should these prove to be permanent returns, it would partly prove that the working conditions in their own countries have attracted them, or that their absences have been related to job mobility.

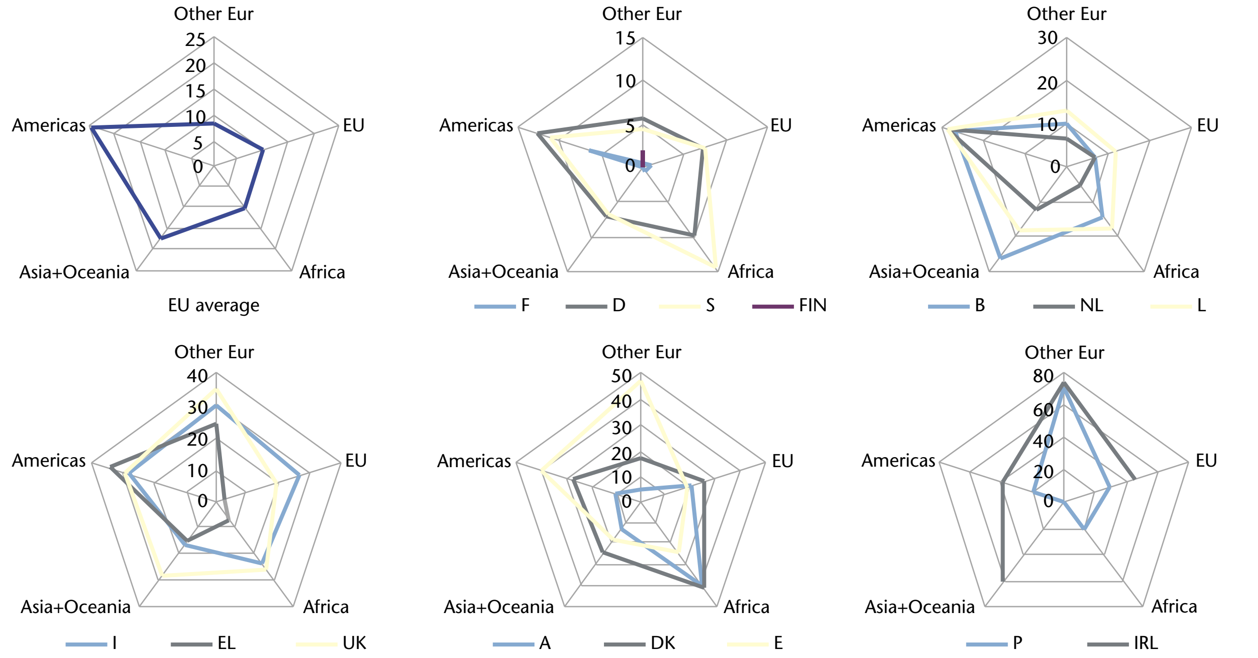
The most exceptional case is Portugal, where the returning numbers are the equivalent of 1% of the working population, or almost four times more than the number of Portuguese who moved to other EU countries during the same period. Next comes Ireland with just under 0.5%. The population movements are always high in this country, since in the same period, almost 1% of Irish settled in another EU country.

Germany should also be singled out. In absolute figures (slightly under 100 000, which is double the figure for Portugal and three times more than the number of Germans moving to other EU countries), Germany is the European country which, along with Sweden, has seen the largest numbers of returnees (around 0.3% in relative values). In the case of Sweden, returning numbers are higher than numbers leaving for other European countries. The data do not lend themselves to drawing any further statistically significant conclusions. It can be added, though, that the number of returnees is extremely small for Spain, Finland, France and Italy, and very small in the case of Belgium. As regards movements to other EU countries, only Finland and the Netherlands feature prominently.

The fact that foreigners working in EU Member States stay for long periods of time, signifies the sustainable appeal of EU Member States for foreigners. Figure 4.4.14 shows the shares of the foreign labour force staying for three years or longer, by region of origin.

According to EU averages, only about 13% of the non-national working population stays in the host countries three for years or longer. This percentage suggests that the majority of immigrants are still mobile and far from settling down in their host country. The largest share of those staying in host

Figure 4.4.14 Shares of the foreign labour force staying three years or longer by region of origin in %, 2000



Source: DG Research
Data: Eurostat, CLFS
Note: No data on Africans in IRL are available.

Third European Report on S&T Indicators, 2003

countries comes from the Americas, followed by Asia and Oceania, Africa, the EU and other European countries. The shares range from 25% for the Americas to 8% for other European countries. In the individual Member States, the largest shares of around 70% of long-term foreign visitors are found in Portugal and Ireland and mostly from other European countries. The shortest stays, on average, are found in France, Germany, Sweden and Finland, where in all cases less than 15% of employees stay for three years or longer. The 15% represents Africans in Sweden. The graph shows the big differences in the shares of different world regions in the EU Member States.

The overall conclusions on the migration of researchers to and from the EU are as follows: The CLFS provides a comprehensive picture of the links between labour force migrations, population with higher education qualifications and S&T employees. Together with data from other sources, such as the OECD, NSF and the student enrolment data, the overall data on world wide migration streams illustrate the importance of foreign students and researchers for Europe's knowledge-based economy. Several conclusions can be drawn which show and to a certain extent explain the migration to the EU.

The EU is a classical recipient region for third world countries and other European countries. Only the US, and to a limited extent also Canada and Australia, are attracting more students and researchers than the EU. Reducing the gap between the EU and the US, or even shifting the main direction of migration from the US towards Europe, could become an ambitious future objective of the EU and its Member States.

Section V Encouraging Women into S&T

As shown in the previous section, attracting students and researchers from abroad is one way of increasing the number of highly qualified human resources in society. Another means of meeting the increasing demand for human resources in S&T is to encourage and increase the participation of women in S&T education, training and careers.

In recent years, the issue of 'gender mainstreaming'[20] has left the realm of being only an 'emancipation' issue and entered the domain of 'economics'. Economic dimensions of gender inequality are now beginning to have an impact at the macro level and are receiving attention. It seems improbable that the transition to a knowledge-based economy will be made successfully while a large part of half of the available human resources are not actively engaged in the process.

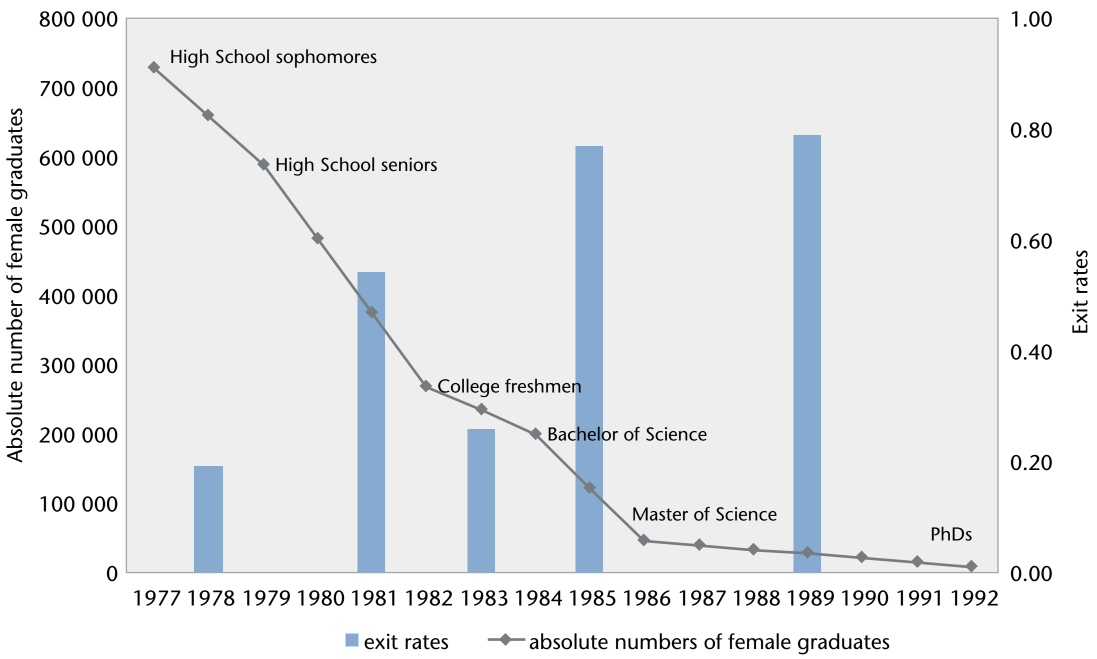
This section sets out to show the potential of women to compensate for the foreseen lack of human resources in S&T. First, some education data on female participation in S&E fields of study are analysed. A breakdown by levels of study and by disciplines will show the gender specificities, such as the high exit rates in the education pipeline and the bias towards non-S&E fields of study. Then secondly, the involvement of women in R&D on the basis of numbers of researchers, is analysed; the breakdown by sectors gives interesting insights. Thirdly, this section ends by looking at some of the data on S&T employment patterns of women, i.e. occupations as professionals and technicians, which pick up again the differences in education levels.

All these analyses suffer from the limited availability of gender specific data on human resources in S&T. In the Dossier on "Women in Science" which follows this chapter, measurement problems are addressed and the discussion on reasons for gender inequalities in S&T careers are looked at in depth.

1. Women's participation in S&T education

Before women can become part of the S&T labour force, they need to be appropriately and adequately qualified. Qualification status is determined by the level of education and the choice of field of study. What are the recent trends in women's participation in S&T education?

Figure 4.5.1 Female S&E students and graduates in the US 1977-1992



Source: World Science Report 1996, UNESCO; own calculations
Data: NSF
Note: Exit rates reflect the ratio between the number of graduates on one level and graduates of next higher degree. The exit rates include therefore the students who did not continue following the education pipeline as well as those who did not finish the next step.

Third European Report on S&T Indicators, 2003

[20] *European Commission, 2000 (ETAN report), 'Science Policies in the European Union: Promoting excellence through mainstreaming gender equality'*

S&T education trends

Figure 4.5.1 shows some interesting data on the so-called 'education pipeline' for women over a 15-year period in the United States, where the minimum level of education required for an S&T job is an MSc (Master of Science) degree.

Of the 730 000 female students who finished high school in the US in 1977, only 46 000 or 6.3% obtained an MSc degree and only 9 700 (1.4%) completed a PhD. This translates into an exit rate of almost 94% at master's level and of more than 98% at PhD level. The highest exit rates occur after the BSc (Bachelor of Science) and MSc degrees, when almost 80% of female students decide to discontinue their academic careers. When these data are compared to the typical science career of male students, the exit rates of women turn out to be much higher.

Differences in professional careers can also be related to the choice of subject studied at university. Figure 4.5.2 shows the average percentages in 1998 for male and female graduates in the EU in different fields of study, such as natural sciences, mathematics and computing, engineering, health and food sciences, social sciences, arts and humanities, educational sciences and others.

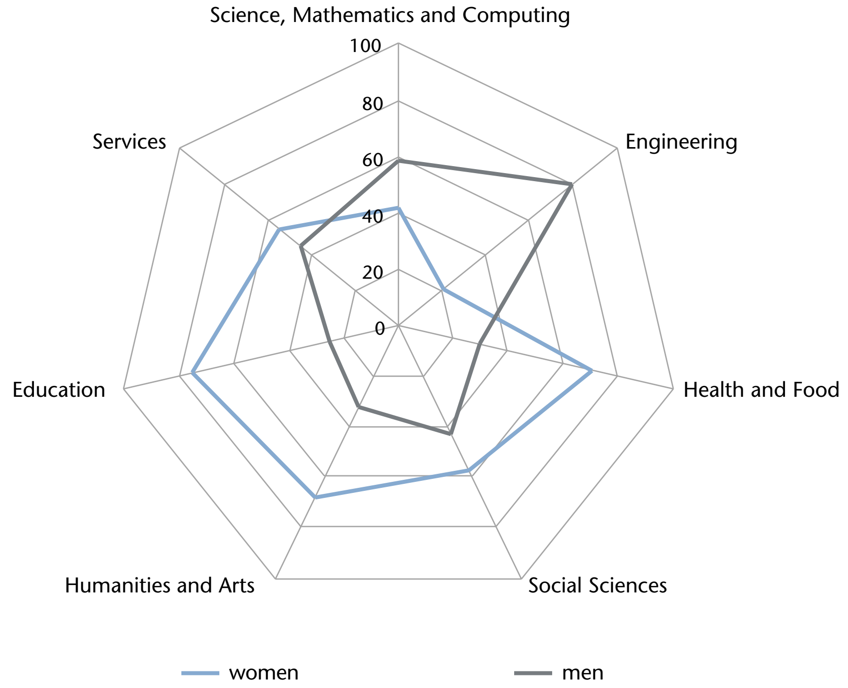
With more than 60% of graduates being female, the fields of education, arts and humanities and the health and food sciences are clearly dominated by women. In contrast, men tend to dominate in engineering and natural sciences, mathematics and computing, with shares of 80% and 59% respectively.[21] The social sciences, which also include economics and law, and the other disciplines show a more equal gender participation.

Overall in S&E (which comprises the natural sciences, mathematics and computing and engineering), women represent 30% of the graduates, while in all disciplines their representation is much higher at 55%. This discrepancy is one that continues to puzzle researchers – is it a question of access or one of interest and priority? Does this trend also apply in individual EU Member States?

Female S&E graduates compared by country and S&E disciplines

Figure 4.5.3 shows the shares of female graduates in S&E and in science and engineering for the EU Member States, the US and Japan.

Figure 4.5.2 Shares (%) of male and female of graduates by field of study 2000, EU averages

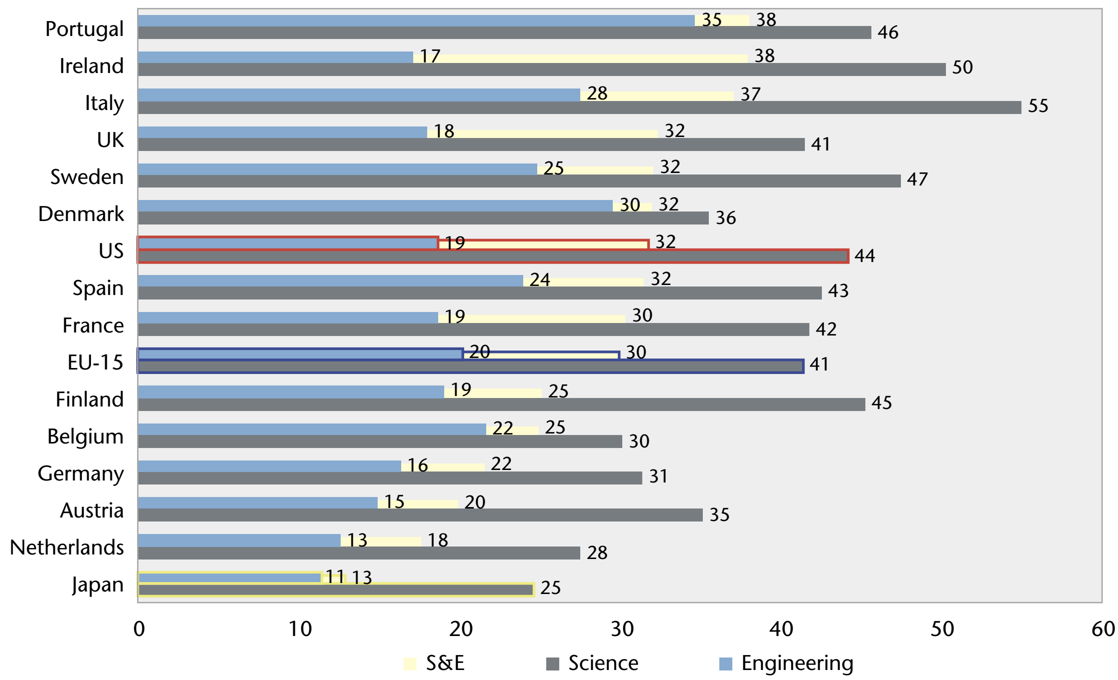


Source: DG Research
Data: Eurostat/OECD
Note: No data were available for EL or P, which are therefore not included in the EU averages.

Third European Report on S&T Indicators, 2003

[21] *In the data for 1998, where natural sciences on the one hand, and mathematics and computing on the other hand, were given separately, the share of natural sciences were almost equal between women and man, but mathematics and computing were dominated by 70% male graduates.*

Figure 4.5.3 Percentages of female graduates in S&E: 2000



Source: DG Research
Data: Eurostat/OECD
Note: No data for EL or L which are not in the EU average.

Third European Report on S&T Indicators, 2003

In 2000, in nearly all EU Member States, more than half of the graduates are women. However, the EU average share of women S&E graduates is only about 30%. This is slightly below the US average of 32% but much higher than Japan's average of 13%. In the EU, Portugal leads with an average of some 38%, while the Dutch with about 18% are below all the other countries.

Overall, across the EU, the end of the 1990s saw the share of women S&E graduates increase from 25% to 30%. The highest growth rates were in the Nordic countries, followed by Ireland and Germany. In these countries, significant progress was made towards equal gender representation during the 1990s. Interestingly, in Italy the growth rate of numbers of women in S&E for the decade is negative, which suggests that this high representation of women among S&E graduates in this country might not be a recent development.

There are striking differences in the representation of women in science and engineering. In the sciences, the representation of women is much higher than in engineering (which also includes town planning and architecture). In the EU, about 41% of the science graduates are women, but in engineering their share is half that at 20%. In the US and Japan this proportion is similar, with lower shares reported for Japan.

So women are generally more strongly represented in the sciences than in engineering at graduate level. With the exception of Italy and Ireland, which both show a somewhat stronger representation of women in the sciences at graduate level, women still account for less than half of the science graduates across the EU. The examples of Italy and Ireland show that equal achievement is possible in science. In engineering, equal representation of women and men remains a challenge. Even in countries with a higher representation of women in engineering, such as Portugal and Denmark, still only a third or so of the graduates are women.

Factors in increasing participation of women in S&E fields of study

An increasing proportion of female graduates in S&E is an important indicator of a narrowing gap between the levels of male and female participation in S&T. However, this does not say anything about the absolute numbers of female S&E graduates. An increase in the share can result from 1) the numbers of women increasing and the numbers of men staying the same, or from 2) the number of female graduates staying the same and the number of male graduates decreasing. Section 4.1 showed that the total number of S&E graduates had increased in most of the EU Member States. So the first of the previous scenarios must apply here for most of the countries under consideration, – the total number of female graduates has increased during the 1990s.

In light of the data presented here, it could be concluded that the low representation of women in some of the S&E fields is the result of insufficient recognition of the potential of this segment of the population to contribute to the human resource pool. Wouldn't a higher level of participation by women help to close the upcoming gaps in the skills supply chain? Science is better gender-balanced than engineering, so the potential for drawing more female graduates into engineering is considerable. There are striking differences between countries in this regard, and their potential to increase the number of women S&E graduates also varies.

It is not certain to what extent policy can influence the current situation in order to make the engineering field more attractive to women and to increase the access of women to S&T programmes in general. However, it is clear that policy alone will not bring about all the changes that are required to tap this potential skills pool. It could well be that the choice of field of study is still rooted in perceptions of these fields and of career options. Cultural and social influences might also still strongly influence choice of field of study. Moreover, it is not just a matter of attracting women into science and engineering at university level but also of keeping female graduates on an S&T career path.

Table 4.5.1 Percentages of female R&D personnel by sector in nine EU Member States: latest available year (1997-1999)

	Business Enterprise		Government		Higher education	
	HC	FTE	HC	FTE	HC	FTE
Denmark	28	25	48	47	40	39
Germany	:	17	:	35	:	35
Greece	:	:	37	40	50	50
Spain	22	22	41	41	37	38
Italy	17	16	36	37	:	:
Austria	15	14	43	40	39	36
Finland	22		46	:	45	:
Sweden	23	25	29	33	43	37
UK	:	:	34	:	:	:

Source: DG Research
Data: Eurostat NewCronos
Note: No data were available for B, F, IRL, L, NL and P
Third European Report on S&T Indicators, 2003

2. Women in R&D

Lack of data on researchers and personnel makes the analysis of female participation in R&D in EU Member States quite a challenge. Attempts are being made to assemble more complete data on women in R&D, through initiatives such as the Helsinki group on Women and Science and various initiatives of the European Commission (see the dossier, below, on 'Women in Science' for more detail). Fortunately, some data for EU Member States are available from the Research DG's 'Women and Science' unit.

Comparisons of employment and sectors by country

As a first step, some of the data from the NewCronos database on R&D personnel by gender are analysed. Although the data are incomplete, it is worth examining what there is, especially given the differences between full-time equivalents (FTE) and headcounts (HC), and between the business enterprise, government and higher education sectors. Table 4.5.1 shows the share of women in R&D personnel by sector.

Women's participation in R&D varies greatly from sector to sector. In the countries examined, the lowest shares of women are in the business sector, ranging from 28% in Denmark to 15% in Austria in terms of headcount. In contrast, the public sectors show much higher shares, ranging, in headcounts, between 50% in the higher education sector in Greece and 29% in the government sector in Sweden.

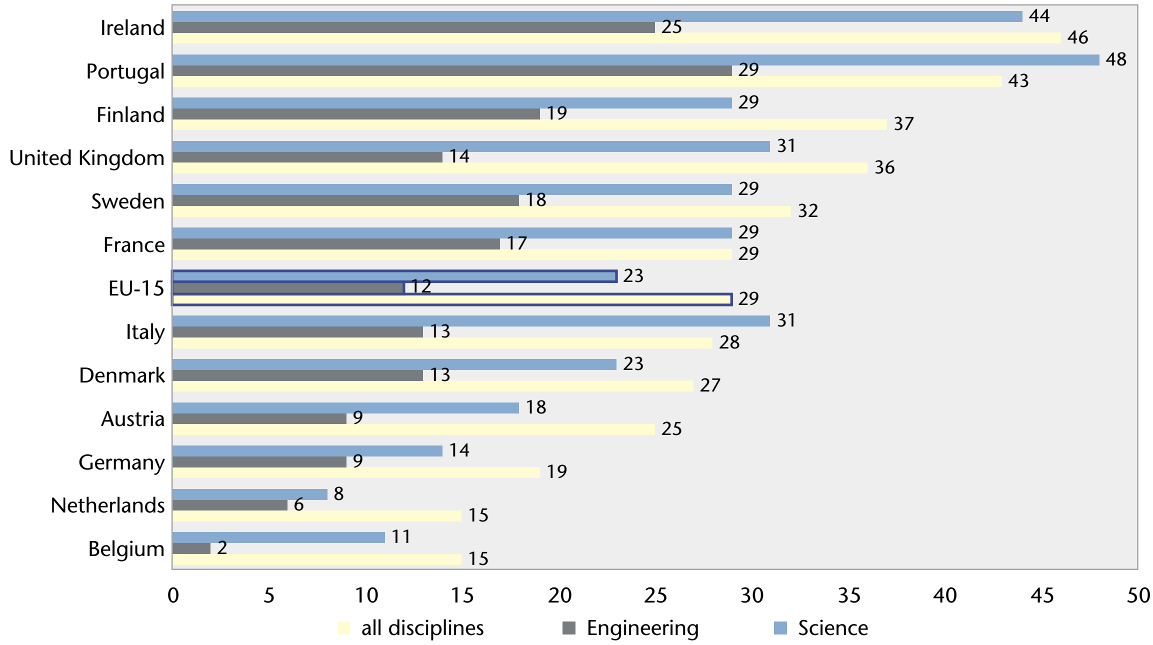
The differences between the HCs and the FTEs, which are indicative of lower numbers of full-time employed female R&D personnel if the HCs are higher than the FTEs and vice versa, are not very large.[22] Only in Sweden are there significant differences in terms of higher FTE shares in the government sector and higher HC shares in the higher education sector. Because these variations go in different directions, it is not possible to reach any conclusions relating to gender specific patterns on full-time or part-time employment in the Swedish sectors. This is even more so in the cases of the other countries under consideration.

The total numbers of R&D personnel are of little use in measuring R&D personnel with higher qualifications by gender. The data on researchers in higher education provided by the DG Research Women in Science unit have more detail in terms of fields of study but these are not complete for all the Member States. Furthermore, because they use a different data source, they are not comparable with the Eurostat NewCronos data on R&D personnel.

Figure 4.5.4 shows the shares of female researchers working in higher education in science, engineering and all disciplines. In all countries the figures for all disciplines show that the proportion of women researchers in higher education is smaller than that of women S&E graduates. In the EU on average fewer than 30% of the researchers employed in higher education were women. The shares of women working

[22] *For interpretation of HC versus FTE, see also the Box at the end of Section 4.1. 3.*

Figure 4.5.4 Higher education researchers in science, engineering and all disciplines: Percentages of women, last available year



Source: DG Research
Data: DG Research, C 5, WIS database
Note: Years to which the data refer: D, P, FIN, UK: 1997; A: 1999; all other countries: 1998. No data were available for EL, E or L so they are not included in the EU average.

Third European Report on S&T Indicators, 2003

in the fields of science or engineering are even less with 23% in science and 13% in engineering.

Portugal and Ireland are in the lead with, respectively, 43% and 47% of higher education researchers in all disciplines being women, 48% and 44% in science and 29% and 25% in engineering. The smallest shares of women researchers in relation to men researchers are found in Belgium, the Netherlands and Germany, with shares ranging between 15% and 19% in all disciplines, 8% and 13% in science and 2% and 9% in engineering. Interestingly, Italy comes out with values near to the average, which seemingly implies that the high shares of women S&E graduates are not pursuing careers in S&T.

If the labour force figures are compared to the data on graduates, it emerges that women on average lose a share of about 18% in science and 5% in engineering. Even for PhD graduates there is a drop of about 10% in science and 4% in engineering.

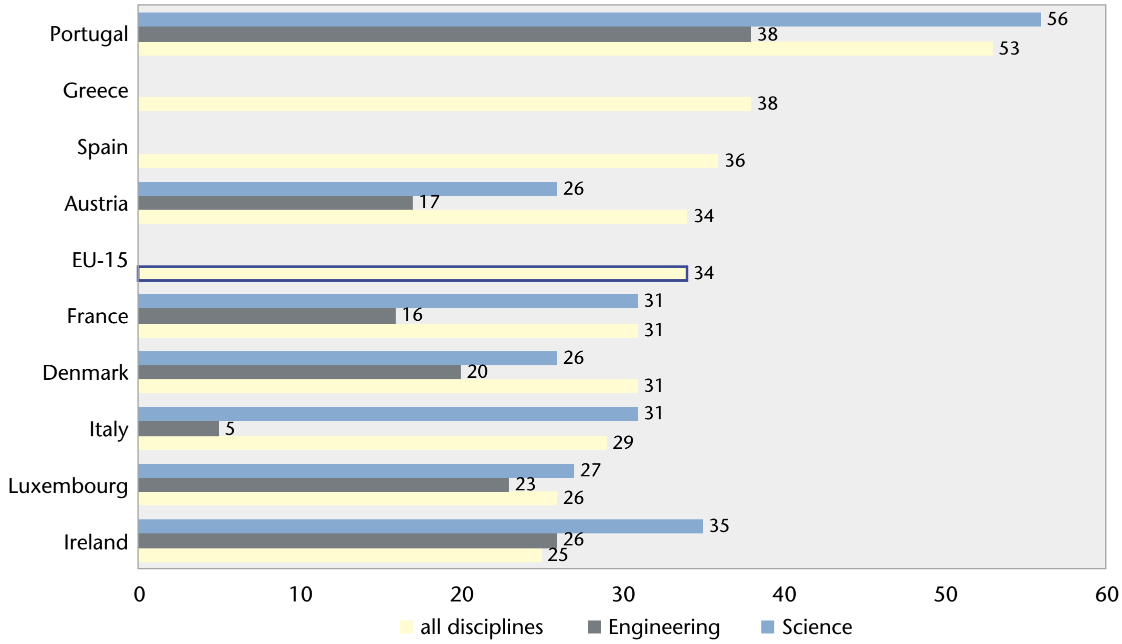
Assuming that a career as a researcher in a higher education or government institution is the most likely occupation for women, the gaps between women S&E graduates and employees in the business sector must be even more substantial. Unfortunately, there is no data for the business sector to prove this, but some government data are available – at least for certain countries. Figure 4.5.5 shows the shares of female government researchers in S&T for a few countries.

As in the higher education sector, Portugal is also in the leading position in the government sector, but Ireland has fallen back. In Portugal the share of women researchers in government institutions is extraordinarily high – more than 50% in all disciplines and in science, and still a high 38% in engineering. The other countries have shares of around 30% in all disciplines and in science, and shares of between 5% and 25% in engineering.

What is striking is that the northern European countries like Denmark or Austria, that feature most prominently in the education data, have nearly caught up with the better balanced southern countries like France, Italy, Spain and Greece. Unfortunately, no data for the Netherlands, Belgium, Germany, the UK, Sweden or Finland are available, so this assumption cannot be tested. Furthermore, the EU average should not be over-relied upon given the narrow statistical base.

Another career path for the graduate is in higher education. Figure 4.5.6 shows the shares of women with full professorships in all disciplines. In the EU, only 11% of full professors are women, which is considerably lower than the representation shown for women graduates in data on all disciplines. Finland, reporting 18% of women in full professorships, has the highest representation at this level, followed by Spain, France and Italy. The lowest shares of between 5% and 6%

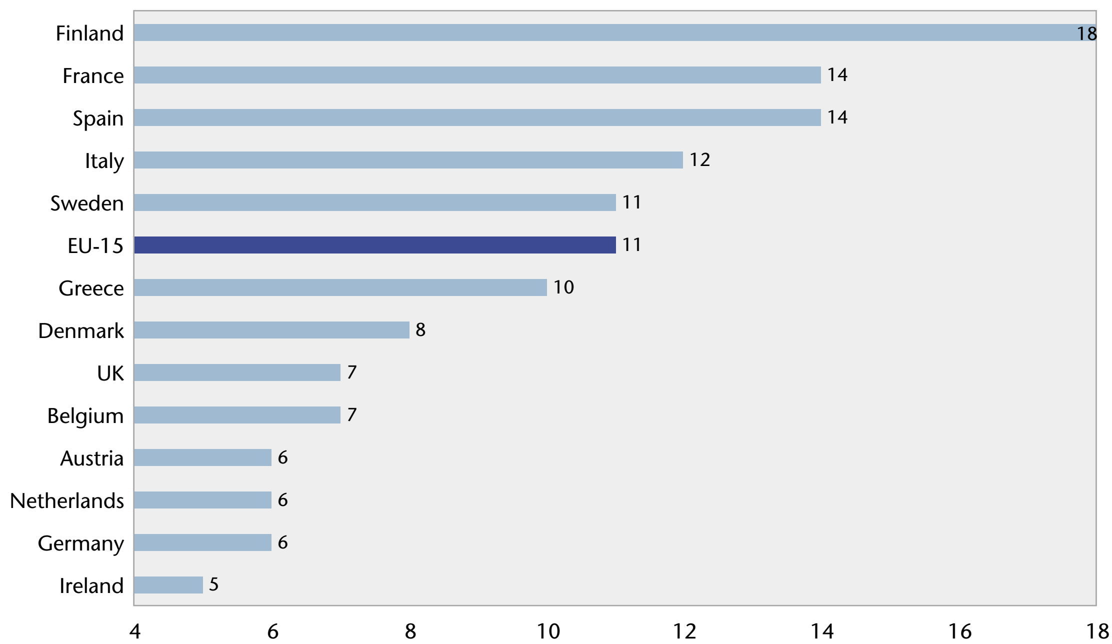
Figure 4.5.5 Government employed researchers in science, engineering and all disciplines: Percentages of women last available year



Source: DG Research
Data: DG Research, C 5, WIS database
Note: Years to which the data refer: A: 1993; P: 1997; L: 2000; all other countries: 1999. No data were available for B, D, NL, FIN, S or UK so they are not included in the EU average.

Third European Report on S&T Indicators, 2003

Figure 4.5.6 Full professors in all disciplines: Percentages of women last available year



Source: DG Research
Data: DG Research, C 5, WIS database
Note: Years to which the data refer: EL, E, FIN and UK: 1997; D, IRL, A and S: 1998; all other countries: 1999. No data were available for P and L so they are not included in the EU average.

Third European Report on S&T Indicators, 2003

were reported in Ireland, the Netherlands, Austria and Germany.

Scenarios for more women in S&T

It is worth considering some possible scenarios regarding the contribution of women to the human resource base in S&T should their increased participation in S&T careers be successfully achieved. Figure 4.5.7 presents a commonly used approach to gender differences in careers: the scissors diagram shows the shares of women and men in the target population, which are students enrolled in upper tertiary education (ISCED 5A) and in postgraduate studies (ISCED 6), the PhD graduates and professors on three different levels (assistant, associates and full professors).

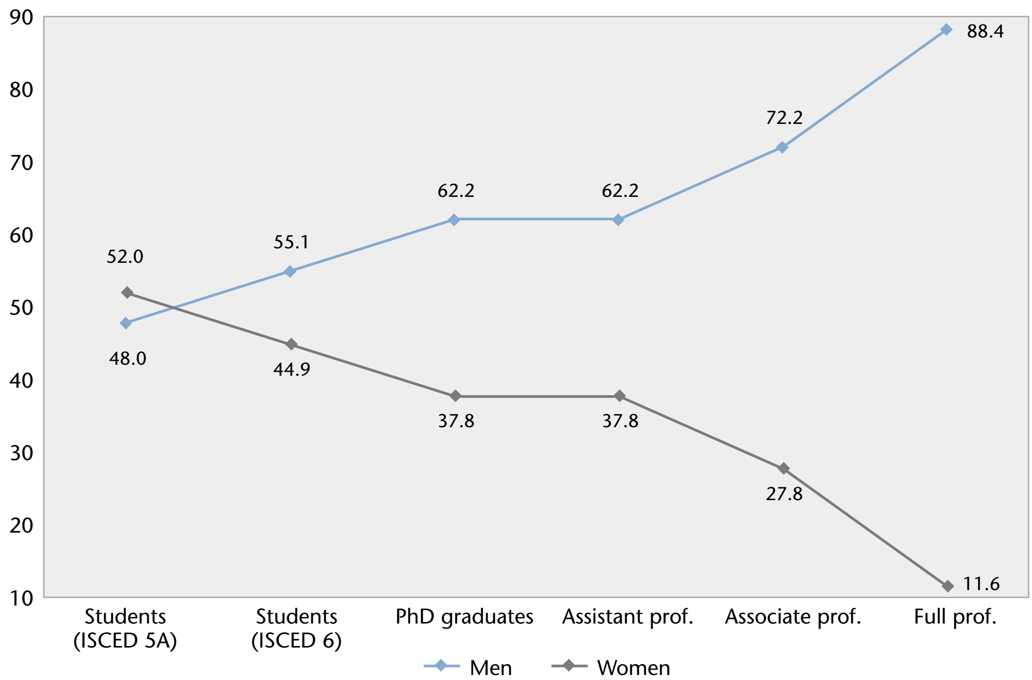
Starting on the same level with slightly more women students, the proportion of men steadily increases to reach 62% of PhDs and 88% of full professorships. In S&E disciplines, lower shares of women can be expected from the outset and become ever more likely on the highest rungs of the career ladder. Making simple calculations based on the data for all disciplines in higher education, the absolute numbers of women assistant professors could be 50% higher if women students followed scientific careers resembling those of male S&E students. At the level of associated professors, the numbers would increase by 150% and for full professors the increase could be as high as 800%.

In absolute figures this translates into a potential 180 000 additional (women) professors in the EU. Other examples are an additional 55 000 women researchers for the government sector and 200 000 women researchers for the business sector. These numbers are hypothetical but indicative of the scale of possible changes in the skills pool if the participation of women in the EU could be canvassed and fully realised.

3. Employment of women

The overall employment figures give also a good impression about women's careers in S&T related occupations. The following analyses are related to the occupations as professionals and as technicians.[23]

Figure 4.5.7 Scissors diagram for EU average in % (1998-1999)



Source: DG Research
Data: DG Research, C 5, WIS database
Note: EU average for PhD graduates does not contain D and L, while the average for professors does not contain L and P. Exceptions to the reference year: EL (students), IRL (PhD gr.): 1997/1998; B (PhDs), P (PhDs), S (PhDs): 1999/2000.

Third European Report on S&T Indicators, 2003

[23] *For the definitions of professionals and technicians and of levels of education, according to the "Manual on the measurement of human resources devoted to S&T" (OECD Canberra Manual), see the methodological annex of chapter 4 at the end of this report.*

Professionals and technicians compared by education levels

Across the EU, almost 45% of professionals (in the wider than usual definition of ISCO–88 major group 2 which is equivalent to graduate level employees) are women**.** Among people employed as technicians about half are women. In both groups, there are differences when it comes to education, as illustrated in figure 4.5.8. The majority (63%) of lower qualified professionals are men, while men make up only 53% of technicians. Among higher qualified (upper secondary or tertiary level education) professionals, around 45% are women. However, among the higher qualified technicians, more than half (53%) are women.

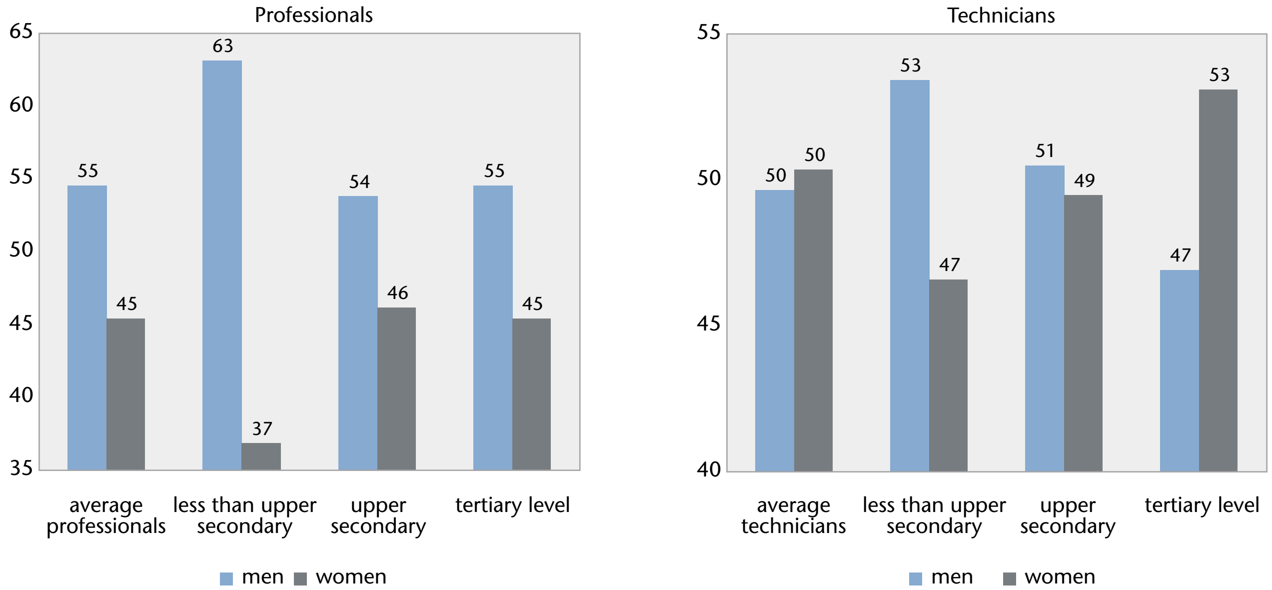
What does this mean? In the "Canberra Manual", the definition of the role of technicians covers support, but not administrative work, that requires a lower qualification level. This may well explain the higher representation of women in the technician group. Similarly, the high share of tertiary level educated women technicians could indicate that, compared to their male colleagues, highly educated women may be occupying positions that undervalue their skills levels. This assertion is supported by the opposite tendency seen in the education levels of male professionals, the majority of whom have lower education levels. Men more often are capable of landing professional positions without the required educational qualification. Typical examples are the male computer experts without formal higher education in contrast to the female secretary with a university degree in social sciences.

Professionals and technicians: EU Member States compared

Figure 4.5.9 shows the shares of women professionals and technicians in the EU Member States by their level of educational attainment.[24]

The participation of women in the two occupational groups varies for the different EU Member States. The shares of women professionals are above the EU average in Finland, Portugal, Belgium, Italy, Ireland, Austria and Sweden, with shares of between 58% and 51%. Lower representation of women in the professionals group is reported by countries such as Luxembourg, Germany and France, ranging between 37% and 38%. Women account for higher shares of the technicians in Germany, Finland and Denmark, each with between 55% and 58%, compared to the lower shares of women technicians – between 39% and 42% – in Belgium, Italy, Spain and Ireland.

Figure 4.5.8 Shares of population aged 15 to 59 occupied as professionals or technicians in 2000 by educational attainment level: EU average

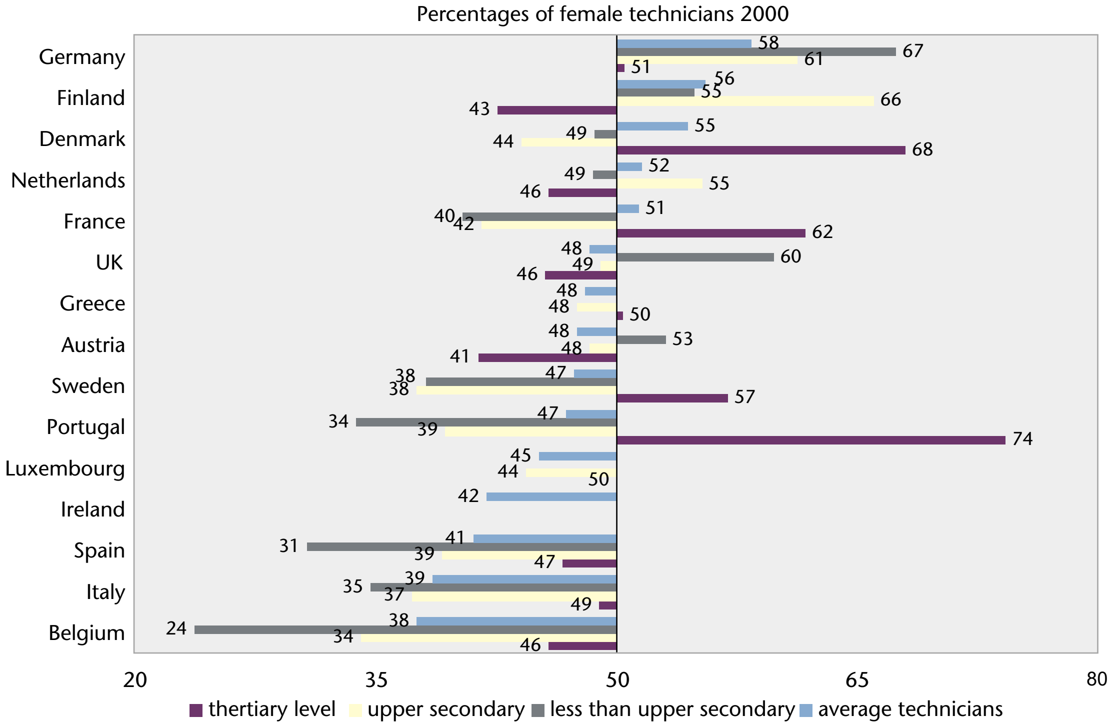


Source: DG Research
Data: Eurostat, CLFS 2000
Note: No data was available for IRL which is not included in the EU average.

Third European Report on S&T Indicators, 2003

[24] *The EU average for the categories of professionals and technicians is represented by the middle axis for a better interpretation of deviations.*

Figure 4.5.9 Shares of women aged 15 to 59 occupied as professionals or technicians in 2000 by educational attainment level: EU Member States



Source: DG Research
Data: Eurostat, CLFS 2000
Note: No breakdown by educational attainment level for IRL.

Third European Report on S&T Indicators, 2003

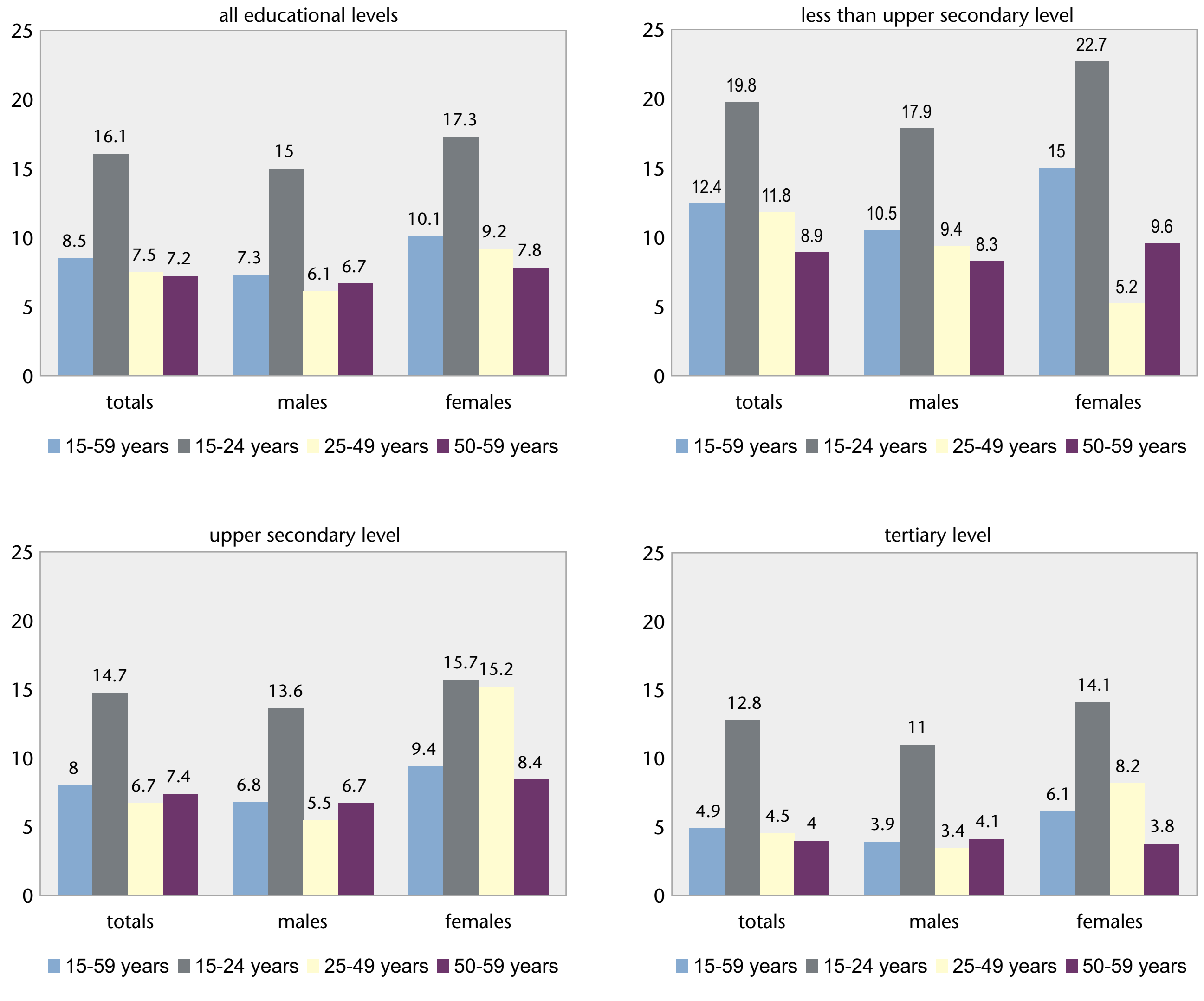
When the levels of educational qualification are taken into account, the biggest differences are found among women professionals with upper secondary education and women technicians educated below upper secondary level. In Italy, around 80% of the upper secondary educated professionals are women. In Belgium and Greece their share is around 60% while France, Denmark and Spain show low shares of around one third. Among women technicians with less than an upper secondary education, the range has Germany at the top with 67% and Belgium at the bottom with 24%.

The largest shares of tertiary educated women professionals are in Finland, Portugal and Belgium and range between 56% and 61%, all significantly higher than the EU average of 45%. Luxembourg, Germany and France have the lowest shares, below 40%. The biggest shares of tertiary educated female technicians are in Portugal, Denmark and France, ranging between 56% and 74%. Austria and Finland are at the opposite end with 41% and 42% respectively.

Unemployment compared to education levels

How do unemployment rates vary for men and women when educational qualifications and age are taken into consideration? Perhaps disturbingly, the youngest age group between 15 and 24 report the highest unemployment rates, as illustrated in figure 4.5.10. The older age groups also show higher unemployment rates, although they do vary according to education qualification levels. As one might expect, unemployment rates decline with higher levels of education. The highest unemployment rates for all age groups are found in the population with less than upper secondary education and the

Figure 4.5.10 Unemployment rates by educational attainment level, age group and gender: EU average 2000



Source: DG Research
Data: Eurostat, CLFS 2000

Third European Report on S&T Indicators, 2003

lowest unemployment rates in the population with tertiary education.

Interestingly, this does not hold true for the age groups across genders. Among women aged 25-49, the unemployment rate of those with less than an upper secondary education is about 5%, which is very low compared to the 15% unemployment rate of those with upper secondary education. Even among women aged 25-49 with tertiary education, an unemployment rate of 8% is reported, which is higher than the overall figure for people with this level of educational qualification. Overall, the unemployment rates of women are higher than for men, the exceptions being middle-aged people with low educational qualifications and highly educated elderly people. Within these categories the unemployment rates for the men are slightly higher than for women.

The data examined in this section support the notion of the enormous potential of women in providing human resources for S&T. That there is potential waiting to be realised is abundantly clear. It is illustrated by the substantial numbers of female graduates in S&E disciplines, from the ranks of those pursuing academic careers to the level of PhDs and professorships and also in the unemployment figures for higher qualified women.

Conclusions

One of the objectives of Chapter 4 was to illustrate the importance of human resources for S&T in the EU, and the implications of growing international pressures and demand for highly skilled S&T personnel. Key statistics on human resources in S&T show that the numbers of researchers have increased in all EU Member States. Even so, the European Union is not homogeneous and there are notable differences between the bigger and smaller countries. Concerns about a possible polarisation of skills and technology between the northern Member States and the southern Member States do have an empirical basis. A number of trends in the EU may be evaluated, and compared with developments in the US and Japan.

Almost all the Member States of the EU lag behind the US and Japan in terms of their ratio of researchers to labour force, and it will be difficult to catch up with these two countries. The typical requirements of a knowledge-based economy are not notably reflected in European countries with small pools of researchers. Recent developments in Sweden and Finland, which pushed up their shares of researchers from an already high level, are a good example of how to cultivate highly qualified human resources in science and technology. Portugal is progressing well too, albeit at a lower intensity. A closer examination of the policies in countries which promote higher numbers of researchers in the work force, could be useful in finding policy instruments for other Member States to consider.

In the public sector but particularly in the business sector there is a need to create more opportunities for highly qualified research personnel. The data show that European companies employ half of the researchers. This is well below the figure in the US and Japan, where the private sector employs up to 80% of researchers.

Why is the business sector in the EU lagging behind the US and Japan in creating opportunities for researchers? The challenge for the EU to extract greater economic and social benefit from its research and development achievements remains. The data suggest that the EU has not yet embarked sufficiently on activity to translate the benefits of research into private sector initiatives and start-ups. Proof of this hypothesis is the fact that countries with low overall numbers of researchers also show a low share of researchers in their business sectors. In this sense, the fundamental ideals of the knowledge-based economy have not fully dawned on Europe's private sector.

In contrast to the number of researchers, the number of graduates who are qualified for high-level occupations in S&T haves grown satisfactorily in the EU. In nearly all Member States the number of S&E graduates increased in the 1990s, although once more the differences between individual countries are striking. Countries such as Ireland, France and the UK are performing well, while others such as Belgium and Denmark have very low shares of highly qualified people in their younger populations. With regard to producing PhDs, Sweden and Finland lead the field, while most other Member States are keeping pace with the US and Japan.

The number of people qualified for S&T produced by the education system in the EU appears adequate, but it could lead to a false sense of security. Shortages may result, for instance, if education policy fails to enhance the appeal of S&T to students entering the education system, and to those on a career path. It is also clear that people with S&T skills are afforded flexibility in terms of opportunities and mobility across occupations and sectors in the economy. In addition, there is the global nature of the S&T labour market and the drawing power of competitors, for example the US. The knowledge-based economy will not reduce the need for people with scientific, technical, analytical and communication skills, as defined by S&E.

Section II identified possible shortages in the future by establishing a link between the production of human resources in S&T through education, and their occupation as researchers. Reasons for the shortage of human resources in S&T have been analysed by focusing on the phenomenon of an ageing population, the educational attainments of the population, age structures, the appeal of S&T in the population, and the employment situation of people with higher education qualifications.

The ageing of the population will not affect the total number of the potential labour force, aged 25 to 64, during the present decade. Nevertheless it will already begin to impact on the number of young people in S&T – which as a section of the population forms the human base for S&E graduates and young researchers. An important factor is the constant renewal of knowledge and skills. It is estimated that the ageing population phenomenon could reduce the human resources in S&T by up to one million young researchers, which is a potentially serious problem for the dynamics of the emerging knowledge-based economies. Again, differences between the EU Member States should be taken into consideration.

According to the results of Eurobarometer, S&T is respected by the population at large, but compared to other fields of interest, it is not rated among the top. The most S&T interest is shown in the medical or environmental sciences, which are important for societal well-being. Scientists and engineers enjoy a good reputation and the importance of S&T is recognised. It cannot be concluded from these results that lack of appeal is a major obstacle to students opting for S&E fields of study.

The education of the majority of the population in a broader knowledge-based society, and higher education for specialised R&D occupation, are both crucial factors in the development of a knowledge-based economy. Traditionally, European countries have understood this and made investments in all levels of education. Investment in tertiary education is not linked directly to output of graduates in higher education.

The share of total population of higher qualified R&D personnel with higher education differs among the Member States. Despite these differences, it cannot be concluded that in some countries, as opposed to others, it is more appealing to work in R&D with an adequate qualification. Some countries have more success than others in exploiting that part of the population with higher education qualifications. In other cases, the appeal of non-S&T jobs and factors such as unemployment or inactivity may be more important.

The unemployment data reveal insufficient use of current human resources in S&T. In the EU, there are up to two million unemployed people with appropriate educational qualifications or job experience who are potentially available for S&T posts. Comparative figures tell a different story. When compared with the rest of the unemployed part of the population, the unemployment of higher qualified people does not seem to be a major problem, due to the larger and growing demand for knowledge workers. The main pattern emerging from the analysed unemployment data is that existing human resources are well exploited in terms of S&T. Shortages may occur on the production side in turning out adequate numbers of S&E graduates.

Investment in education, especially tertiary education, was analysed in section III. Huge differences between the EU and the US are identified. The US is investing a far higher proportion of its educational budget and its GDP on tertiary education than most EU countries. Owing to major efforts made by all EU countries, especially during the first half of the 1990s, the gap between Europe and the US decreased between 1990 and 1998. Europe's overall gain in educational expenditure on the US during the 1990s occurred primarily in respect of secondary, intermediate education, with a much smaller gain at tertiary level. The growth in tertiary education expenditure during the 1990s took place at more or less the same rate as the overall GDP growth. In 1995, as in 1998, the same proportion of EU GDP was devoted to the financing of tertiary education.

The immigration of students and highly qualified people has potential for satisfying the growing demand for researchers (Section IV). International mobility, which is not a new phenomenon, is increasingly seen as representing the enhancement of skills and flow of knowledge. Still, there are real fears of talented R&D personnel not returning to their countries of origin once they have practised S&T in foreign countries. An obvious example is the drawing power of the US for foreign-born skilled people from all parts of the globe.

A second significant method for increasing the number of researchers is stimulating greater participation by women in S&T by drawing more female students into university programmes and careers in S&T (Section V). At the same time, the employment opportunities for women have to be expanded and issues of exclusion investigated. Some more aspects on this will be discussed in the subsequent dossier on 'Women in Science'.

A keen awareness of the problems the EU faces today, and may face in the future, is crucial in achieving the goal of transformation into a knowledge-based economy. Researchers need to continue exploring the links between human resources and innovation, and mobility of human resources between occupations, sectors and countries around the world. Only on the basis of empirical evidence can discussions result in positive policy actions to ensure that Europe has sufficient numbers of highly skilled people in S&T.

Selected Bibliography

Boekholt, P., E. Arnold, J. Kuusisto, M. Lankhuizen, S. McKibbin & A. Rammer. 2001. *Benchmarking mechanisms and strategies to attract researchers to Ireland. A study for the expert group on future skills needs.* Forfás, Ireland.

European Commission. 2000. *Statistics on Science and Technology in Europe, 2000 Edition.* Brussels.

European Commission. 2000a. *Key Data on Education in Europe 1999 – 2000.* Brussels – Luxembourg.

European Commission. 2001a. *Europeans, Science and Technology.* DG Research, Brussels.

European Commission. 2001b. *High-level expert group on improving mobility of researchers.* Final report. Brussels. Unpublished report.

European Commission. 2001c. *Women in public research in Europe, Statistics in Focus, Theme 9.* 07/2001. Brussels.

European Commission. 2002. *Benchmarking national R&D policies: human resources in RTD.* Brussels. Unpublished report.

European Council Lisbon. 2000. *Conclusions of the Presidency.* 23./24. March 2000.

Eurostat. 2000a. *European social statistics: Demography.* 2000 edition. Luxembourg.

Eurostat**.** 2000b. *European social statistics: Labour force survey results 2000.* Luxembourg.

Eurostat**.** 2000c. *European social statistics: Migration.* 2000 edition. Luxembourg.

Eurostat. 2000d. *Education Across Europe. Statistics and Indicators 1999.*

Finn**,** Michael G. *Stay rates of foreign doctorate recipients from US universities.* Oak Ridge Associated Universities.

Marey Philip, Andries de Grip and Frank Cörvers. 2001. *Forecasting the Labour Markets for Research Scientists and Engineers in the European Union.* ROA Working Paper, Maastricht.

OECD. 1993. *Proposed standard practice for surveys of research and experimental development.* "Frascati manual". OECD, Paris.

OECD. 1994. *Manual of the measurement of human resources devoted to S&T.* "Canberra manual". OECD, Paris.

OECD. "Oslo manual". OECD, Paris.

OECD. 1995. *Education at a glance.* OECD indicators. OECD, Paris.

OECD. 1996. *The Knowledge-based Economy.* STI. OECD, Paris.

OECD. 1998. *Human Capital Investment. An International Comparison.* OECD, Paris.

OECD. 1999. *Analyse des politiques d'éducation.*

OECD. 2000a. *Education at a glance.* OECD Indicators, Education and skills. OECD, Paris.

OECD. 2000b. *Mobilising Human Resources for Innovation.* OECD, Paris.

OECD. 2001. *The well being of Nations. The Role of Human and Social Capital. Education and Skills.* OECD, Paris.

OECD. 2002. *International mobility of the highly skilled.* OECD, Paris.

Responding to Ireland's growing skills needs. The third report of the expert group on future skills needs. 2001. Forfás, Ireland.

Swedish Open: the need for attracting foreign skills. 2001. Invest in Sweden Agency ISA, Sweden.

UNESCO. 1996. *The World Science Report, The gender dimension of science and technology.* UNESCO, Paris.

United Nations. 2001. *World Population prospects. The 2000 Revision. Volume II: Sex and Age.* United Nations, New York.

DOSSIER III

Women in Science: What do the indicators reveal?

Although female participation in science has increased in recent decades, women are still rarely seen in top scientific positions, such as professorships or other high-level research positions. Career opportunities in science are determined by a number of complex factors, which cannot easily be described using simple statistical indicators. ‘Internal’ factors – those that depend on the organisation, operation, and structuring of the scientific community itself – form an essential part of the explanation. The internal factors interact with ‘external’ factors, which are determined and shaped by society at large – such as existing gender roles inside and outside the family, the changing status of women with regard to education and the labour market, and the political frameworks that support equal opportunities[1].

In this dossier,[2] a set of established and new indicators will be presented to evaluate whether there is a gender bias in science[3] that prevents European women scientists from realising their full human and intellectual potential. The dossier does not address the questions of whether the contributing factors are specific to science, or part of a wider problem in society as a whole; or whether the problem is of greater or lesser importance in science than in other domains. What it does attempt, using established and new indicators, is to present an overview of the presence and participation of women in science, and to show gender-specific patterns of both presence and career opportunities.

Section I Measuring gender in Science and Technology

Giving prominence to the inclusion of a sex variable in data collection on science and technology (S&T) personnel and in the analysis of an S&T personnel profile has been identified as a priority at the European level.[4] Proposals to include the gender dimension in the revision of the current Frascati Manual (OECD, 1993) are widely supported by the European Union Member States. Recent Europe-wide initiatives to compare and contrast national policies and their outcomes have become more sensitive to issues of gender. The EU’s exercise‘Structural Indicators’ include a measure for the gender pay gap, and the ‘Benchmarking Exercise for National Research Policies’ includes a sex breakdown for all human resource indicators. It also includes a specific indicator that reflects the presence of women in publicly funded research.

However, these initiatives are all very recent. In the past, science claimed to be gender-neutral. In spite of a recommendation by UNESCO’s Division of Statistics on Science and Technology that all research personnel be classified by sex as early as 1984, sex-disaggregated data on S&T in Europe have only been collected at supra-national level since 2001. Previous editions of the European Report on S&T indicators and the World Science Report have underlined both the importance and the difficulty of obtaining appropriate statistical data and analysis for human resources in science and technology (Harding & Mc Gregor, 1996; Papon & Barré, 1996). The sex-disaggregation of information on scientific personnel in Europe was identified as a priority during the late 1990s[5]. Subsequently, efforts within Member States have yielded significant results[6], most notably the first statistical evidence that women are underrepresented in European research, especially in top academic positions.

---

[1] *It has been shown in chapter 4 that the goal of gender equity is not only an ethical one. For a variety of economic and technological reasons, the under-exploitation of women as human resources in science could become a serious obstacle to the future competitiveness of countries with higher levels of gender inequality. The emancipation and active empowerment of women in science, as well as in other sectors of society, on the other hand, present an opportunity to reduce potential future problems of scarcity of human resources, which should not be ignored by the European Union Member States.*

[2] *This dossier is a contribution of unit C5 “Women and Science” of directorate C “Science and Society” of the Research DG of the European Commission.*

[3] *In this dossier, the term is used in a very broad sense and includes the social sciences and humanities.*

[4] *Cf. the Communication from the Commission entitled: “Women and science: Mobilising women to enrich European research” – Brussels (COM [1999] 76 ferial of 17.12.1999); and Council resolution on “Science and Society and Women and science” Brussels, 01/06/99 (OR. En) 8565/99; Action Plan on Science and Society, COM (2001) 714 final of 4.12.2001, (Action 21), “A set of gender indicators will be produced in co-operation with the statistical correspondents of the Helsinki Group of Women and Science to measure progress towards gender equality in European research.”*

[5] *Cf. European Commission (ETAN Report) (2000) Chapter 8, Gender statistics in science: measuring inequality.*

[6] *See the European Commission“National policies on Women and Science in Europe” (2002), the Helsinki Group on Women and Science.*

The Commission has adopted a two-pronged approach to data collection at a European level. The first, referred to as the ‘Top Down approach’, aims to promote the breakdown by sex of data collections at institutional, national and international level in order to obtain comparable data. This approach, although more comprehensive, is relatively slow. In order to obtain an informed overview of the situation in the meantime, it has been decided to implement a simultaneous ‘Bottom Up approach’ – i.e. a collection of existing data at national level in Member States.

Although indicators on R&D personnel and S&T education are mainly input oriented, it is also possible to analyse the output of research by gender. Two feasibility studies on bibliometric and patent indicators by gender have been funded by the Commission’s Research DG within the CBSTII[7] activity. It has been established that collecting bibliometric data by gender is difficult, time-consuming and expensive, as the sex of authors and inventors could only be identified by their first names. Furthermore, the authors’ first names are often indicated by initials only (Biosoft, 2001). Tracing them is time-consuming, and contains a margin of error. However, the Biosoft feasibility studies have shown that at present, first name analysis is probably the only solution for obtaining retrospective output data by gender. If further and meaningful analyses of women’s patterns of productivity are to be undertaken, a sex breakdown should be given prominence in the major cross-national patent and bibliometric databases.

A mapping exercise of available data and sources in the European countries has demonstrated the need for comparable data concerning women in science, both at macro and micro level (Glover & Bebbington, 1999). However, the harmonisation of data to ensure comparability is a problem and tends to come to the fore only at the analysis stage. The lack of comparable data between countries, disciplines, occupational grades and career pathways, resulting from the different national academic, institutional, scientific and educational systems, should not block the on-going process of making the empowerment of women in science an important issue for society.

The data presented in this dossier, unless otherwise indicated, are based on national information provided on a goodwill basis by the Statistical Correspondents of the Helsinki Group on Women and Science. The data are validated by Eurogramme[8] for consistency and conformity, where relevant, to the International Standard Classification of Education (ISCED), the International Standard Classification of Occupation (ISCO) and the Frascati (OECD, 1993) and Canberra (OECD, 1994) manuals. Data on the US and Japan were obtained from “Women, Minorities and Persons with Disabilities in S&E” (National Science Foundation, 2000) and Kissho (2002) respectively. The sources of other analyses used in this dossier, such as on the family situations of women scientists or on productivity, are fully cited and listed in the references. All the data presented refer only to the two public sectors: the Higher Education Sector and the Government Sector.

SECTION II NEW CONCEPTS, INITIATIVES AND INDICATORS

The most resourceful and logical way to approach the measurement of sex differences in science is to draw upon the wealth of work that has already been accomplished in employment at large.

Indicators of ‘occupational segregation’ are well established for highlighting differences between sub-groups, such as sex or ethnicity, in employment (Siltanen et al., 1995). Overall occupational segregation is composed of horizontal segregation and vertical segregation. Only vertical segregation is sensitive to vertical inequality, since it represents the extent of the differences between sub-groups throughout the entirety of a hierarchy or hierarchical system (Blackburn and Jarman, 2002). Horizontal segregation, on the other hand, is a measure of the differences between groups across sectors, fields or disciplines.

In the current absence of an agreed international methodology for quantifying overall, vertical and horizontal segregation in a comparable way, there are, fortunately, other kinds of indicator that still tell us something about the patterns of vertical and horizontal differences between the sexes in European science.

1. Horizontal differences between women and men in S&T sectors and fields

At the end of the 20th century approximately 722 000 people, of whom 31% were women, were working as researchers in the Higher Education Sector (HES) and in the Government Sector (GOV) in the 15 EU Member States.[9] The sex composition of the labour force is often taken as a baseline for determining a point of equality. Figure D3.2.1 compare the share of women researchers in each of the two public sectors (HES and GOV) with the overall share for the labour force.

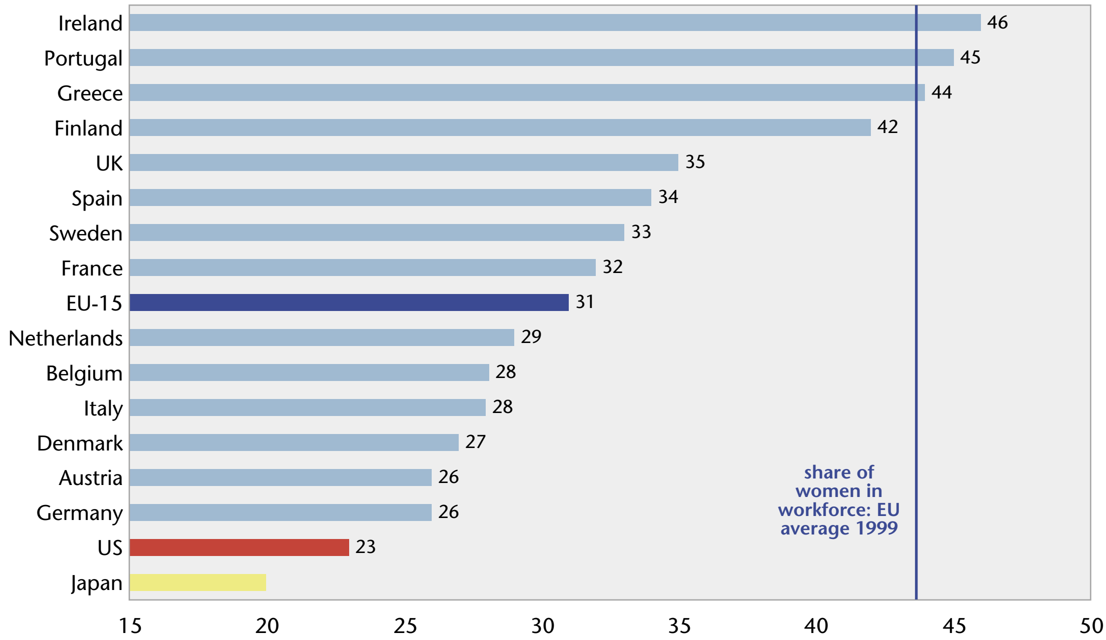
In 11 of the 14 applicable European Member States – Portugal, Ireland and Greece being the exceptions – the percentage of women working in science in the public sector is below the average for the total labour force. However, there is nothing

[7] Common Basis for Science, Technology and Innovation Indicators.

[8] A statistical consultancy based in Luxembourg, contractors to Unit C5, Women & Science, at DG Research, in co-operation with Unit A4, Eurostat.

[9] “National policies on Women and Science in Europe in 2002”, the Helsinki Group on Women and Science. This figure is presented in head count, and therefore differs from the OECD total, which is presented in full time equivalent. cf. Chapter 4 of this report for general data on human resources.

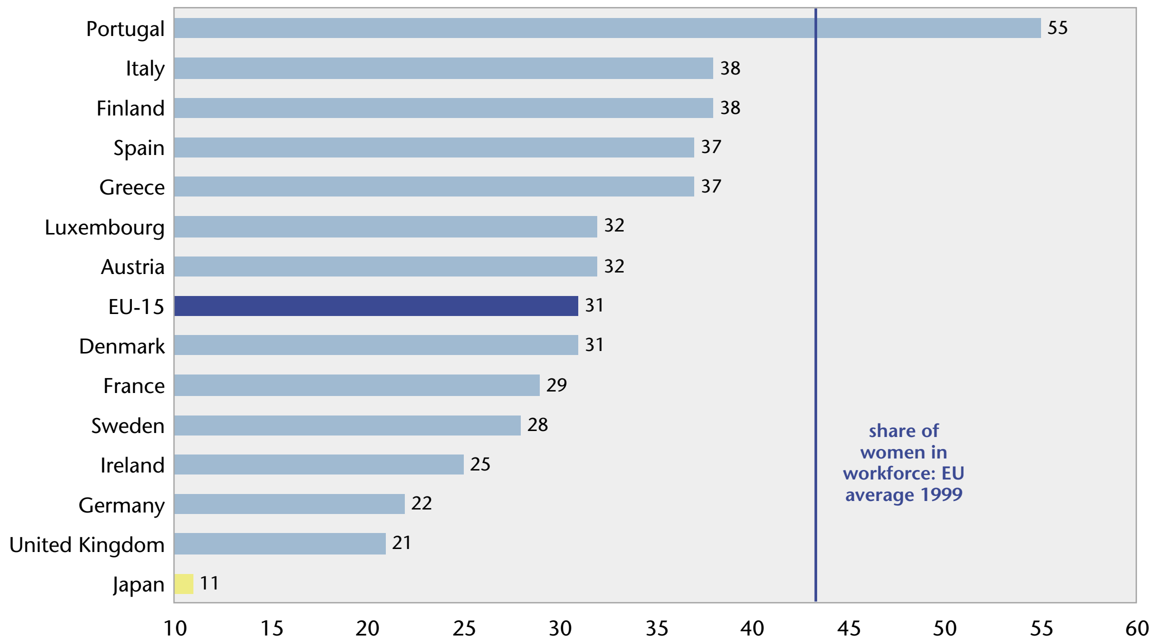
Figure D3.2.1a Share of women in the labour force and as researchers in HES (in %, 1999)



Source: DG Research
Data: WiS database
Notes: Exceptions to the reference year: 1998: A, UK (GOV); 2000: B (French speaking part); D (HES), LU. Exceptions to the Frascati Manual definition of researchers: B, IRL, NL, UK (HES). Estimated data: B, NL (HES); D, IRL, S (GOV); EU (HES and GOV).

Third European Report on S&T Indicators, 2003

Figure D3.2.1b Share of women in the labour force and as researchers in GOV (in %, 1999)



Source: DG Research
Data: WiS database
Notes: Exceptions to the reference year: 1998: A, UK (GOV); 2000: B (French speaking part); D (HES), LU. Exceptions to the Frascati Manual definition of researchers: B, IRL, NL, UK (HES). Estimated data: B, NL (HES); D, IRL, S (GOV); EU (HES and GOV).

Third European Report on S&T Indicators, 2003

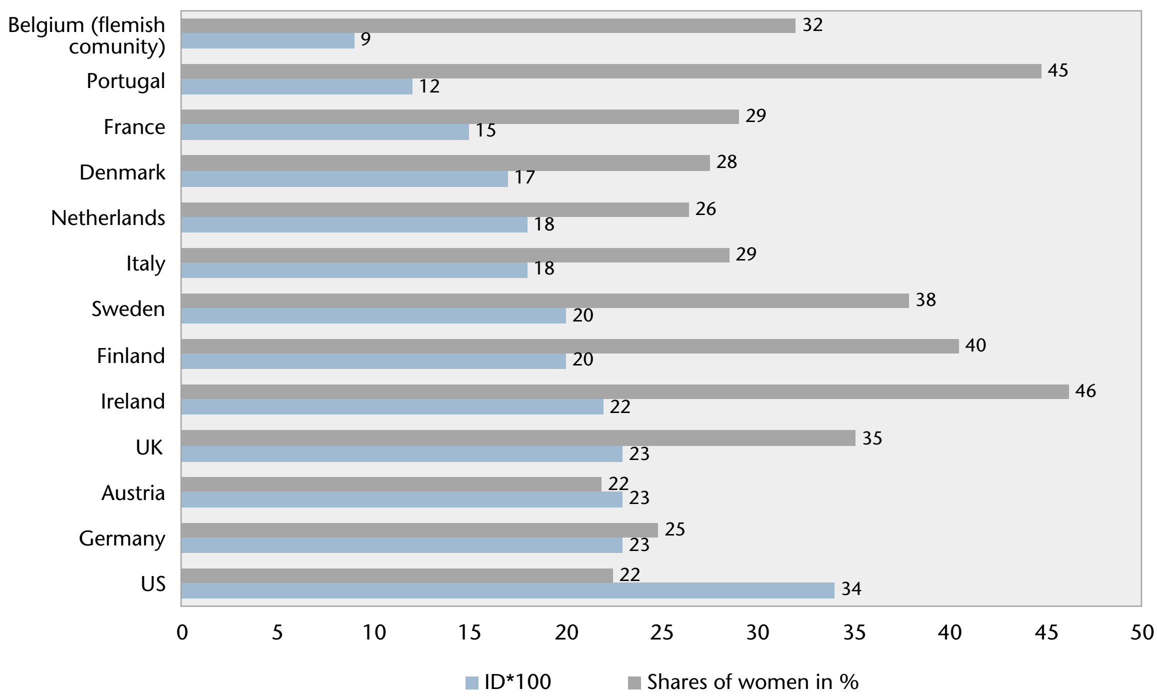
to suggest that there are any major disparities in this respect between HES and GOV.

Four countries – Greece, Ireland, Portugal and Finland – have more than 40% women researchers. Finland has a tradition of sensitivity towards gender issues. It appears that women are better represented in the countries in which the scientific professions are less developed and where the institutions are relatively new. In countries where the research system is more developed, larger numbers of women only started entering the labour market in an established system where men far outnumbered women. These findings demonstrate that in most EU Member States, it is likely to be easier for women to remain in non-scientific than to enter scientific professions. It is also interesting that the percentage of female scientists and engineers in the US and Japan are not only below the European average, but also below those of all EU Member States.

When measuring horizontal differences in science, the implicit assumption is that a more balanced distribution of women within disciplines may be a good result in terms of gender equity. A statistical measurement which is commonly used is the *Index of Dissimilarity* (ID)[10], which expresses the percentage of scientists and engineers who would have to switch occupational fields to match the percentage distribution by occupation of a referent group. This index is calculated as the sum of the absolute difference between the percentage of engineers and scientists working in a particular group working in each occupational field, and the percentage of engineers and scientists in the reference group working in each occupational field. The reference for women is men. Furthermore, the index of dissimilarity must be interpreted alongside the proportions of sexes in the analysed population to ascertain whether the dissimilarity favours women or men. The Organisation for Economic Coorporation and Development (OECD) and the National Science Foundation in the US (NSF) both use these indicators to highlight existing inequalities between the sexes.

From the horizontal perspective, a low ID score shows that men and women are equally distributed between disciplines with regard to the overall presence across all disciplines. In their report on indicators on gender equality in European employment, Rubery et al. (2001) remarked that differences between men and women are found in countries with high levels of female employment. This is confirmed by the results shown in figure D3.2.2, but is not necessarily always the case

Figure D3.2.2 The ID and shares of women by country for researchers in HES (1999)



Source: DG Research, Unit C5
Data: WiS database
Notes: Exceptions to the Frascati Manual definition of researchers: IRL, I, NL, FIN and UK. Exceptions to the reference year 1993: A.
Third European Report on S&T Indicators, 2003

[10] *The Index of Dissimilarity has some limits since the basic hypothesis is that there should be an even distribution by gender in every disciplinary group. This is clearly unrealistic, allowing for no element of variation in the processes that match people to occupations (Hakim, 1998, p. 8). It is, nevertheless, useful for promoting the concept of gender in the scientific community. It should be borne in mind that the greater the aggregation by disciplines, the lesser the difference, since the overall variability decreases.*

for science. The figure shows that Austria and the Netherlands, with an ID of 22, have the least equitable distribution of women by field. In comparison, the US has a score of 34. Not surprisingly, Austria and the Netherlands also have comparatively low shares of women. However, Ireland and Portugal, which appear to be the most highly feminised countries, have significantly different levels of horizontal inequality, emphasising the need to make careful interpretation of simple percentages.

Table 3.2.2 shows that in 12 EU Member States, there are clear imbalances in the share of women researchers between the different scientific disciplines. The share of women among all researchers is a good indicator – if the data can be provided for each field – as this information is simple to construct and interpret. The representation of such an indicator where it refers only to part of a system, such as a single discipline, is termed 'concentration' (Siltanen et al., 1995).

Although the representation of women varies across countries, table D3.2.1 reveals that the patterns of concentration are surprisingly similar. In other words, there are scientific fields where women are scarcely present (engineering, in particular), and others where they occasionally form the majority, as in the medical sciences. As a general rule, the data show that women are more concentrated in medical sciences, social sciences and humanities than in engineering and the natural sciences. Case studies show that these disparities are also pronounced within more detailed fields, such as biology or computing, but these data are not yet collected at cross-national level.

Horizontal gender inequality is important because it has an impact on the different career choices and opportunities available to women and men. In a study of the attrition of female and male natural and health scientists carried out in the UK, based on longitudinal data, Blackwell (2001) observed that horizontal inequality resulted in distinctive employment patterns within each of the two discipline areas. The study looked at whether women are feminising their working environment, or whether they are choosing disciplines that are known to be 'friendlier' to women's work/life balance. Overall, men are more likely to be employed and less likely to be unemployed than their female counterparts. However, within each field and for each employment scenario, both sexes are subject to the vagaries of change over time.

When measuring horizontal inequality in science, the implicit assumption is that a more balanced distribution of women within disciplines may be advantageous in terms of gender equity. However, in European universities and scientific institutions, women and men share many aspects of working together, collaborate with each other in various and complex ways, and yet often end up with very different rewards and recognition (ETAN, 2000; Harding & McGregor, 1996; Siltanen et al., 1995; Wirth, 2001).

2. Vertical inequality: careers and empowerment of women in S&T

The measurement of vertical inequality reflects a country's ability to make optimal use of its female human resources. It investigates the distribution of women throughout the scientific career ladders, and indicates the level of female partici-

Table D3.2.1 Shares of female researchers in HES by main fields of science in some European Member States (1999)

	Natural sciences	Engineering	Medical sciences	Agricultural Sciences	Social Sciences and Humanities
Belgium (Flemish comunity)	0.30	0.22	0.39	0.35	0.36
Denmark	0.23	0.13	0.32	0.43	0.32
Germany	0.17	0.11	0.33	0.31	0.30
France	0.29	0.17	0.21	(incl. in med. sc.)	0.38
Ireland	0.45	0.26	0.68	0.12	0.55
Italy	0.31	0.14	0.23	0.24	0.36
Netherlands	0.20	0.14	0.37	0.26	0.30
Austria	0.15	0.06	0.27	0.26	0.30
Portugal	0.49	0.29	0.50	0.44	0.49
Finland	0.34	0.22	0.52	0.36	0.48
Sweden	0.31	0.19	0.51	0.41	0.44
UK	0.25	0.15	0.52	0.33	0.39

Source: DG Research, Unit C5
Data: WiS database
Note: F: Agricultural sciences are included in Medical Sciences. Exception to the Frascati Manual definition of researchers: IRL, I, NL, FIN, UK. Exception to the reference year: 1993: A. Data for NL are estimated

Third European Report on S&T Indicators, 2003

pation at the highest decision-making levels. A European Commission *ETAN* report (European Commission, 2000) on women in the sciences has shown that across all European countries, there are few women in top university and research positions. It stresses that this under-representation of women compromises the attainment of excellence in scientific work. Furthermore, it represents a waste of talent because women's potencial in being under-untilised.

A comparison of the percentages of women in senior grades and those in junior positions is a useful indicator of the real presence of inequality, particularly if this percentage gap is significantly different from the one that applies to men (figure D3.2.3).

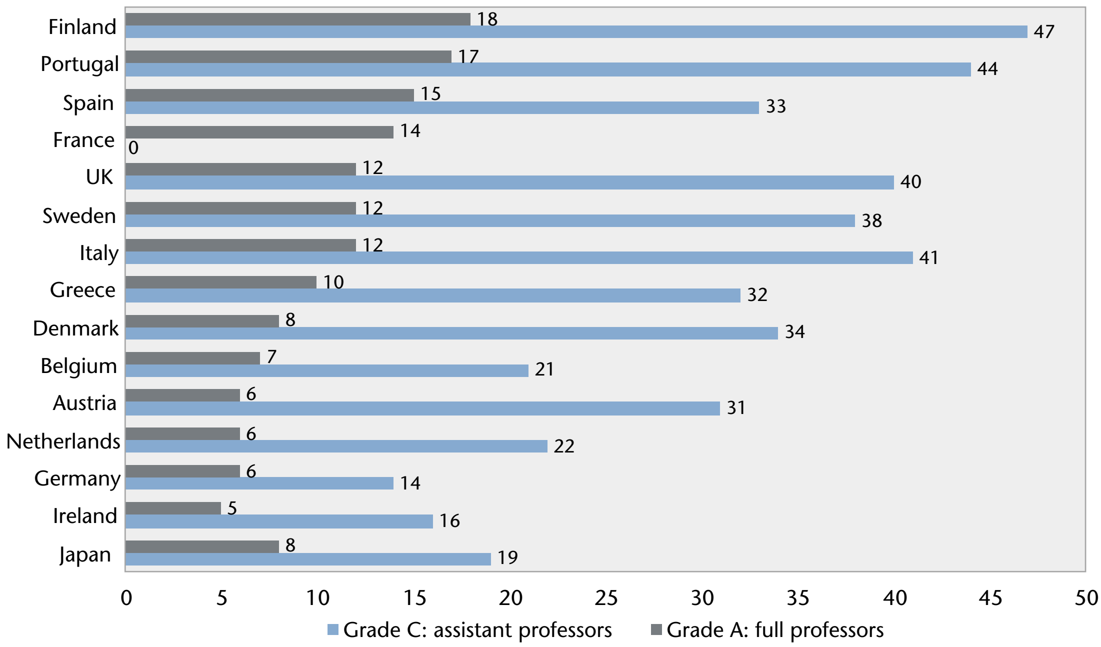
Existing inter-country differences in the grades of career paths in government scientific bodies, academia and other educational systems make comparisons difficult.[11] Notwithstanding these differences, it is clear from the figure that the higher the academic rank, the lower the presence of women.

To identify the point between graduation and full professorship at which women are being excluded in a given country, it is useful to look at the broader context of different career patterns by sex. The so-called career "scissors" (figure D3.2.4) refer to the crossover from relatively high graduation rates to low rates of appointment to professorial level. They are one of the most constant and regular phenomena that can be observed statistically. The scissors diagram is a cross-sectional image of the career opportunities available to today's female graduates in a given country under present conditions.

The figures show that in spite of the healthy representation of women at entry level, the differences between the numbers of men and women increase progressively up the hierarchy. With the rise in the rank (and in importance and salary), the number of women decreases considerably, until they become a distinct minority at the top. As status in contemporary society – science being no exception – is often equated with income-earning capacity, women are undervalued both socially and economically through the lack of recognition of their contribution to the advancement of science.

The scissors diagrams show that in Europe an overwhelming majority of men occupy the top academic positions. Two distinct career models can be discerned (Palomba, 2000). The first model, called 'The Overtaking', characterises countries

Figure D3.2.3 Share of female professors at academic grade C and A in some European Member States and Japan (in %, 1999)

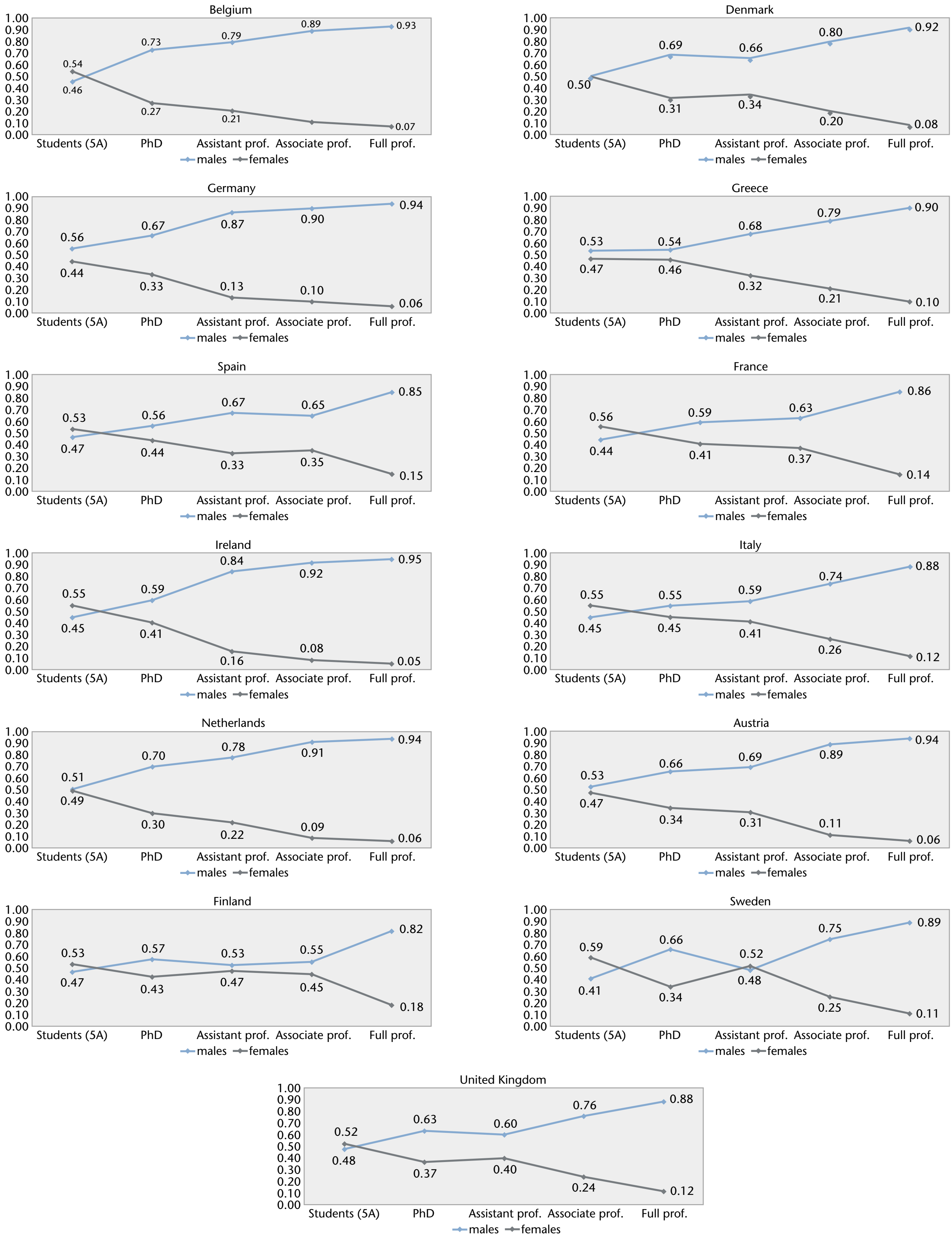


Source: DG Research, Unit C5
Data: WiS database
Notes: Exceptions to the reference year 1997: EL, P; 1998: E, IRL, A; 2000: JP.

Third European Report on S&T Indicators, 2003

[11] *The grades used here are drawn from the three categories of professor proposed in the ETAN Report: C, B, and A (European Comission, 2000). A is equivalent to full professor, B to associated professor and C to assistant professor. They identify the junior, mid-term and senior posts in a typical path for each national junior academic system. Although tests have shown that comparability is good for grade A and reasonable for B, there are major differences between countries for the coverage of grade C.*

Figure D3.2.4 Scissors diagrams for 13 EU Member States



Source: DG Research, Unit C5
Data: WiS database
Note: Exception to the reference year 1997: EL; 1998: E, IRL, A; head counts for NL are estimated. No data for full professors for F. No data for P or L.

Third European Report on S&T Indicators, 2003

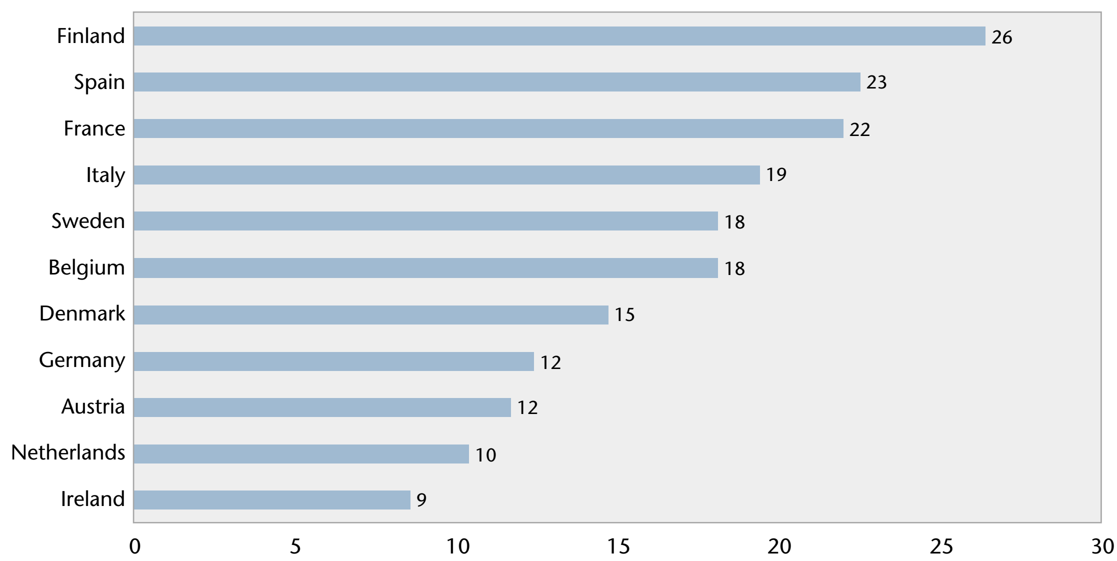
such as Belgium, Spain, France, Ireland, Italy, Finland, Sweden) and the UK. In this scenario, women researchers start with a considerable advantage (in terms of numbers) over men, but progressively lose ground until they end up as a distinct minority in the top positions. The second model, called 'The Impossible Pursuit', characterises Denmark, Germany, Greece, Austria and the Netherlands, where it is impossible for women to recover from, or even to maintain, the minimal numbers in which they begin at student level. Within the different national academic career structures, there is clearly some diversity in the stages at which the gender difference takes effect, but the overall picture is alarmingly homogeneous for all 15 Member States.

The Equally Distributed Equivalent Percentage (EDEP) is another way of illustrating the extent to which women are being utilised as a human resource in science. This single indicator is a component of the UN Gender Empowerment Measure (GEM) (cf. UNDP, 2001). The objective of the GEM is to concentrate on the professional participation of women, and in particular the degree to which they have been empowered within national systems in comparison to men.

The advantage of calculating the EDEP is that potentially different national situations can be compared, in spite of the differences in the educational systems and career pathways. This is relevant, because when comparing different countries, it is useful to be able to simultaneously take into account the extent to which achievements can be attributed to the background context. The EDEP is the harmonic mean calculated by taking the reciprocal of the population-weighted mean of female and male achievements in the top career grades. The harmonic mean has the property of taking into account both the value of the overall ratio and, to a certain extent, the disparity between men and women (UNESCO, 1997). Using the percentages of female students in each country to derive the weighting for the full professors, an EDEP for the participation of women in science[12] was estimated for 11 EU countries (figure D3.2.5).

From figure D3.2.5, it is clear that no country is anywhere near the EDEP equality score of 50%. In Finland, with a score of 26%, women students only have half as much chance of

Figure D3.2.5 Equally Distributed Equivalent Percentage (EDEP) for scientific participation in some European Member States (1999)



Source: DG Research, Unit C5
Data: WiS database
Notes: Exception to the reference year: 1998: ES, IRL, A and S. The formula is EDEP = 1/(SF/DF+SM/DM) where: SF = % of women in the 'source' population (i.e. students) expressed as a fraction (i.e. 0.1); DF = % of women in the 'destination' population (i.e. Grade A researchers) expressed as a whole number (i.e.10); SM = % of men in the 'source' population (i.e. students) expressed as a fraction (i.e. 0.9); DM = % of men in the 'destination' population (i. e. Grade A researchers) expressed as a whole number (i.e. 90).

Third European Report on S&T Indicators, 2003

[12] *The indicator varies between 50% and 0%. If there is total equity in career pathways, the EDEP score is 50%; the greater the disparity between female and male shares, the lower the EDEP will be. The weights are the female and male percentage shares in the bottom grade of the career ladder. For the reference population in each country the ISCED 5A students (Master's and Bachelor's degrees) are selected. ISCED 5A was selected because it eliminates bias emanating from the 'cross-over' point in the scissors diagram. It also considers the complete potential pool of researchers.*

becoming a professor as male students. For the four countries with scores of less than 12.5%, young men are four times more likely to achieve the top level of recognition and rewards than young women, if no change occurs in the gendered patterns of career trajectories.

Section III The debate on Women in Science: Does the evidence confirm general opinions?

In this section, three stereotyped perceptions on gender differences in professional life are analysed:

- *The situation will redress itself naturally as more women qualify in science.* Underlying this perception is the idea that "women have to be patient and wait." The belief that their under-representation at the top of the scientific hierarchy will eventually disappear "naturally" over time as their numbers increase at the entry level, is examined by analysing the careers of women in S&T occupations, relative to men.
- *Women are more affected by the ongoing double standard in family and domestic responsibilities.* This perception reflects the opinion that "family and children are a handicap for female scientists, because science and raising a family are both totally demanding (and therefore mutually exclusive) jobs". The family status of women in S&T in comparison with those of men is a focal point of the analysis.
- *Women are less productive than men.* The perception that "women publish less than men and that it is therefore normal that they fail to arrive at the top level", is examined by presenting some gender-related activity indicators.

1. Is "natural redress" sufficient?

Most of the measurements presented in the previous section concerning the paucity of women at the top of the academic and scientific hierarchy, are cross-sectional period indicators. Because of observed changes in the numbers of men and women entering science, it could be argued that it is simply a matter of time before gender equity is achieved.

Assuming that there is no active gender discrimination, and women must simply wait patiently for their turn to have a more equitable career structure, a new question arises: how long will this take? The Gender Segregation Index (GSI)[13] by position presents the number of men who would have to leave their posts, in favour of the same number of women, to equalise the presence of men and women in the career grades.

Examination of the GSI in the EU concerning the top grade A reveals that natural recovery is in many cases impossible in the short term. For example, in France this would require at least 5 980 male full professors to retire. In all the countries, 31 305 grade A male professors (more than 30%) would have to be substituted by the same number of women before achieving quantitative equality.

The number of years to equality can be calculated by applying recently observed growth trends to current data. In Belgium, for example, if women's shares in the different grades continue to increase at the current annual rate, it will take 40 years to reach equality in the C grade, 140 years in the B grade and 211 years in the A grade (De Henau & Meulders, 2001). In Italy, equality in the A grade could only be reached in 79 years if full professors continue to increase at the current rates. Considering the annual growth rate of the C grade pool, where the male rate of increase is higher than that of women, gender equality will never occur. It is clear that "simply waiting one's turn" is not on option for today's women. Moreover, merely condoning a short wait would also be symptomatic of a patronising attitude towards the question of women's participation in science.

Does this mean that vertical equality is unobtainable? To answer this question, longitudinal studies on the careers of men and women who have all entered academies and/or research organisations during a given year would have to be undertaken. If gender inequalities persist, when seniority and other related factors are held constant, the option of waiting patiently cannot be regarded as valid.

If an eventual "natural" recovery in vertical gender inequality can be expected, this can be confirmed by comparing longevity in each grade of the career ladder. The hypothesis would be that there is a relationship between promotion and longevity in that women and men with the same length of service in a certain career grade, and the same capacities and merit, have the same probability of being promoted to the upper level. Without gender discrimination in career paths, and assuming that the quality of the scientific work done by women is equal to that of men, the increase in the female presence at the entry level should result in an increasing female share in the top scientific grades.

The existence of vertical gender inequality was the subject of a survival analysis in Italy (Palomba, 2000). A cohort of 1 022 scientists – 224 women and 798 men – who entered the B grade at the National Research Centre (CNR) in the same year was studied. The results showed a relationship between the length of stay in the B grade and the probability of being promoted to the A grade – the longer the duration of stay, the higher the probability of being promoted. Although this was the case for both sexes, women appeared to be spending more time in the be grade that men. For example, after 11 years in

[13] *In UNESCO, 1997 it is defined as the percentage of all persons enrolled in a given occupational grade, who would need to be replaced by the other sex to achieve the 50% ratio of men and women, assuming that there is no change in the total enrolment.*

the B grade, women had a 16% probability of being promoted, whereas their male colleagues had a 39% probability.

Although longevity was not the only factor affecting the possibility of being promoted, it still played a role when other factors were considered[14]. For example, after seven years in the B grade, men had a 23% probability of being promoted to A grade, whereas women only had a probability of 11.9%. After 11 years in the B grade, men had a 28% probability of being promoted. Women had less than half the chance, at 13.5%. The same analysis carried out for university professors again showed that men are twice as likely as women to become associate professors and hence have a 30% better chance of becoming full professors (Micali, 2001).

In conclusion, the results showed that factors such as age at promotion, field of science and number of publications only partially explain the gender differences in the science hierarchy. The main explanatory factor is, and remains, gender. Accordingly, it can be stated with some confidence that gender discrimination against women still exists. Possible solutions are discussed in the concluding section of this dossier.

2. Are women more affected by the family double standard?

Throughout Europe, high birth rates, which have severely restricted women's freedom of choice of a career in the past, have fallen drastically. In Spain and Italy, for example, fertility rates are the lowest in the world (UNFPA, 2001). In spite of this general reduction in the birth rate, women scientists striving for career advancement are expected to choose between their female identity and social role, and adopting the "male model" of total involvement in work.

Careers and promotions in highly professional and qualified jobs require heavy investments in terms of time (unlimited working hours, unforeseen commitments, high levels of productivity, etc.), availability, and geographical mobility. Even in the most flexible work situations, such aspects may be hard to reconcile with family responsibilities, which are still largely left to women to shoulder (Arve-Parès, 1996).

Thus, for women the lack of career upgrading is often explained by their 'life choices'. Female scientists are confronted with a 'choose-or-lose' dilemma. They can choose to have a family and children or to strive to achieve a top position in their scientific career. The choice may have a symbolic value rather than a concrete effect on their careers. Moreover, from the empirical studies outlined below it emerges that there is no evidence that being childless will produce positive results in terms of career mobility. No one questions whether men, who remain at lower levels on the career 'ladder', do so by "choice" with respect to other social dimensions, or whether successful male scientists have ever been confronted with the same 'choose-or-lose' dilemma.

In EU countries, existing data concerning marital status and number of children of male and female researchers are fragmented. Such studies are undertaken by disciplinary associations, as a result of personal initiatives by women researchers, contingent curiosity and general interest, and do not facilitate cross-national comparisons. In many cases, they are related to specific science sectors. However, case studies from six EU Member States on this topic reveal similar results.

The family formation patterns of highly qualified women scientists in a UK longitudinal study was analysed quantitatively, using 1971 and 1991 cross-sectional information and cohort comparisons (Blackwell, 2001). The results confirmed that scientifically qualified women have distinctive patterns of marriage, cohabitation and childbearing. Women with health-related qualifications were compared with natural scientists (including those with qualifications in mathematics), technologists, women with non-S&T qualifications (degree level and above) and women with no degree-level qualifications.

High proportions of women aged 25-44 years in 1991 had never been married. The highly qualified were less likely to be married than those with no degree-level qualifications. The technologists were more likely than other graduates to be single, and more than twice as likely as non-graduates to have never married. Among the highly qualified, those qualified in health-related subjects were the most likely group to have married and had children. The author suggests that women within the health fields have more children because these are more flexible working environments. However, it cannot be ruled out that women choose health fields because they are perceived to be more family friendly.

The ages at which women in different types of occupation entered motherhood were subject to a survival analysis (Blackwell et al., 2001). The obstacles to women remaining in their profession becoming a mother, was determined for each year between the ages of 15 and 49. Clear differences emerged between the different occupations, with those working in technology and in natural sciences least likely to have children.

Another study conducted in the UK on women in engineering careers (Evetts, 1994) found that the efforts of women engineers to balance their professional and family roles limited their prospects of promotion. An obvious way to avoid the difficulties of trying to combine engineering and motherhood was not to have children.

In Sweden[15], male and female professors differ with regard to their marital/reproductive behaviour and the fulfilment of successful scientific careers. Among A grade professors, the percentage of married men is significantly higher in the sci-

[14] *The factors considered were age at entrance into B grade, age at recruitment, number of publications, disciplinary field, and geographic area.*

[15] *Data provided by Higher Education Statistics Unit, Statistics Sweden.*

ences (81%), than in the economically active population (47%). This also applies to women, but to a lesser extent (59% of A grade professors are married, compared to 50% of economically active females). Furthermore, the percentage of unmarried women among all A grade professors is twice the percentage of men (14% and 7% respectively).

With regard to parental status, at every grade the percentage of childless women among professors exceeds that of the total for economically active women. This is especially evident in the A grade. For men, no relevant differences emerge apart from a reduction of childless male professors in the B grade. It can be concluded that for Swedish women, there is a trade-off between having children and advancing their careers.

These results are reinforced by a recent study conducted among French engineers (Gadéa and Marry, 2001). When comparing the family situations of men and women in the top career grades (director or president), an 'inverted stairway' emerges. Men with four or more children are more likely to appear in the top grades than men who remain unmarried and childless. Women with four or more children are less likely to appear in the top grades and more likely to appear in the lowest grades. Although this is possibly due to an age effect, it may be concluded that if women scientists are not having remarkably fewer children than their male counterparts, they are waiting longer to have them.

A German study of women and men in physics (Krais, 2001) showed that, whereas men prefer traditional family settings, 71% of women physicists do not have children, and do not intend to have children in the future. An Italian study of female economists showed that 29% female professors were unmarried compared to 16% of women of the same age in the labour force. 39% of female professors aged 39 or more were married and childless as opposed to 11% in the corresponding age/sex sector of the work force (Bettio, 1999). In Ireland, 49% of female academic personnel were childless, compared to 25% of men (O'Connor, 1993).

Although it is too early to draw any definite conclusions from this data, the evidence suggests three different hypotheses concerning the existing gender relationships between family, children and the scientific profession:

- in several European countries, women scientists are less likely to have a family;
- women appear to be paying the price of their fertility themselves, either by deciding not to have children, or by placing their family before their careers;
- the presence of wives and children appears to have a positive impact on the career opportunities of men.

3. Are women less productive than men?

One of the criteria widely used by the scientific community to evaluate the merit of researchers is the quantity and impact of their scientific and technological productivity. This is usually measured by the numbers of publications and patents (cf. the paragraph on bibliometric and patent indicators by gender at the beginning of this dossier).

The number of publications and citation rates are the most commonly used measures of scientific performance (cf. chapter 5) because it is extremely difficult to measure the quality of scientific work statistically. In order to quantify women's productivity, it is necessary to identify the sex of an author. However, this is not easy as very few scientific institutions have a database of publications by gender. The results of the Biosoft feasibility study on bibliometric indicators by gender show that the share of female authors in terms of total numbers was about 15% to 30% in the six countries covered (Biosoft, 2001). As the feasibility study did not put an emphasis on representation but on feasibility, the results are only indicative, but still representative enough to identify a south-north bias between the countries studied. The southern European countries of Italy, Spain and France have a significantly higher share of female authors than the northern European countries of Germany, the UK and Sweden. There are also notable differences between the different disciplines. The highest share of female authors is found in publications within biology, earth and space sciences and biomedicine, and the lowest in mathematics.

Besides the feasibility study, information on gender differences in publishing comes mainly from studies which cover a particular scientific field. An American study on biochemists (Long, 1992) showed that the average lower productivity of females resulted from their over-representation among non-publishers and their under-representation among the extremely productive. However, if the extreme cases are not taken into account, women and men showed comparable levels of productivity. In addition, papers written by women on average receive more citations than those written by men. American data on the number of publications by full-time scientists and engineers point in the same direction, although with some differences (NRC, 2000). The data show that on average women publish less than men (5.8 for women and 7.3 for men). However, the difference depends on the over-representation of men in the extremely productive group and takes no account of women's participation as part-time employees.

A subsequent study carried out by Long (2001) in the US shows that differences in the positions held by men and women are likely to cause differences in productivity. There is a strong correlation between career stage and publication rate for men. Full-time male professors published 30% more papers than women in the same grade. Differences in productivity appear to decrease as the prestige connected to the position declines. Holding a position of responsibility tends to multiply men's publications, whereas for women this is less true. The under-representation of women in the top grades of scientific careers is therefore not the only factor in explaining their lower productivity figures.

It is also important to understand if and how differences between the productivity of men and women may change over time. Analysing scientific productivity, using national surveys from 1969 to 1993, Xie and Shauman (1998) found that gender differences in productivity had declined.

In summing up the results of the studies presented, there does not seem to be any proof that women are a priori less productive. Lower productivity of women is mainly due to structural circumstances such as their under-representation in science, but also due to the inequalities in career opportunities. It is important to stress that a lower hierarchical position appears to cause lower productivity, and not vice versa. Some results indicate that women have to outperform their male counterparts to establish a scientific career and to receive the necessary recognition for their work.

Conclusions

The studies that have been reviewed, identify a stratified system in which men are favoured in career advancement in science at the expense of women. Women do not share equally with men in the opportunities, benefits and responsibilities of scientific development and citizenship. In the long run this triggers a mechanism of exclusion that appears to exclude them from the same reward systems and deprives science of their input. All the indicators presented here illustrate the existence of inequalities and gender bias in the mechanisms underlying scientific excellence. These inequalities, which are produced through a wide variety of small differences, make the discrimination mechanism less visible, harder to identify and therefore more insidious.

The goals of equal opportunities in science differ from one country to another, depending on the social, economic and cultural context. Thus, in striving for gender equality, different European countries may set different priorities, including encouraging more young women into S&T disciplines, reserving more high-level posts for female scientists and ensuring that existing recruitment and promotion mechanisms are fair and transparent. Fundamental to all the above priorities is that women must have an equal share in all aspects of scientific decision-making. The limited participation of women in drafting programmes for the national research system, assigning funds for projects, and generally managing resources is an issue of great importance (European Commission, 2000).

The achievement of gender equality in science is a long-term process in which existing social and political norms and rules must undergo profound changes. It also implies a new way of thinking in which the stereotyping of women and men no longer limits their opportunities, or continues to reward only one of the sexes. This dossier has pointed out the pointlessness and wastefulness of "waiting for equality" and the impossibility of a 'natural' recovery. It has been argued that until the gender dimension is given prominence in bibliometric and patent measurements, there is no firm evidence to support the myth that women are less productive. Paradoxically, the utility of the main output indicators for gender analysis is shown to be fundamentally flawed.

The responsibility for family and children still represents an obstacle to women's careers in science as well in society at large. Several studies presented show that having families is detrimental to women in their careers, whereas men benefit from the presence of wives and children. Finding equitable solutions to this situation means challenging long-held stereotypes (such as the prevailing gendered division of domestic work) that underlie the power relationships and define the status of women and men in society. It is important to stress that science should no longer be considered immune, either from gender inequalities in power structures, or from job and family reconciliation responsibilities.

In Europe, as indeed worldwide, much remains to be done to improve gender equity in science. Women remain a rare commodity in the corridors of scientific decision-making. The development of indicators suitable for highlighting gender differences, for measuring equity-sensitivity, and for monitoring changes over time, depends largely upon the awareness of the value of gender statistics as a tool for policy-makers in the management of science. Women are increasingly regarded as essential agents of change, and so the measurement and analysis of gender gaps in science are a necessary tool for designing and adjusting policy actions (European Commission, 2002).

The collection of new gender-sensitive data and the construction of good indicators are also essential. Subjects such as the impact of the family on scientific careers need to be investigated extensively from a gender perspective through comparative and longitudinal surveys. Other topics, such as scientific productivity by gender, and understanding patterns of productivity in terms of both patents and number of publications by gender, remain an essential element if European science is to be competitive and sustainable. Further analysis is necessary to ensure that obstacles to women's productivity are identified and removed through policy measures.

For women to share equally in developing scientific knowledge, regulatory mechanisms conceived for a male-dominated work environment must be corrected. Rethinking the rules of scientific engagement from the point of view of equal opportunities, means creating the conditions for an increase in the number of women scientists in positions of excellence and leadership. As their numbers grow, they will serve as positive role models for the next generation.

SELECTED BIBLIOGRAPHY

Arve-Parès B. (ed.) (1996) *Concilier Travail et Vie Familiale – un enjeu pour l'Europe?*, Proceedings of the seminar in Saltsjöbaden, Sweden, 19-20 June 1995.

Bettio L. (1999) 'Economisti nell'università italiana. Che genere di economista?' , in: *I numeri della carriera*, Carabelli A., Parisi D., Rosselli A. (eds), Il Mulino, Bologna.

Biosoft SAS (2001) *Development of Bibliometric indicators by gender,* Final report under European Commission's contract ERBHPV2-CT-1999-14 N.

Biosoft SAS (2001) *Development of Patent indicators by gender,* Final report under European Commission's contract ERBHPV2-CT-1999-15.

Blackburn, R. and Jarman, J. (unpublished) *Occupational Vertical Segregation*, Draft Working Paper for workshop on vertical segregation, 9 September 2002.

Blackwell L. (2001) *Retaining women scientists: a longitudinal perspective*, Paper presented to the Gender Work and Organisation Conference, 27-29 June 2001, Keele University, Staffordshire.

Blackwell L. et al. (2001) 'Science Teaching: The demographic squeeze', *Labour Market Trends*.

De Henau J. and Meulders D. (2001) *La représentation des femmes dans la recherche au sein des institutions universitaires de la communauté française de Belgique*, Interim report of the Department of Applied Economics, Université Libre de Bruxelles, September 2001.

European Commission (2002) '*National Policies on Women and Science in Europe The Helsinki Group on Women and Science*'**,** Report about women and science for 30 countries, prepared by Rees, T. for the Helsinki Group on Women and Science.

European Commission (2001) '*Towards a European Research Area, Key Figures 2001, Special Edition – Indicators for benchmarking of national research policies*', OPOCE, Luxembourg.

European Commission (2000) *Science Policies in the European Union: Promoting Excellence through mainstreaming gender equality, a report from the ETAN Expert Working group on Women and Science:* Osborn, M. et al. (eds) OPOCE, Luxembourg.

Evetts J. (1994) 'Careers and Motherhood in Engineering : Cultural Dilemmas and individual solutions', in: *Journal of Gender Studies*, pp. 177-185.

Gadéa, C & Marry C. (2000) 'Les pères qui gagnent : descendance et réussite professionelle chez les ingénieurs', *Travail, Genre et Sociétés*, N°53, l'Harmattan, Paris, March 2000, pp. 109-135.

Glover J. and Bebbington D. (1999) *Women and scientific employment: mapping the European data*, 2nd Edition. Report of the exercise carried out for Women and Science Unit, European Commission, Directorate C, DG Research.

Hakim C. (1998) *Social change and innovation in the labour market*, Oxford University Press, Oxford.

Harding S. and Mc Gregor E. (1996) 'The conceptual framework', In *World Science Report*, *1196*, UNESCO, Paris, pp. 303-324.

Hedman B., Perucci F. and Sundström P. (1996) *Engendering Statistics: A Tool for Change*, Statistics Sweden, Stockholm.

Kissho M.Y. (2002) *Equal opportunities in Japan*, Paper submitted to ICWES12 (12th International Conference of Women Engineers and Scientists), 27-31 July 2002, Ottawa, Canada.

Krais B. (2001) *Physikerinnen und Physiker im Beruf - Eine schriftliche Umfrage zur aktuellen beruflichen Situation von Physikerinnen und Physikern,* Report produced in co-operation with the equal opportunities working group of the German Society for Physics, Technical University of Darmstadt, Institute for Sociology.

Long J.S. (1992) 'Measures of sex differences in scientific productivity', *Social Forces*, 71, pp. 159-178.

Long J.S. (ed.) (2001) *From Scarcity to Visibility : Gender Differences in the Careers of Doctoral Scientists and Engineers*', Panel for the Study of Gender Differences in Career Outcomes of Science and Engineering Ph.D.s, , Committee on Women in Science and Engineering, National Research Council, Washington.

Micali A. (2001) *Donne all'università,* Il Mulino, Bologna.

National Science Foundation (NSF) (2000)'*Women, Minorities and Persons with Disabilities in Science and Engineering, 2000*', (NSF 00-327), Arlington VA.

O'Connor C. (1993) 'Women in S&T in Ireland', in: *Women in Science in Europe*, Logue H.A. and Talapessy L.M. (eds), European Commission, Brussels.

OECD, (1994) 'Manual of the measurement of human resources devoted to S&T', *Canberra manual*, OECD, Paris.

OECD (1993) 'The measurement of scientific and technological activities: proposed standard practice for surveys of research and experimental development', *Frascati Manual*, OECD, Paris.

Palomba R. (ed.) (2000), Figlie di Minerva, Franco Angeli, Milano.

Papon P. and Barré R. (1996) 'Science and Technology Systems: a global overview', *World Science Report, 1996*, UNESCO, Paris, pp. 8-23.

Rubery J. et al. (2001) *Indicators on Gender Equality in the European Employment Strategy*, Report produced as part of the work of the European Commission's Expert Group on Gender and Employment (EGGE), November 2001.

Siltanen J. et al. (1995) *Gender inequality in the labour market,* ILO, Geneva.

UNDP (2001) *Human Development Report, 2001,* Published for the United Nations Development Programme, Oxford University Press, New York, p. 244.

UNESCO (1997) *Gender-sensitive education statistics and indicators*, Training material for workshops on Education statistics and Indicators, UNESCO, Division of Statistics, Paris.

UNESCO (1996) *World Science Report*, UNESCO, Paris.

UNESCO (1984) *Guide to Statistics on Science and Technology,* UNESCO, Office of Statistics, Paris.

UNFPA (2001) *The state of the world population, 2001 - Footprints and Milestones: Population and Environmental Change*, United Nations Publications, New York.

Wirth L. (2001) *Breaking through the glass ceiling: Women in management,* ILO, Geneva.

Xie Y. and Shauman K.A. (1998) 'Sex differences in research productivity. New evidence about an old puzzle', *American sociological review,* Official Journal of the American Sociological Association, 63, pp. 847-870.

PART I
Concluding remarks: Policy implications and perspectives

The EU and its ambitious goals

The Lisbon European Council in 2000 formulated a strategic goal for the European Union's next decade. The European Union should "become the most competitive and dynamic knowledge-based economy of the world capable of sustainable economic growth with more and better jobs and greater social cohesion". The main elements of the strategy to achieve this goal are the preparation of "the transition to a knowledge-based economy and society by better policies for the information society and R&D" and the investment in people (European Council Lisbon 2000, paragraph 5).

While on the one hand a high rate of unemployment needs to be reduced, on the other hand an increasing skills shortage is recognised, especially in information technology where increasing numbers of jobs remain unfilled. This problem also occurs in higher qualified technical professions and jobs within R&D. The Lisbon European Council and the follow-up councils in Stockholm and Göteborg, 12 and 15 months later, developed a catalogue of strategies and measures to be taken in order to reach the above mentioned strategic goal.

Three main elements can be identified:

- the transfer towards the Information Society shall be done by increasing and maintaining the accessibility to information technologies, broad education and training on information technologies and the establishment of an infrastructure for e-commerce;
- a European Research Area (ERA) should be established by creating attractive prospects for "the best brains" and the removal of obstacles to the mobility of researchers in Europe and to attract and to retain high quality research talent in Europe. Concerning the R&D environments within ERA, the encouragement of key interfaces in innovation networks, e. g. between R&D and training institutions, is another important element;
- the measures should be accompanied by macroeconomic policies which improve employment and training incentives in the tax and benefit systems, public expenditure for human (and physical) capital accumulation, support of R&D, innovation and IT.

Europe's education and training systems need to adapt both to the demands of the knowledge society and to the need for an improved level and quality of employment. They will have to offer learning and training opportunities tailored to target groups at different stages of their lives: young people, unemployed adults and those in employment who are at risk of seeing their skills overtaken by rapid change. This new approach should have three main components: the development of local learning centres, the promotion of new basic skills, in particular in the information technologies, and increased recognition of qualifications. (European Council Lisbon 2000, paragraph 25)

The European Councils gave a lists of concrete quantitative and qualitative objectives (European Council Lisbon 2000, paragraph 26), amongst others:

- a substantial annual increase in per capita investment in human resources;
- the number of 18 to 24% with lower secondary level education who are not in further education should be halved by 2010;
- a European framework should define the new basic skills to be provided through lifelong learning: IT skills, foreign languages, technological culture, entrepreneurship and social skills, a European diploma for basic IT skills, with decentralised certification procedures, should be established in order to promote digital literacy throughout the European Union;
- establish mechanisms to encourage the mobility of students, teachers and training and research staff both through making the best use of existing Community programmes (Socrates, Leonardo, Youth), by removing obstacles and through greater transparency in the recognition of qualification and periods of study and training; to take steps towards to remove obstacles to teachers' mobility by 2002 and to attract high-quality teachers.

At the Stockholm Summit (March 2001) the Swedish Presidency included Environment as one of the three 'Es' around which it organised its Presidency, the two others being 'Employment' and 'Enlargement'. The heads of State and Government agreed that sustainable development too would from henceforth be given the Lisbon treatment. Amongst other things, this means the formulation of national development strategies by all Member states, and the inclusion of sustainable development on the agenda of the annual Spring Meeting. Concerning education and training skills, the Council has set several priorities. This is in particular the improvement of basic skills, particularly IT and digital skills. This priority includes education policies and lifelong learning as well as overcoming the present shortfall in the recruitment of scientific and technical staff.

The European Council concludes that a knowledge-based economy requires a strong general education system in order to support labour mobility and adequate lifelong learning. Special attention has to be given to ways and means of encouraging young people, especially women, into scientific and technical studies, as well as ensuring the long-term recruitment of qualified teachers in these fields. In this context, the mobility of workers in new open European labour markets should be increased, this concerns students, persons undergoing training, young volunteers, teachers and trainers. (European Council Stockholm 2001, paragraph 11).

Investing more and better in the knowledge-based economy

In setting a target for R&D expenditure of 3% of GDP by 2010 at the Heads of State summit in Barcelona in 2002, European governments made their ambition clear. The goal of competitiveness must be pursued by an examination of the roots of the gap between the EU and the US, and co-ordinated actions to address this gap by increasing both the quantity and quality of investment in research.

The detailed examination of the composition of research expenditures found in this part of the Report has provides valuable information that allows an assessment of where investment needs to be increased for Europe's objectives to be attained.

The main message coming from this analysis is that the largest part of the increase in R&D investment needs to come from the business sector. This is not simply a matter of individual firms spending more money. Indeed, a recent study found that the largest European multinational firms are spending comparable amounts to the US on research (see also Section 3.1.4). The problem is that there are just more firms spending large amounts of money in the US, in a number of different industrial sectors. This points to more of a systemic problem in that the European environment does not seem to be conducive to producing lots of successful (new) companies, that spend on research, and that ultimately become world leaders in their respective markets. In order to achieve this sort of systemic improvement in Europe's research environment there needs to be:

- a strengthening of private sector effort in R&D through updated policy measures (loans, guarantee schemes, fiscal incentives, venture capital support, public subsidies) and through creating a favourable environment for increasing R&D investment by private sector;
- the creation of suitable conditions for strengthening the production of knowledge by public research;
- a favourable environment for the transformation of new knowledge into technological advancement and innovation;
- enhanced the transmission of knowledge and know-how in society as a whole through interplay and collaboration between various economic actors across the innovation systems and through education, training and life-long learning.

Throughout the 1990s, spending by EU governments on research was clearly at the lower level compared to that of the US. The gap between the US and the EU didn't increase or decrease, but remained more or less the same. However, the trend of the EU-level government investment now appears to be one of decline. Although, the main part of the increase in investment needs to come from the business sector it is important that levels of government expenditure are also maintained and increased. This maintenance of government R&D expenditure is not just important to reach the overall target of 3% to achieve a "critical mass", but also, if spent in the right way, it can form an important element of the systemic improvements. These improvements will help improve business sector investment and enhance research conducted by public sector R&D organisations. A "multiplier effect" through joint-financing schemes and research infrastructure support is an important part of creating a fertile environment for new technology-based businesses. The point is that government expenditure contributes not only to the overall levels of expenditure, but also creates new incentives for increases in expenditure in other sectors. This is also important in the context of attracting investment in research from overseas. Foreign multinationals spending money on research in the EU is not only important for improving the knowledge-based activities in the EU, but also for helping to integrate European scientists into international networks of knowledge-production. All these issues relate to the overall *quality* of the investments made by governments in R&D.

Progress has been already been made in terms of the rationalisation of certain research funding instruments. During the 1990s a clear change took place in the allocation criteria of public funding, with greater emphasis on how to invest most effectively. The trend included a movement towards allocating funds on the basis of greater competition, often through intermediary organisations rather than directly out of the government budget. Schemes involving collaboration between multiple partners and those involving university-industry co-operation have also been developed as a way of trying to improve the economic impact of public research funding. Such rationalisation of research funding instruments has been important and could be argued to have had an important role in maintaining Europe's relatively strong position (and improvement) in scientific and technological performance, presented in chapters 5 and 6 of this report. However, such rationalisations will not be enough on their own to redress the gap between Europe and its main competitors that has emerged in recent years. Improvements in policy instruments have to be reinforced by an important increase in the overall amount of money invested by EU governments and industry.

In spite of the modest development of government contribution to R&D financing in the EU, the role of government has not diminished. Indeed, the opposite is true. For instance, instead of being mainly a financier, today's governments are expected to act as facilitators, and to create a fruitful regulatory framework and environment for various organisations to collaborate and conduct research.

In order to safeguard the high standards of research and to maintain the capacity to initiate research in new areas, there should always be a sufficient volume of long-term funding available for research that is not tied in advance to any specific purpose. To make sure that researchers can work in a positive atmosphere, it should be in the interest of the government also to underline the importance of all types of research and their relevance to well-being in society.

The importance of human resources for S&T

An important development during the 1990s in nearly all the EU countries was the increased participation of private agents in the financing of education. This was most noticeable at tertiary level. Fully or nearly fully public funding is in all countries less common at the post-secondary stages of the education system, and during the last decade post-secondary education has been relying more and more on private sources for its financing. Subsequently, the issue of more significant involvement of private agents in tertiary education financing is being debated in many EU countries. Given the supply and demand discrepancies in respect of highly skilled graduates, the question has been raised in recent years whether (increased) private funding of tertiary education might contribute to a better balance between skills and employment opportunities, as market incentives would play a major role in guiding career decisions and curriculum plans. One problem matching skills with jobs is that fewer young people choose to enter disciplines like engineering, natural sciences or information technology than in the past. Private educational institutions might be able to offer more attractive curricula and to provide closer links to industry with better job perspectives. Because of higher levels of participation also by new client groups, governments are forging new partnerships in mobilising resources for tertiary education. New policies are designed to allow the different players and stakeholders to participate more fully and to share the costs and benefits more equitably. Universities are facing new challenges, not only to increase the availability and range of educational services, but also to re-orient their programmes towards student needs in the new global marketplace.

Policy should stress the importance of augmenting the human resources in Europe by education and training (both in basic knowledge and skills and the specific disciplines). At the same time policy should try to solve short-term problems by attracting scientists and engineers (S&Es) from abroad (including the return of emigrated S&Es who emigrated and persuading S&Es who immigrated to stay). European policy makers have to make mobility within Europe and between and the most of the world easier, increase the attractiveness of Europe as a place to work and to undertake research by providing adequate economic, legal and social environments. At the same time, they have to strengthen the education and training systems and try to foresee gaps in R&D personnel and support university education in these deficit fields. It is important to check out potential source of R&D personnel that are currently not used or that are underused such as women, older employees and foreign citizens. The generation, development and exploitation of human resources affect many areas of social, political or economic life. This will become one of the most crucial challenges of the ERA in the future.

The major building blocks for a policy supporting human resources in S&T were laid out in late 2000 and throughout 2001, with the conclusions of the Stockholm European Council of March 2001 constituting the cornerstone. They include various Commission initiatives in the area of mobility such as the Action Plan on Mobility[1], followed by the issuing of a recommendation on mobility[2], and the Commission Communications on “Making a European Area of Lifelong Learning a Reality”[3], and “A Mobility Strategy for the European Research Area”[4]. From the point of view of addressing skill gaps, of particular relevance is the Commission's Communication on the impact of e-economy on European enterprises[5]. The Stockholm European Council also endorsed a report on common objectives of education and training systems[6], on the basis of which a detailed work programme is currently being developed jointly by the Council and the Commission.

Integrating, and building on the elements above, the Commission put forward an Action Plan on Skills and Mobility[7], destined to address the obstacles to mobility and skill development. It covers a wide variety of actions, from making education systems more responsive to the needs of the labour market to an EU-wide immigration policy. It also includes as key elements actions on the recognition of learning, the transferability of qualifications, the removal of administrative and legal barriers to geographic mobility – for example through a universal health card, the development of language and cross-cultural skills, the promotion of cross-border recognition of qualifications and better information related to cross-border mobility.

---

[1] OJ 2000/C 371, 23.12.2000.

[2] Recommendation of the European Parliament and of the Council (2001/613/EC).

[3] COM(2001) 678 final.

[4] COM(2001) 331 final, 20 June 2001.

[5] “The impact of the e-Economy on European enterprises: economic analysis and policy implications”, COM(2001) 711 final, 29.11.2001.

[6] Commission Report on “Concrete future objectives of education systems”, COM(2001) 59 final, 31.1.2001.

[7] COM(2002) 72 final, 13.2.2002.

PART II

Performance in knowledge production, exploitation and commercialisation

The competitiveness of countries is reflected not only in how much money they are willing and able to invest in R&D and their innovation systems, but crucially in the wealth created through the production and sale of goods and services. Economic growth has since Schumpeter primarily been linked to technical change and the capacity of countries to innovate.

The previous Part on investment in R&D dealt with input data, that is, the amounts spent by countries on their respective R&D systems. Together with the data on human capital these represent the most important inputs of the innovation process where the ideas, dreams, interests, and very often endless diligence of researchers and scientists are the nucleus of basic and basic oriented research. Needless to say, researchers and scientists, who form the core of the scientific and technological human capital, are also partly the output of a country's R&D investment.

However, the input indicators are only one side of the coin. They tell us nothing about the performance of any given innovation system or the ability of countries to innovate. Unfortunately, available output indicators are rather limited, especially if one insists on using internationally comparable and reliable data. The question 'What happens between input and output?' is no longer such a 'black box' (Rosenberg 1976, 1982), and it would be desirable to have quantitative information about the innovation processes themselves, but very shallow, unknown areas still exist. However, owing to its often tacit nature and the many forms of research and innovation activities, the innovation process tends to be explored primarily through qualitative empirical studies.

Although performance indicators do not tell us much about underlying structures or cultural habits, analysed correctly, information on scientific and technological outcomes can provide some important insights. It is not sufficient simply to count numbers of scientific publications or patents, but it is much more instructive to analyse the disciplines a country's scientific community publishes in and in which fields innovators patent. The same is true for example for the indicator of high tech trade: the intensity is one side of the story, but which high-tech products are traded tells much more about the industrial structure and capabilities of countries.

The following chapters aim at providing a broad overview of Europe's scientific and technological performance compared to the rest of the world.

Chapter 5 provides an overview of scientific performance. Scientific publications are primarily the outcome of basic research carried out predominantly by public research institutions. There are of course also some disciplines where one can find publications relating to more applied research emanating from industry. While general figures are presented indicating a country's or world region's shares, the main focus is on a more detailed analysis of particular fields, a European specialisation index, co-publication patterns as well as the most actively publishing European research institutions.

A 'classic' and much used indicator of outstanding achievements in basic research remains the Nobel Prize. In recognition of the centenary of the foundation of the Nobel prizes which occurred in 2001, a dossier on the value of this indicator has been added (Dossier IV).

Chapter 6 will focus on the technological performance of countries. The main indicators chosen here are patents and high-tech trade. Patents can be used as a valuable indicator, but here, the choice of which patent data to use is crucial. As the dominant patent offices are the European Patent Office and the US Patent and Trademark Office, both data sources are used for different analysis. For the patent data there will be both macro data analysis and analysis by technology field. In addition, patenting behaviour by multinational firms and the so-called 'triad patents', patents which have been applied for at the European, U.S. and Japanese patent offices receive special attention. As already mentioned, high-tech trade can serve as an important indicator of the competitiveness of countries, and a section on trade in high-tech products has therefore been added.

As measuring scientific and technological output needs careful analysis and cautious drawing of conclusions, the chapters will also provide technical notes and explanations.

Despite the economic impact of high-tech products, the service industries are of growing importance for the European competitiveness. Compared to traditional industry sectors, the service sector is far less researched and difficult to grasp, due to a lack of a common understanding, definitions, and indicators. A dossier on patents in services tries to shed some light on the use of intellectual property rights in the service industries (Dossier V).

A second issue, which deserves special attention are so-called future, or key-technologies. During the past decade one has observed the rise of biotechnology, and currently one sees also the emergence of nanotechnology. These two important key-technologies are considered to be strategic in many respects, and an introduction and analysis of these two technologies is presented in the third section.

The final dossier provides some insights into science-technology linkages. A lot of innovation literature and research has focused on the linkage between basic research and industrial applications. Yet, until now, few quantitative data have been available to allow us to trace direct linkage patterns. This dossier presents the results of a recent research project, which has developed a method to map the interactions between science disciplines and fields of technology, and to build up appropriate indicators (Dossier VI).

CHAPTER 5
Scientific output and impact: Europe's leading role in world science

Europe's goal is to become the most competitive and dynamic knowledge-based economy in the world. As set out at the Lisbon Council in 2000, this goal is focused on promoting growth, social welfare and employment. One of the most important ways to achieve this is through investing in people, and their ability to absorb and generate knowledge – human capital is the resource in demand.

The knowledge capabilities of individuals, groups or even whole countries can be estimated by using a variety of indicators. Any meaningful economic analysis in this area should examine the extent of this knowledge base in terms of inputs (such as research and development funding and numbers of researchers), outputs (such as publications, patents and licences) and impacts (such as citations of publications in other publications and in patent applications). While measurement of the knowledge-based economy is in its early stages, and some working definitions for different kinds of knowledge have been put forward, these are the most widely used, accepted and reliable indicators. The subset of scientific indicators is the one used in this chapter.

This chapter explores these aspects of scientific activity – scientific outputs and their impacts. Measuring the quantity of scientific outputs produces an indicator of the scale of scientific activity in different countries and scientific fields. A proxy for the impact of these publications can be obtained by measuring citations. This chapter uses the most recent available data for scientific publications outputs and analyses and interprets the data in a variety of ways. By doing so, it aims to give a comparative picture of the outputs, impacts, strengths and weaknesses of European science. It compares different European countries to each other, and Europe and its countries to other major science producing countries and regions of the world. It also gives a number of cross-cutting reviews, for example of scientific activity in various disciplines.

The first section starts with a review of the methods used to measure scientific performance. The rest of the chapter continues at the global scale, and goes on to deal with increasingly local and specific analyses. Section two gives a review of global trends in scientific publishing, including an assessment of the strengths and weaknesses of the various world regions in different scientific fields. Thereafter it considers developments in the outputs of several scientific fields.

The next section deals with scientific co-operation within and between countries, as measured by co-publication indicators. The impact of scientific research is the next topic of focus, as measured by citations of scientific publications. A comparative analysis of global trends is made, including examples from the two fields of aerospace engineering and the life sciences, followed by a detailed examination of the impact of European science. Finally, the chapter considers the research institutions that are most actively publishing in the EU.

Following a set of concluding comments, the chapter has a number of annexes. The first is a more detailed discussion of the methods used in the measurement of scientific output. The second gives a classification of science and engineering fields and sub-fields. A list of references follows at the end.

Section I Measuring scientific output and impact

1. Measuring scientific performance

The performance or output of science can be measured by a number of different indicators. The most common ones are probably publications and related citations, patents, and widely recognised scientific honours such as the Nobel prizes. An annex to this chapter at the end of the report gives a detailed account of the methods used to measure scientific performance. Therefore, this introduction gives an overview of some of the main techniques and challenges.

While publications reflect the scientific basis of a single country or world region, patents are taken as signs of innovation. From these two indicators, a third one can be constructed, namely a science-technology linkage which aims to measure the actual scientific input to technological outputs, e.g. by measuring the scientific citations in patent applications. The latter indicator is dealt with in dossier VI.

Scientific honours such as the Field Medal and Nobel prizes are widely considered to be a sign of achievement and respect, recognising important scientific findings of global significance (cf. dossier IV). However, as those prizes are awarded only in a limited number of disciplines, by default much important research is not recognised in this way. In addition, while Nobel prizes and the Fields Medal generally come in a later stage of an individual's lifetime, publications and patents are a more current reflection of achievement.

2. Influences on scientific production and impact

Various factors influence the production of scientific publications and their validity as an indicator of scientific activity.

Investment: the numbers of scientific publications, and recent growth rates, reflect previous investments in science at the national and global level by various public and private sector actors, which in turn have seen political and socio-economic influences. The surge in life sciences publications can be attributed to political will (e.g. the US funding strategy for the "war against cancer"), scientific developments (e.g. revolutionary findings in molecular biology) but also to socio-economic needs (e.g. the aging of society and age-related diseases, and the rapid spread of animal diseases such as BSE[1]).

Timescales: the relevance of publications as an indicator of more recent developments in the scientific knowledge-base can certainly be challenged. It might take a scientist several years to do the research and to have it published. There are certainly wide differences between disciplines. While important findings in the life sciences can be researched in, say, a couple of months in other disciplines, for example particle physics, the research takes more time. In addition the publication process can be time consuming: in some cases, a publication can follow within weeks, in others the review process for publications can take months and months. Even though such time lags are difficult to deal with and to measure properly, these patterns and their impact have to be taken into account when comparing input and output data, research and development (R&D) funding, publications and patents.

Patterns of scientific co-operation: an important aspect of publication analysis is co-publications. It is a rich source of information that is of particular interest to policy makers. A single co-publication might reveal much about the attractiveness of single scientists and institutions nationally as well as internationally. On a more aggregate level, for example countries or disciplines, one can analyse patterns of co-operation between countries and see whether geographical proximity or a common language might play a role.

Importance in scientific production: in this chapter, while the focus is on the production side of science, it is necessary to bear in mind the issue of scientific importance. The number of publications produced by a country or region in specific disciplines does not reveal much about the quality of the scientific knowledge embedded in a publication, or even its usefulness. The importance of publications is very often linked to the number of citations a publication receives, which might be thought of as an indicator of the usefulness and importance of a publication. Despite the fact that citations and impact scores are strictly speaking quantitative indicators, they are nevertheless used for assessing influence and importance, and they are accepted, to a certain extent, to represent quality. This reflects the assumption that the more important a publication is, the more others will cite it. The issue of scientific impact is discussed in section 3 of this chapter.

Data on scientific output and impact: there is no national or international agency collecting data on scientific publications, and researchers and scientists are not required to introduce a new publication in any official database. Therefore, the measurement of scientific output of a country or a single researcher cannot rely on centralised data such as the patent data collected at the national or European patent offices. Instead, most analyses rely on data collected at the global scale by a private company, ISI Thompson Scientific, which produces databases such as the Science Citation Index® (SCI). The journals and scientific publications included in its databases follow some quality criteria (e.g. most journals covered are peer-reviewed), but the database comprises several biases, of which the English language bias and a bias towards the life sciences are worthy of note (cf. methodological annex to chapter 5). Despite the deficiencies of the SCI® database, it is currently the only source that allows for

[1] *Bovine Spongiform Encephalopathy (BSE): degenerative brain disorder of cattle, popularly known as mad cow disease.*

a complex analysis of publications by countries, institutions, single authors, and scientific disciplines.

The rest of this chapter analyses indicators of scientific performance resulting from different bibliometric indicators. The basic indicators of publications and citations are used as a foundation, and a number of more sophisticated indicators are built around these.

Section II Global scientific output compared: Europe resumes the lead

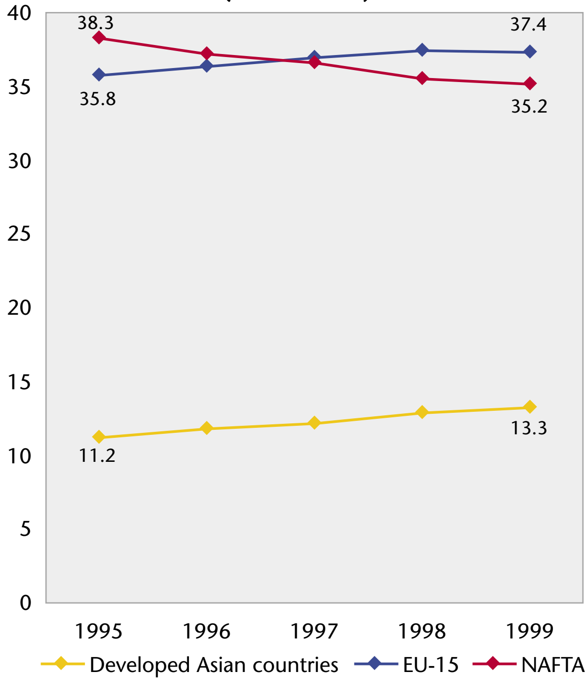
Starting the chapter off with a broad-brush overview, this section reviews global trends in scientific publishing. It compares the overall performance of the world regions, and then proceeds to review the performance of the main countries involved in scientific publishing. As an aside, it gives an analysis of the main factors involved in the growth of scientific publishing, including competition for funding and the rise in research evaluation. It ends by considering world trends in publishing in the main scientific fields, and regional strengths in the various fields. Having considered scientific *output* in this section, the next section considers scientific *impact*, as measured by publication citations.

1. Europe: Re-taking the lead

For decades, the North American Free Trade Agreement (NAFTA) consisting of the United States, Canada and Mexico, was the world's single largest producer of scientific knowledge[2]. The European Union used to be the second largest producer. However, the EU-15 overtook NAFTA in 1997, and the EU countries have been producing the largest shares of scientific papers ever since. While the share of EU-15 publications rose by 3.3% in the period 1995-1999, NAFTA had to contend with a zero per cent growth. The trends are continuing for the EU-15, the US and Japan – if one has a closer look at the three largest producers of these world regions in 2000 and 2001.

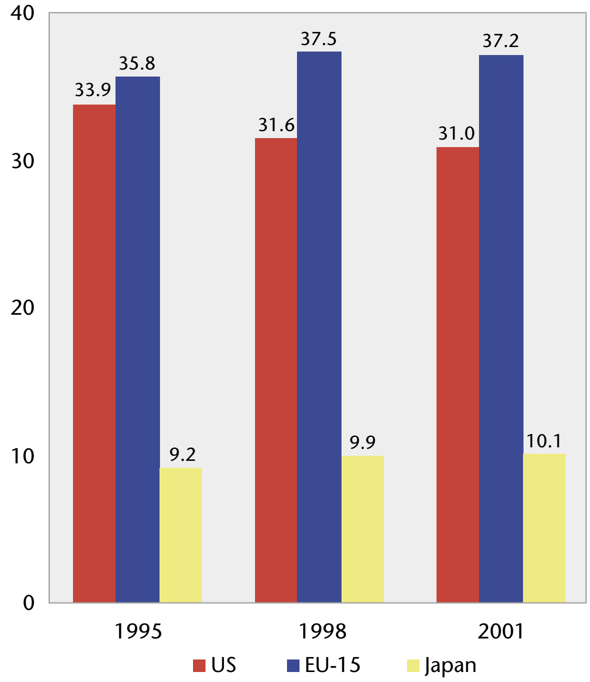
The Developed Asian countries, which include Japan, Korea, Singapore and Taiwan, achieved a growth rate of 6.5%. In terms of numbers of publications, it is the third largest regional bloc in the world. While in terms of growth, NAFTA finds itself at the negative extremity, mainland China and Hong Kong are at the other end with a growth rate of 16.3%. As shown in figure 5.2.2, in relative terms China and Hong Kong together became the sixth largest producer of scientific knowledge in 1999, surpassing Australia and New Zealand.

Figure 5.2.1.a Publication shares (%) by EU-15, NAFTA, and Developed Asian countries (1995-1999)



Source: DG Research
Data: ISI, CWTS (treatments)

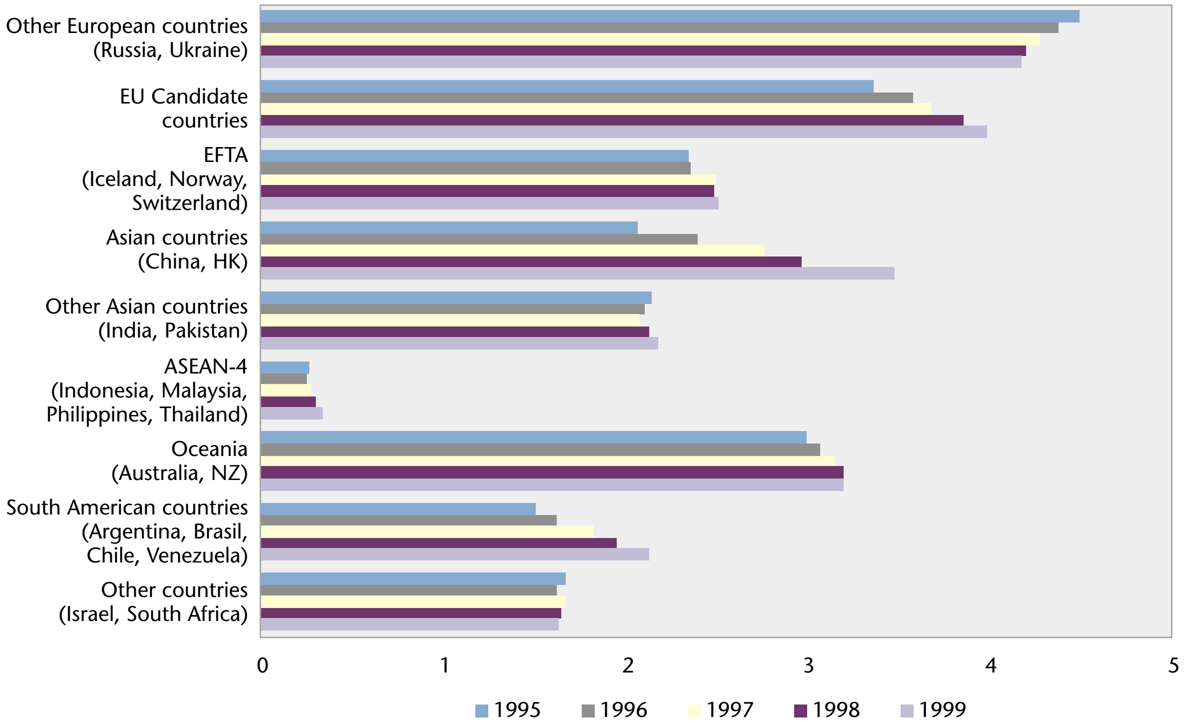
Figure 5.2.1.b Publication shares (%) by EU-15, US, Japan (1995, 1998, 2001)



Third European Report on S&T Indicators, 2003

[2] *The US produces almost 90% of the scientific publications within the NAFTA region.*

Figure 5.2.2 Publication shares (%) by other world regions (1995-1999)



Source: DG Research
Data: ISI, CWTS (treatments)

Third European Report on S&T Indicators, 2003

Publication growth rates within Europe vary considerably. The EU-15 average growth of 3.3% is slightly lower than EFTA's[3] rate of 3.9%. A very positive trend has emerged for the EU Candidate countries, with a growth rate of 6.5%. The latter development, in particular, signals the importance of the EU's policy. While the science base of the former eastern bloc countries contracted with the lifting of the iron curtain, the association of these countries with the EU, allowing them to participate in the community's Framework Programmes, seems to have had a positive impact on their knowledge base.

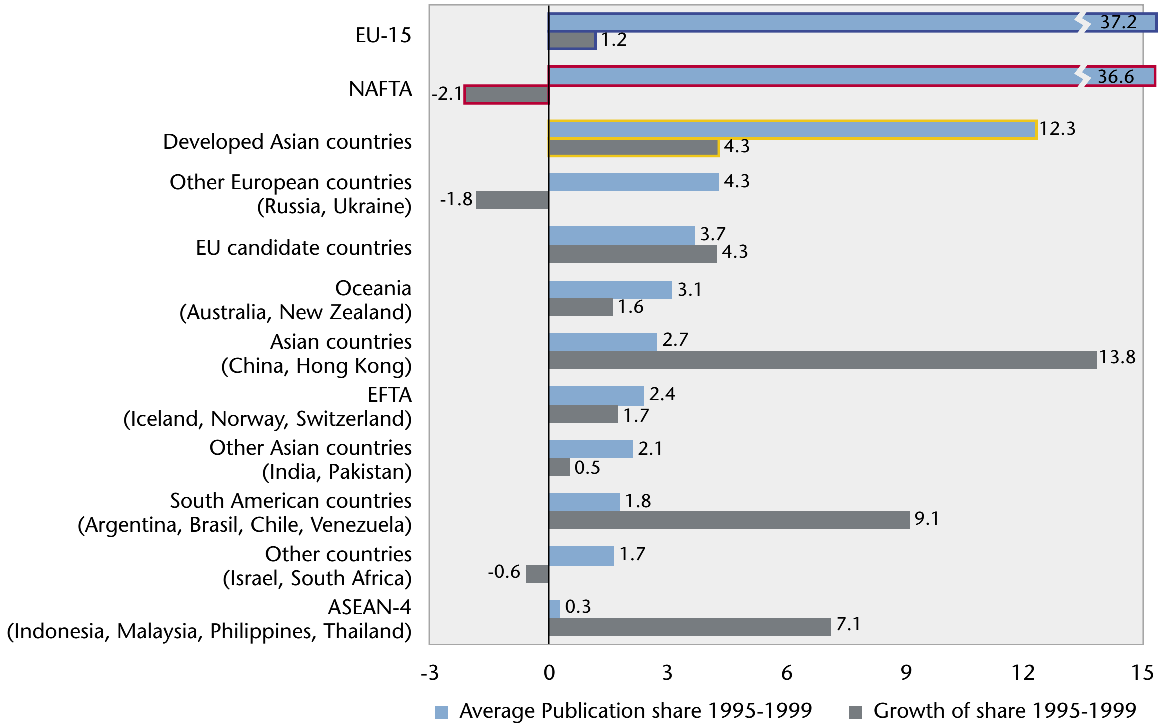
In terms of the world regions' shares of average annual global publication output, as shown in figure 5.2.3, the EU-15 raised its share of the world total by 1.2%, while NAFTA's share dropped significantly by 2.1%. The Developed Asian countries increased their share significantly by 3.4%. Between 1995 and 1999 the EU-15's average share amounted to 37.2% and NAFTA's to 36.6%. The third largest producing region is the Developed Asian countries with an average share of 12.3%. The other regions produce between 0.3% (ASEAN-4) and 4.3% (Russia and Ukraine) of total world scientific output.

It is noteworthy that the world regions are quite heterogeneous. Whereas NAFTA comprises the scientifically large US, the EU Candidate countries and South American group comprise numerous countries that have smaller scientific outputs. For a like-for-like comparison, it would be more indicative to consider the size of the scientific production of the countries that make up a world region. For this purpose, figure 5.2.4 reflects the annual publication output share of the 20 largest scientific producers.

The three dominating regions include some of the most prolific scientific publishing countries. In the case of NAFTA it is the US, in the Developed Asian countries it is Japan, and in the European Union the United Kingdom, Germany and France. In figure 5.2.4, the countries are ranked according to their share of the global total. Only five countries have a share of 5% or more. The dominating country is the US. Even though its share is declining, the US still produced a third of the world's output in 1999. The leading countries include Japan, which over the years has increased its share, as well as Germany. France has remained stable, while the UK has shown a marked decrease. The shares of Canada and Russia are also marked by significant decreases.[4]

[3] *European Free Trade Association (EFTA): trading bloc officially established in 1960 by Austria, Denmark, Great Britain, Norway, Portugal, Sweden, and Switzerland as a response to the creation of the European Economic Community (EEC). By 1994 many member nations had left EFTA to join the European Union (EU). The remaining members include Norway, Liechtenstein, Iceland, and Switzerland.*

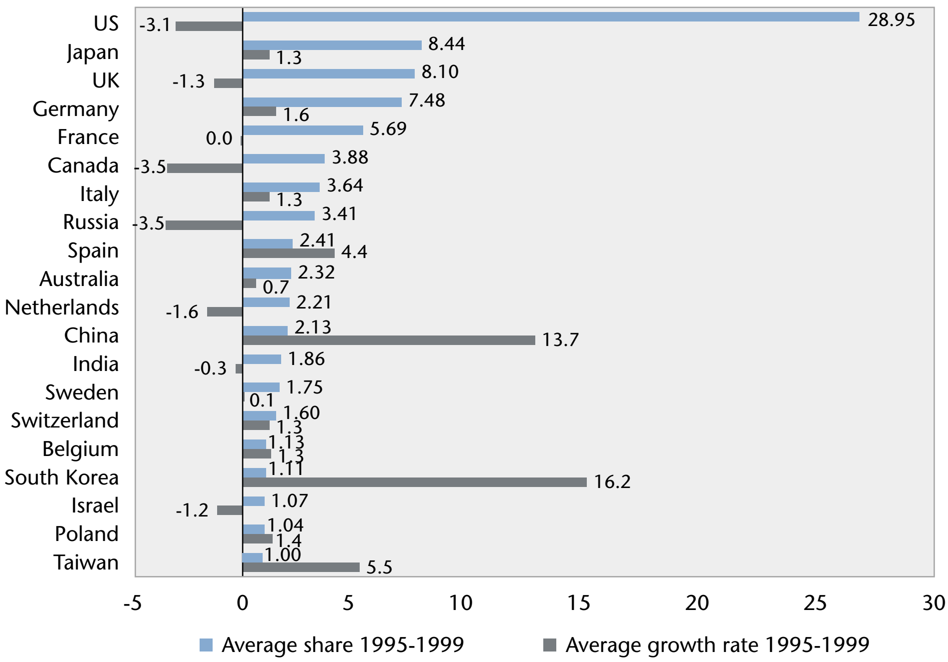
Figure 5.2.3 Average publication share and growth of share in % (1995-1999)



Source: DG Research
Data: ISI, CWTS (treatments)

Third European Report on S&T Indicators, 2003

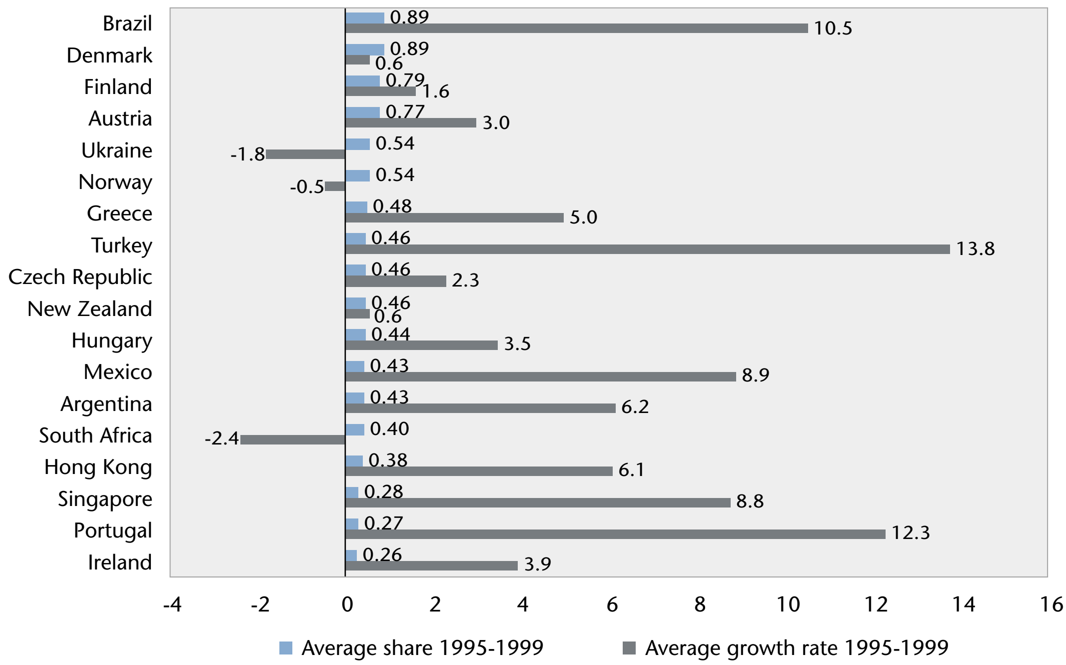
Figure 5.2.4 The 20 largest publishing countries (≥1% of world share)
Share and average growth rate (1995-1999)



Source: DG Research
Data: ISI, CWTS (treatments)
Note: Includes the five countries that have a world share of above 5%, and the 15 medium contributing countries that produce between 1% and 5%.

Third European Report on S&T Indicators, 2003

Figure 5.2.5 The 18 smaller-sized publishing countries (between 0.25% to 0.99% of world share). Share and average growth rate (1995-1999)



Source: DG Research
Data: ISI, CWTS (treatments)
Note: Smaller contributing countries have shares of between 0.25% and 1%. Several countries (Luxembourg, Malta etc.) have a share of below 0.25% and are not taken into account.

Third European Report on S&T Indicators, 2003

Below the five leading countries in figure 5.2.4, the second grouping within the 20 largest scientific producers might be termed medium contributing countries. They each produce between 1% and 5% of the world total. Of the 15 countries in this group, five are from the EU-15: Italy, Spain, the Netherlands, Sweden and Belgium. Of the European countries in the group, only the Netherlands shows a decline in its share of world publications. India and Israel also have declining shares. By comparison, large increases have been recorded by China and Korea.

Figure 5.2.5 shows 18 other countries – in terms of scientific production, smaller contributing countries – which each produced an average of between 0.25% and 1% of the world total during 1995-1999. Six other EU-15 countries belong to this group, but differences are evident. While Denmark is at the upper end, Portugal and Ireland are at the lower end.

In terms of growth rates, a distinction can be drawn between those countries making large and small contributions to the world total: the average growth rate of the 20 larger contributors is 3.1%, while that of the smaller contributors is 3.4%. The distinction between larger and smaller contributors is also useful for an analysis of world regions as well as individual countries: regions containing a number of small, evolving countries in terms of science production, will be more likely to score higher growth rates.

Comparing scientific productivity

It is useful to examine and compare countries' scientific productivity by normalising scientific output for the number of people involved in R&D. This can be measured in terms of numbers of researchers or, to include for example technicians, the total number of R&D personnel[5]. In figures 5.2.6 and 5.2.7 the total publication output for the period 1995-1999 and the total number of R&D personnel and researchers (full-time equivalent – FTE) in 1995 have been used for calculating per capita productivity ratios.

The first observation to make is that productivity levels can depend on a country's scientific specialisation. Those with a strong science base in the medical and life sciences tend to

[4] *In fairness, these changes may only partly reflect the reality of research performance. One of the explanatory factors for the changes is modifications to the ISI database. This includes the addition of various non-English language journals and journals in which the US and UK researchers do not publish much, or journals that do not complement the scientific profile of the US and, to a certain extent, the UK. These amendments help the other previously misrepresented language groups and fields (cf. also methodological annex to chapter 5).*

[5] *Data on R&D personnel or total researchers is not collected by every country and furthermore not harmonised on a world-wide level. The US for example, does not publish data on total R&D personnel; therefore, the US cannot be used for comparison in this category. The broadest coverage and a reasonable harmonisation level has been so far achieved for OECD countries and those countries which submit data to the OECD.*

Figure 5.2.6 Publications (1996-1999) per total R&D personnel

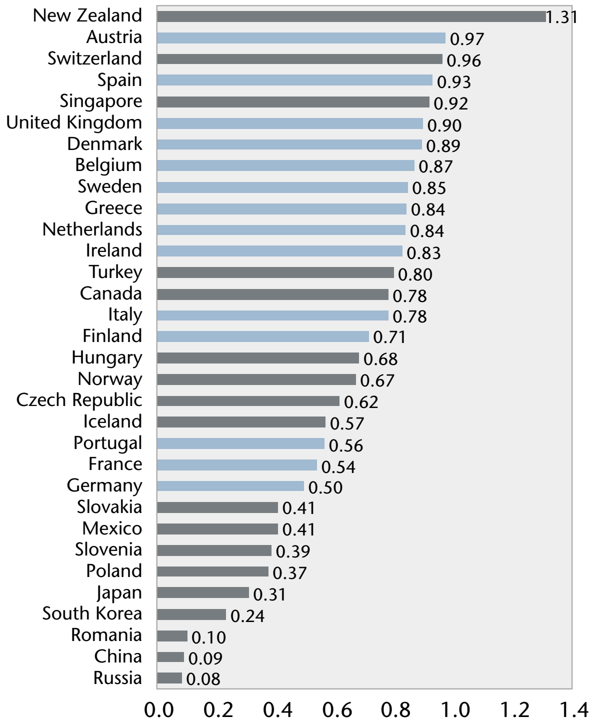
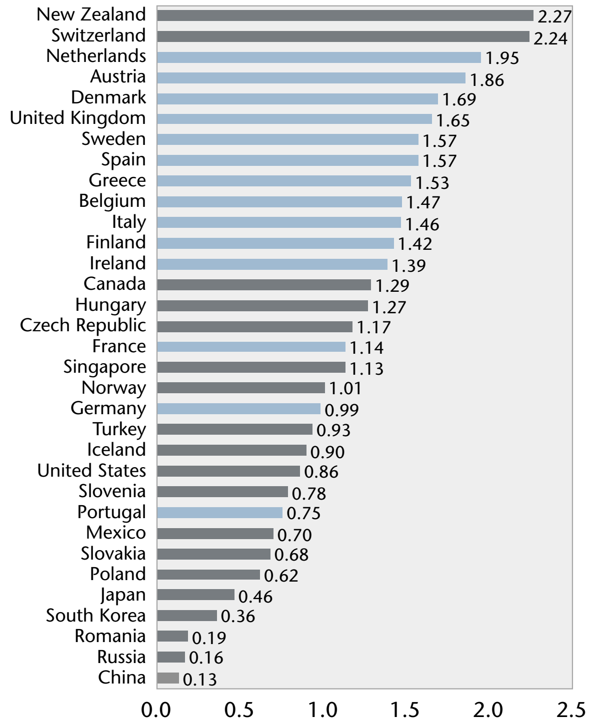


Figure 5.2.7 Publications (1996-1999) per total researchers (FTE)



Source: DG Research
Data: ISI, CWTS (treatments), OECD
Note: All R&D personnel and researchers data: 1995; except A: 1993; CH: 1996. Publications 1996-1999 totals.

Third European Report on S&T Indicators, 2003

produce more papers on average, because (academic) researchers in these fields are more productive in writing English-language research articles, and because these fields are better covered in the SCI database. Among the OECD countries and a small number of non-OECD countries, the most productive country in terms of publications per total R&D personnel is New Zealand, with a ratio of more than one publication per person.

The EU countries have ratios of between 0.97 in Austria and 0.50 in Germany. It is interesting that two scientifically productive countries, Germany and France, as well as the small producer Portugal, show the lowest ratios of the EU Member States. This is partially due to their propensity for publishing research findings in non-English outlets that are not covered in the database (Van Leeuwen et al., 2001).

In figure 5.2.7, only the total number of researchers is included. Here too New Zealand leads, followed closely by Switzerland, each with ratios of above 2. All EU countries, except Germany and Portugal, have ratios between 1 and 2.

While most countries remain in similar positions in a ranking within both calculations, or show higher ratios when – as here – only the total number of researchers is taken into account, the productivity gains are more remarkable for some and less so for other countries. The most significant gain can be found in Switzerland, which more than doubles its performance when only researchers are taken into account (from 0.96 publications per R&D personnel to 2.24 publications per researcher).[6] Second comes the Netherlands with an almost equally impressive productivity gain. While Switzerland, New Zealand and Austria have already comparably high publication ratios per total R&D personnel, the Netherlands comes from a medium position in the first category to be near the top in the second category.

When calculating the proportion of researchers to all R&D personnel, Switzerland and the Netherlands have the lowest shares. This might be due to the large R&D-based multinational enterprises such as Philips in the Netherlands and the various pharmaceutical companies in Switzerland. One can speculate why both countries achieve these ratios but others

[6] *It should be noted that the impressive numbers for Switzerland can be ascribed partly to a measurement artefact: in such a small country the presence of an international institution such as the Conseil Européen pour la Recherche Nucléaire (CERN – the European Council for Nuclear Research) with a high number of researchers and publication output, can influence the publication/researcher ratio significantly. If one examines the overall publication profile for Switzerland, one notes large numbers in clinical medicine, followed by physics, chemistry, and biomedical sciences. While all the other very active fields can be associated with industry structure, physics can clearly be attributed to CERN. However, even without CERN publications and researchers, the Swiss numbers can be expected to be rather high.*

not. For example, France or Singapore also have shares of researchers in total R&D personnel of below 50% but do not achieve high ratios. One explanation could be linked to the research performed in these countries. Some science fields such as physics require large numbers of technical support personnel, while for others, for example material sciences and engineering, engineers and less so large-scale technical support is needed.

What lies behind the growth of scientific publications?

The ever-growing numbers of scientific publications in most world regions seem to have two major determinants: firstly, advances in research infrastructures and more coherent science policies, and secondly, advances in science. For the latter, the life sciences are probably the most pervasive example: revolutionary findings in molecular biology open up enormous research opportunities. In order to disentangle the complexity of molecular biology and to produce research findings, a large scientific community is needed to tackle the various research questions. It becomes even more complex with growing interdisciplinarity. Advances in information technology, biotechnology, and material sciences bring key technologies that are driving new scientific methods and approaches. They open up even more research opportunities which are equally complex, e.g. the sphere of nanotechnology. The tendency for the boundaries of disciplines to become blurred, and the necessity of interdisciplinarity – and important findings thereof – might be the main reason for the surge of scientific publications.

The rest of this review examines various other factors that may be influencing the growth in the number of scientific publications, including co-publication counting methods, competition for scientific funding, the use of research evaluation, and the basis for bibliometric analysis, its databases.

Counting co-publications

The growing number of publications at a country level can also be explained by counting methods. It is standard practice to account an internationally co-published paper to all of the countries involved. For example, if a publication is co-authored by a researcher from India and one from Australia, both countries would be credited with one publication each. This leads to a 'virtual inflation' of the numbers of publications counted at the country level. This full-counting method has some advantages compared to the fractionalised counting scheme (cf. methodological annex to chapter 5 for a full discussion), which in the above example would give Australia and India each only 0.5 publication.

This method tends to raise the apparent scientific output of smaller countries. How does this work? Smaller countries in general have smaller research communities that in turn have a higher propensity for international co-publications. Publishing in this way not only raises the researcher's chances of being internationally recognised, but also offer a means of tapping international knowledge that might not be available domestically. Such features of any international co-publishing behaviour can only be estimated when the total figures are taken into account, and when the number or percentage of single-authored, domestically co-authored and internationally co-authored publications have been separated.

Restricted finance for public R&D

Advances in research infrastructures and changes to national science policies also help explain part of the rise in the number of publications. During the 1990s, the financing of the science system has been a major issue for policy debate and policy changes in most countries. To put it bluntly, because of financial restrictions, public opinion and policy thinking about the role of publicly funded research, and expectations of it, have changed. In most Western countries, a reduction in public funding for science has been accompanied by expectations that research communities will be more active in commercialising research outcomes. The hope is that this would not only lead to opening up private sources of research funding, but that it also might result in the more effective transfer of information and skills. Nonetheless, commercialisation is not viable in all disciplines, at least not that easily and immediately. Even where public funding has been stable or increased, such as in Japan and Finland, the competitive funding mechanism is becoming the dominant means for the allocation of monies.

Evaluation of research

Almost complementary to the changes in science funding, a second policy instrument is of growing importance, especially for funding decisions: the evaluation of research performance. Several research evaluation methods have been built and tried, with differing results, leading to a debate about their usefulness and their effects. Evaluation of research systems is undisputedly a complex issue, and different countries have chosen different paths.

For example, the UK's Higher Education Funding Council (HEFCE) undertakes a *Research Assessment Exercise* every four years, using inputs (research personnel), throughputs (e.g. research students, studentships, external funding) and research outputs (e.g. patents, publications, exhibits) to gain insights into the research strategies, collaborative behaviour, and interdisciplinarity, but above all the productivity of research departments. The impact of the assessment is felt directly by universities and colleges. Not only are HEFCE funds allocated according to research outcomes and achievements, but the research assessment also helps to guide the funding decisions made by industry, commerce, charities and other sponsors. The assessment seems to have had a considerable effect on the number of papers published by UK university departments.

Databases

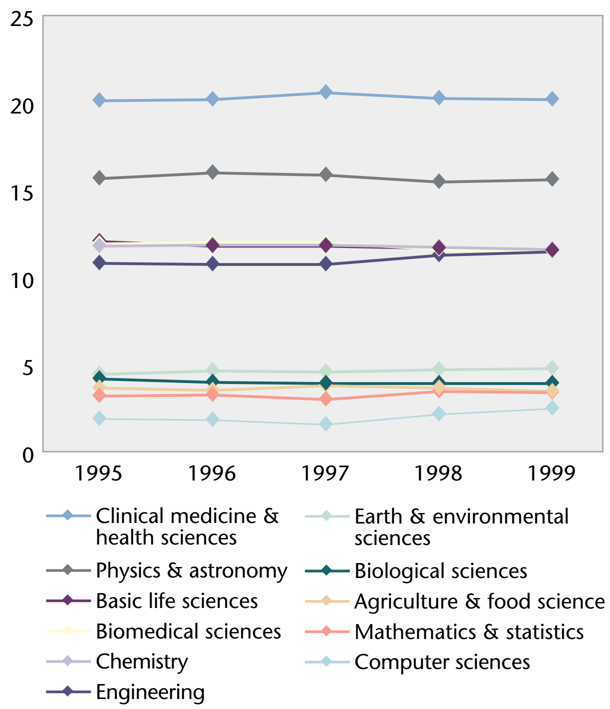
Most bibliometric analyses rely on a limited set of databases. These databases are limited in various dimensions: they can cover different types of publications (e.g., journal articles, working papers), publications by disciplines (e.g., EconLit covering all sorts of economics publications, or Chemical Abstracts covering publications out of chemistry). Some are limited by country or language, but there is no single database covering all publications. Books, 'grey literature', research reports etc. are very often not covered in any database. The most comprehensive database up to now is the 'Science Citation Index®' (SCI) of the Institute for Scientific Information (ISI) which is most often used as the reference database. Now, every year a number of new journals is included and therefore an indigenous growth of the database which does not necessarily reflect the real publication growth rates of countries can be calculated. For example, between 1995-1999, the number of publications indexed in the CD-ROM edition of the SCI has increased by 6.8%. However, this growth rate is certainly not evenly distributed and shared by all countries covered. If for example new journals in the field of immunology are included, countries which have this kind of research and publish in these journals receive a higher coverage of their scientific publications. If is difficult but not impossible to calculate this database effect which might show over longer periods.

2. Scientific publishing by field: world trends

By looking at the production of scientific publications by each of the main scientific fields since 1995, one can detect differences between the fields according to their size and growth rates. It starts with an analysis of overall trends in the main fields, which then allows for an analysis of the strengths and weaknesses of the world's main science producing countries, by scientific field.

Figure 5.2.8 shows that in terms of shares, the largest scientific fields are clinical medicine and health science with an average of 20%, or, a total of more than 700 000 publications, and physics, on average 15.7% or a total of almost 550 000. In a medium range one finds the basic life sciences, biomedical research as well as chemistry and engineering. The smaller fields are earth and environmental sciences, biology, agriculture, mathematics and computer sciences. The smallest field, computer sciences, is also the fastest growing: almost 70 000 papers were produced in the period 1995-1999, which represents a growth rate of almost 10%. Earth sciences, engineering and mathematics also show high growth rates, varying between 4.2 and 4.6%. Biology and agriculture have the lowest growth rates with 1.4% and 1.6% respectively.

Figure 5.2.8 Evolution of scientific publications (%) by main field (1995-1999)



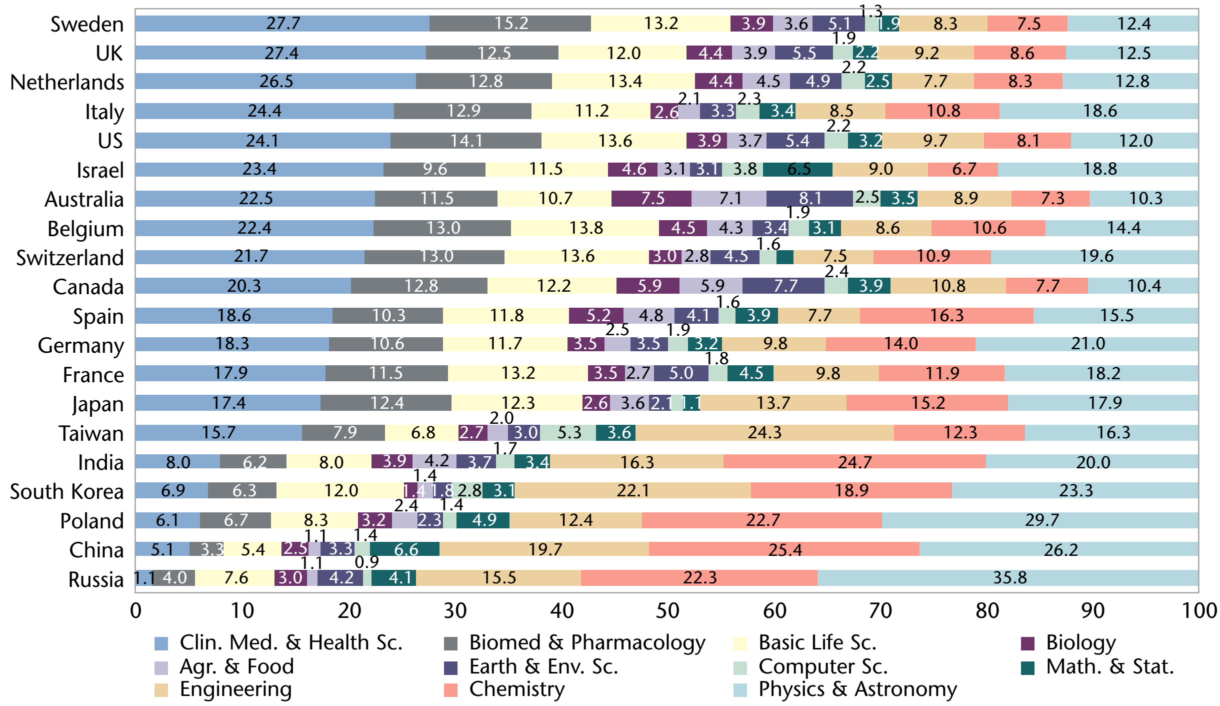
Source: DG Research
Data: ISI, CWTS (treatments)
Third European Report on S&T Indicators, 2003

Country strengths and weaknesses

To assess the scientific strengths and weaknesses of each country, it is useful to analyse the proportion of each country's scientific output produced by researchers in each scientific field. Figure 5.2.9 shows such a breakdown for the 20 most productive countries, as measured by scientific output. Note that for most, a significant share of a country's total publications is produced either in clinical medicine and pharmacology or in chemistry and physics.

Despite these very obvious foci, specialisation in other broad fields is less often seen. For example, in the agriculture and food domain, one will find only Australia having a higher

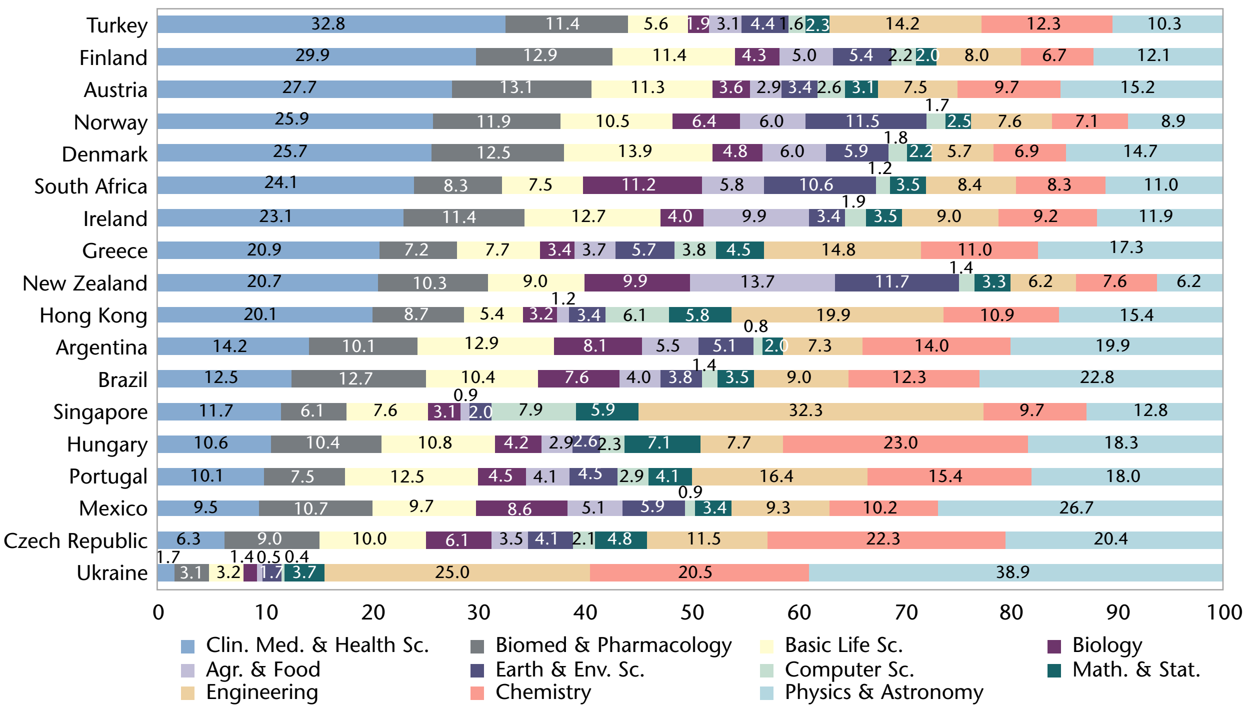
Figure 5.2.9 The 20 largest scientific producers: publications (%) by main fields (1995-1999)



Source: DG Research
Data: ISI, CWTS (treatments)
Note: Countries are listed according to decreasing share in the life sciences, especially clinical medicine and health sciences. The field "Multidisciplinary" has been omitted.

Third European Report on S&T Indicators, 2003

Figure 5.2.10 The 18 medium-sized scientific producers: publications (%) by main fields (1995-1999)



Source: DG Research
Data: ISI, CWTS (treatments)
Note: Countries are listed according to decreasing share in the life sciences, especially clinical medicine and health sciences.The field "Multidisciplinary" has been omitted.

Third European Report on S&T Indicators, 2003

share. Compared to the other countries it holds the highest share in this field, compared to its own distribution of fields, agriculture is almost as strong as chemistry. The agriculture and food domain is more often found to be of significant size in the medium sized group of 18 countries, the results for which are presented in figure 5.2.10. Only New Zealand and Ireland show significant shares in the agriculture and food domain too. Another focus is engineering were Asian countries are relatively strong. Japan, Hong Kong, Singapore, China, Korea, and Taiwan all have large publication shares, but also the Ukraine has a high share.

Within the group of the five most productive countries (the US, Japan, the UK, Germany and France), certain degrees of specialisation do appear. For example, Japan publishes strongly in engineering and very little in earth sciences, while the UK publishes strongly in clinical medicine and pharmacology. In the group of medium scale contributing countries, Russia and China show a very similar profile with a strong focus on physics and chemistry. Several other former eastern bloc countries in the group of smaller contributors are also relatively strong in chemistry and physics, whereas the European medium and smaller contributors demonstrate a preference for the life sciences.

3. Active vs. influential – profiles of world regions

As seen previously, the number of research publications in international journals reflects not only a country's scientific activity and research capabilities at an international level, but also its scientific specialisation and the relative size of its scientific fields. However, it does not reveal much about the importance and external utility of the research outcomes. This section examines the evidence about the impact of scientific publications in the various world regions by looking at publications and citations.

The number of citations received from other research papers can be used as a proxy of the scientific visibility and influence of a research publication in the scientific world, which in turn partially reflects the scientific utility of that paper. This is commonly referred to as the 'citation rate'. Citations cannot, however, be used directly as an estimate of research quality of individual papers – even in the case of papers with high numbers of citations[7]. At higher aggregate levels, for example on the institutional level, a positive correlation can exist between citation frequency and scientific quality, but citation frequency can also depend on the reputation of an institution.

In figure 5.2.11, the eleven broad fields per region have been compiled in activity/impact graphs, showing scientific activity by the number of research publications, and scientific influence by the number of citations (excluding self-citations). The field-normalised relative citation impact score is indicated by the size of the bubbles.[8]

Most regions show lower numbers of publications and citations in computer sciences, mathematics, engineering, and earth and environmental studies. This is also due to the fact that these fields are relatively underrepresented within the database. It is however most interesting to compare the position of the different fields. Beside the size of the bubbles which represent the impact of the region for a given field, the overall layout of the positions can reveal some interesting insights.

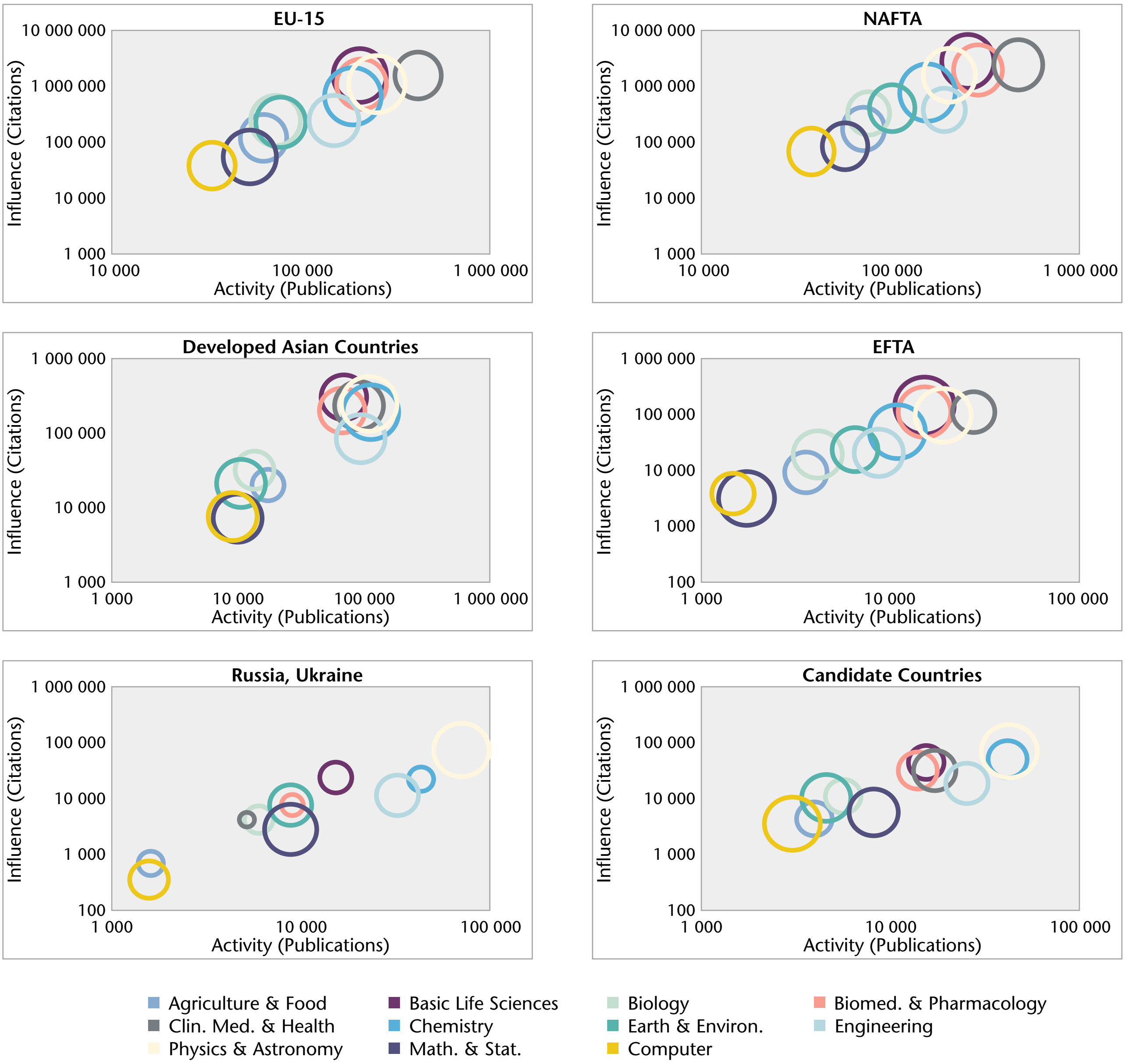
The two largest producers of scientific output, NAFTA and EU-15 display a very similar publication pattern, if one compares the positions of the coloured bubbles. Despite decreasing publication shares, NAFTA publications tend to have high citation rates, and high relative citation impact records. While the EU-15 performs around world average in all 11 broad fields of science, NAFTA performs above world average in five of those broad fields: physics, clinical medicine, biomedicine, and does especially well in chemistry and the basic life sciences. The Developed Asian countries, being the third largest producer, show an interesting pattern: there are two clusters in terms of publication size as well as number of citations. This region has world average impact scores in most of the broad fields. Only in agriculture, the basic life sciences and biology, its impact is less than world average.

All other regions are smaller in terms of publication size, which has been taken account of in the graph with changes on the publication axis. The EFTA region shows above world average performance in the basic life sciences and displays a positioning of the fields similar to NAFTA and EU-15, however, on a smaller publication scale. Comparing Russia and Ukraine to the Candidate countries, one finds for the former a more heterogeneous layout in terms of number of publications and especially in the size of the bubbles. The bloc of Israel and South Africa scores above average in computer sciences and in physics and astronomy. Looking at the position

[7] *Not only groundbreaking publications receive large numbers of citations, but also review articles with no original research and publications which state an opposite scientific view to the common understanding, can receive high numbers. For the analysis of single authors or institutions, based on a small number of publications, these kind of outliers can influence the citation rate for an author or institution significantly. In order to attain statistically significant results at the level of an institution, a certain number of publications is necessary (cf. also Section 5 and the methodological annex to chapter 5).*

[8] *A field normalisation of citation frequency data enables comparisons of scientific specialisation patterns and disciplines in the broad fields. For example, in the field of physics, there might be 1 000 publications and each publication is cited on average five times within a pre-specified time-interval after publication. In the field of computer sciences, on the other hand, the number of publications might be 100, and each publication is cited 12 times, on average. To level out the different citation habits within fields, as well as the size of fields, they are normalised, both at the level of (broad) fields, by computing the ratio of the actual number of citations received by a paper and its 'expected' number of citations. The latter is calculated as the average number of citations received by all papers in the (broad) field.*

Figure 5.2.11 Number of publications, number of citations and relative citation impact score for world regions in broad fields (1993-1999)

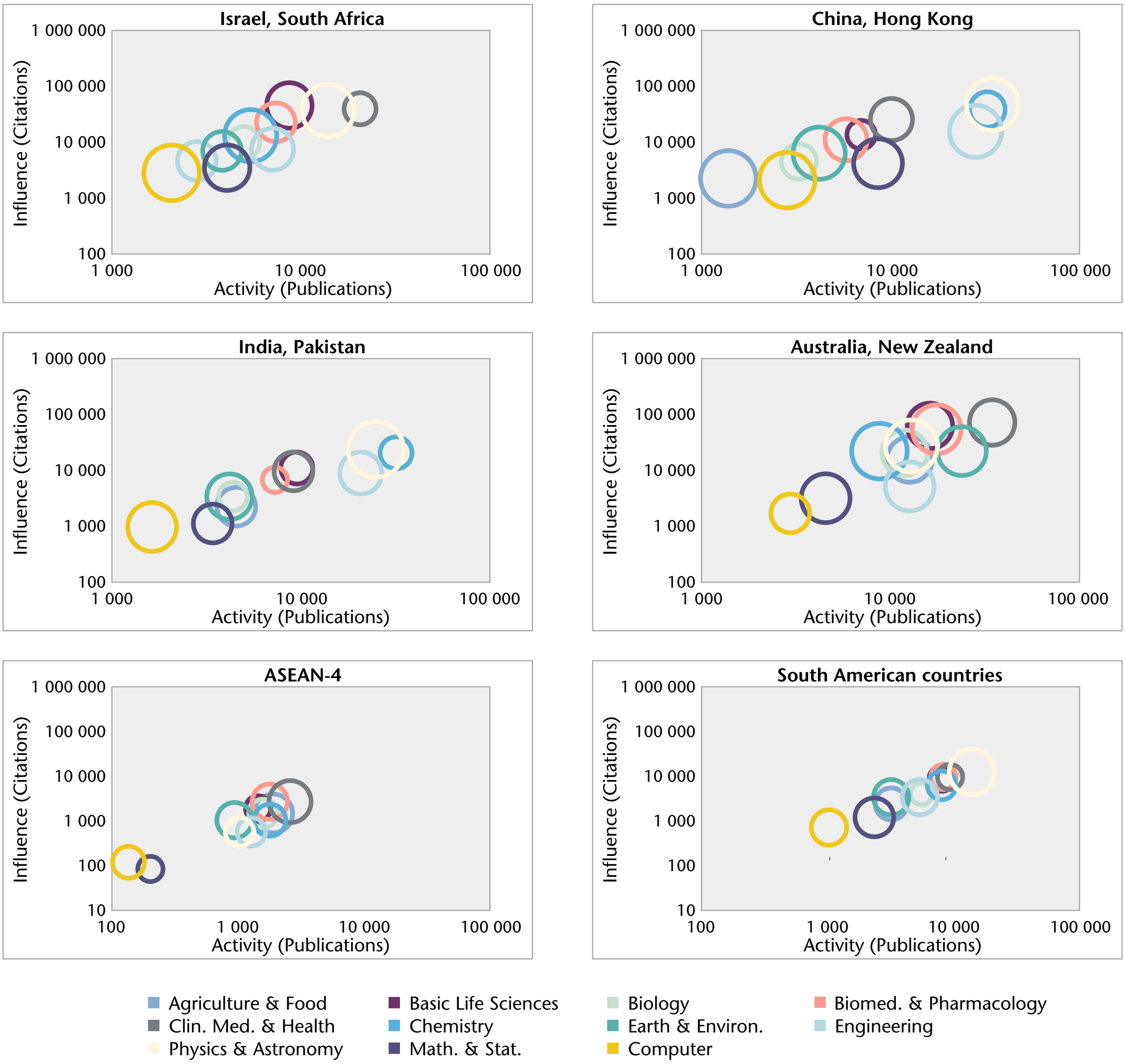


Source: DG Research
Data: ISI, CWTS (treatments)
Note: The size of the bubbles represents the field citation impact, normalised by field. The centre ot the bubble gives the information on activity (horizontal axis) and influence (vertical axis). Publication numbers are cumulated 1995-1999.

Third European Report on S&T Indicators, 2003

of the scientifically emerging bloc China and Hong Kong, one can note the remarkable production size. Already in five broad fields, China and Hong Kong produce publications achieving at least world average impact scores. The following blocs of India and Pakistan and Australia and New Zealand display a wide difference in terms of impact. While the latter achieve impact scores around world average in all eleven broad fields, India and Pakistan score on average only in the field of physics and astronomy, all other fields are below world average. The smallest producers are the ASEAN bloc of countries and the South American countries. While the latter still produce a larger number of publications in some fields, the number of publications from the ASEAN countries remains very small in all fields. However, both world regions display impact scores around world average in five fields each, ASEAN countries score very well for example in the field of clinical medicine while the South American countries score high in physics and astronomy.

Figure 5.2.11 Number of publications, number of citations and relative citation impact score for world regions in broad fields (1993-1999)



Source: DG Research
Data: ISI, CWTS (treatments)
Note: The size of the bubbles represents the field citation impact, normalised by field. The centre ot the bubble gives the information on activity (horizontal axis) and influence (vertical axis). Publication numbers are cumulated 1995-1999.

Third European Report on S&T Indicators, 2003

4. Case studies: world developments in scientific disciplines

This part outlines several case studies of highly significant disciplines, or those whose recent development is notable. These case studies help to illustrate some of the general trends in science around the world.

Physics and life sciences – two important scientific paradigms

Recent trends in scientific publishing may be indicative of where science is heading and also of where politically driven choices have been made. What is possibly the most important divide can be seen by comparing physics and the life sciences.

Military and defence-related research – and therefore physics – played a crucial role in various influential countries from the early 1900s until at least the late 1980s; the number of physical scientists has been comparably high in such countries and physics was the most prolific scientific paradigm.

Large amounts of physics research require huge investments in technical and organisational infrastructure. For smaller European countries, this has not been a feasible option. Due to the European and Transatlantic military alliances, however, the necessity for indigenous investments in infrastructure has been limited, and with the establishment of CERN, for example, some particle physics research has been centralised. The large physics community is very well connected and tends to convince policy makers to finance large public investments – a new detector for CERN is one example of such influence.

Physics as a scientific specialisation pattern has been evident in several countries. While such large-scale specialisation is unlikely to change rapidly, the scientific discoveries of deoxyribonucleic acid (DNA) in the early 1950s and recombinant DNA (rDNA) and antibodies in the 1970s have been milestones for the rapid growth of the biomolecular research paradigm (cf. chapter 6 section 3 point B). One could say that the 'age of the atom' is being overtaken by the 'age of the molecule' and more recently, the gene.

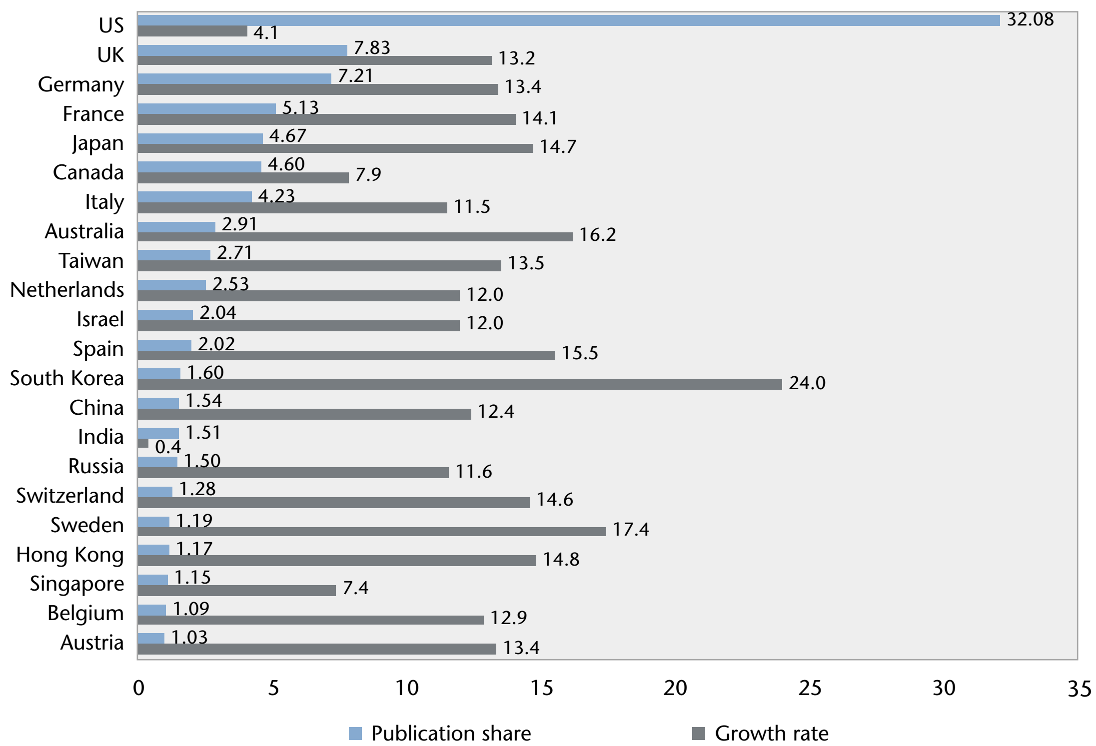
Considering the evolution of the science, the biomolecular paradigm is at an early stage of development. Even so, revolutionary findings are underway, and the prospects encourage both policy makers and the business sector (especially the pharmaceutical firms) to invest into and perform research in this domain. In turn, this would result in larger numbers of scientists and more publications. Statistics show that the share of physics in total scientific publications declined by 0.15% from 1995 to 1999, while the broad field of life sciences as a whole experienced a growth rate of 2.33%. Differences can be found within this broad field as well. The shares of basic life sciences and biology were 1.76% and 1.36% respectively, while the biomedical share reached a growth rate of 2.06% and clinical research 3.03%.

Life sciences seem to be the field of much important future research, and a safe haven for public investment. However, a too narrow policy, such as focusing only on these fields, runs the risk of passing over other equally important fields for human well-being and economic prosperity, such as earth and environmental sciences.

Computer sciences: US the largest but Israel the best?

Analysing the rapidly growing field of computer science – undoubtedly an important field for the knowledge-based society – shows that some producers of scientific publications are becoming relatively specialised in this field. In computer sci-

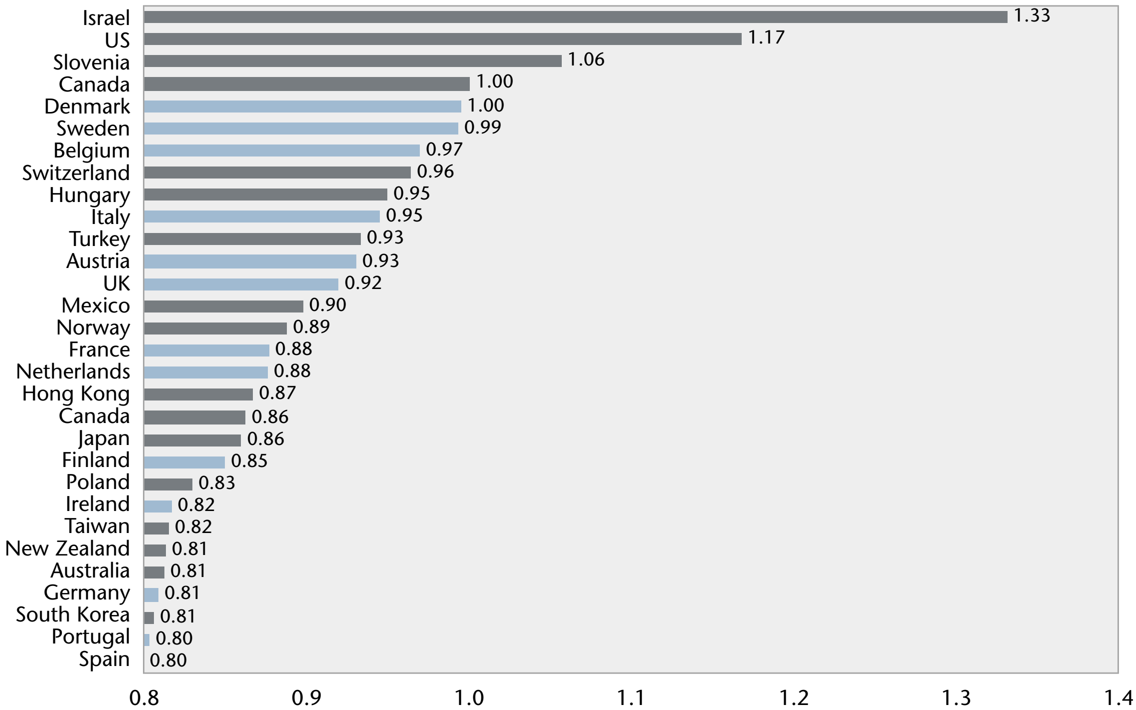
Figure 5.2.12 World share and growth rates in computer sciences (publications, 1995-1999) (%)



Source: DG Research
Data: ISI, CWTS (treatments)

Third European Report on S&T Indicators, 2003

Figure 5.2.13 Citation impact by country in computer sciences (1993-1999)



Source: DG Research
Data: ISI, CWTS (treatments)

Third European Report on S&T Indicators, 2003

ence, only four countries produce more than 5% of total world output each. Another 18 countries manage a share of more than 1% (figure 5.2.12). In terms of dominance, the US is clearly the leading nation. The largest number of publications and citations, as well as a very good citation impact score, prove its dominance. In general, computer science is a fast growing field with an average growth rate of 12.6% in the top 22 countries. Within the whole group of 56 analysed countries, the growth rate is slightly lower at 11.9%.

In terms of citation impact, Israel is the only country performing significantly better than the world average, with a score of 1.33. Figure 5.2.13 lists all 30 countries that score at least a world average citation impact of 0.80. A comparison to the average world share reveals some differences in the rankings. Israel's output share is in the medium range, while impact-wise, it is leading. Germany, by comparison, produces a high share of publications, but impact-wise it has a relatively low score.

The reason for these performances may be that the field of computer science comprises diverse sub-fields such as computer applications, artificial intelligence, software, graphics, programming, theory and methods, hardware and architecture (for a full list see table A.4 in methodological annex at the end of this report), and it is difficult to trace changes in publication habits to specific national science and technology programmes. Nonetheless, there are policy related national features that explain part of the picture.

The US dominance in this field can be explained by its pioneering work on computers, its extensive information technology (IT) industry, and especially its long tradition of defence related research in IT related fields of science. The latter may also be an explanation for Israel's research performance in the field of computers. Israel has apparent strengths in this field especially in encryption techniques, which are closely linked to defence related research. Furthermore, the military training most businessleaders have received, includes highly advanced technical expertise in computers and electronics and provides for managerial qualities important for innovations and competition. Now, from a policy perspective, computer sciences is a hot issue and often linked to regional competitiveness and growth (with frequent references to Silicon Valley and Bangalore). In general, technological strength would be measured by high-tech trade data and a strong trade position would then be linked to a strong knowledge base. However, can the research performance be used as an indicator for technological strength?

Looking for example at Israel, India, and Ireland – all strong export countries in high-technology trade – and supposedly very strong in computer related technologies - one finds that the knowledge base in India and Ireland tends to be rather limited in this particular field. Despite having in common some structural features of their respective software industries (e.g. large numbers of qualified personnel) (Arora et al., 1999), Irish high-tech exports depend on multinational companies, while in India, exports strongly follow US demand (D'Costa, 2001). There is a risk that such growth may be rather short-term, being dependent on US demand, and that it may not strengthen the local knowledge base or R&D infrastructure in the long run.

The pattern is indeed different in Israel, as basic research in computer science is backed primarily by national defence research. The Indian success in computer science and programming is mostly due to the US science base where a large number of Indians receive secondary and post secondary education (NSF, 2001). Upon returning to India, these people do not necessarily join the academic sector, but tend to be involved in entrepreneurial businesses that form partnerships with US firms. The relatively weak Indian R&D infrastructure is also a hampering factor. However, as Indian entrepreneurs start moving up the value chain, they will need to establish partnerships with local universities to tap the academic knowledge base (D'Costa, 2001). Learning is already taking place due to international exports links – a pattern that holds true in Ireland as well.

US and Israeli models suggest that strong links to defence, space and security related institutions seem to be crucial for success. The European situation produces some questions. Does the fact that the research base in Europe is less defence-oriented, hamper basic research in computer science? Does Europe lack critical mass' and a focus on application in its computer science research? It seems reasonable to point out that the strong European infrastructure, varied R&D landscape, and complementary industrial structure, should at least partially compensate for the large US defence R&D system. European specialisation patterns differ from US and Israeli ones, and computer science research in Europe may be more focused on 'academic' fields where defence and security play less important roles. In order to prove or reject this hypothesis, further detailed analyses examining IT-related R&D outputs, specialisation patterns, the economic value of Europe's IT innovations and, if possible, related intellectual property rights (copyright, patents, trademarks, designs) would be required. Research activity and resulting output refer mainly to academic science, which is not directly linked to current economic performance. It may, of course have a significant impact on innovations and economic competitiveness in the near future.

Engineering sciences: a European strength

Engineering sciences is another interesting and important field and a puzzling one as far as publication analysis is concerned.[9] It covers a wide range of sub-fields (figure 5.2.14) and deserves a closer look.

Between 1995 and 1999 there were more than 385 000 publications in the field of engineering. The growth rate in the same period was 4.5%. Material sciences comprise the largest part of this figure, with some 136 000 publications, or 35%. The size of this figure may be explained by the importance and widespread usage of material sciences, and also by the overlap that exists between the material sciences and physics and chemistry. The second largest component, namely electrical engineering with almost 68 000 publications, is only half the size of material sciences.

At the opposite end of the scale are the smallest sub-fields of aerospace engineering and geological engineering, with only 6 000 and 1 500 publications respectively. A negative growth rate of 12% can be seen in the sub-field of instruments and instrumentation. Very positive growth rates are shown by aerospace engineering, with 13.1%, and electrical engineering, with 5.9%.

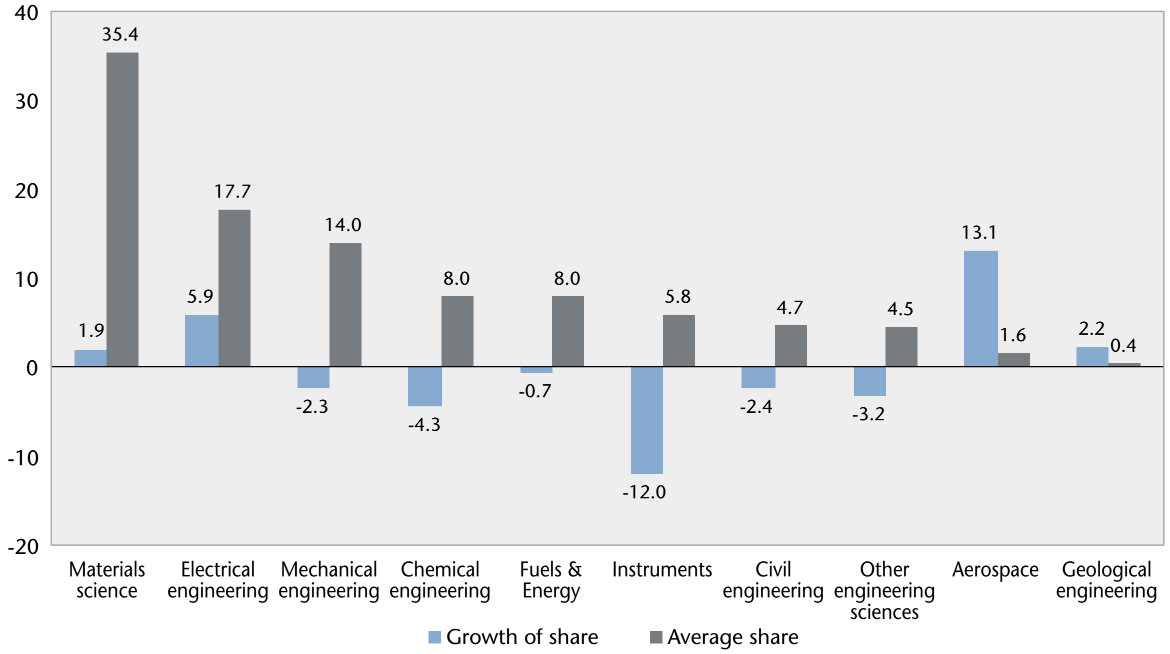
The largest engineering sub-field of material sciences would be worth having a closer look at as one can suppose that all regions are active in this very general and broad sub-field. The geographical distribution of publications, citations and publication growth rates by world regions is given in figure 5.2.15.

While the EU-15 had the largest number of publications between 1995 and 1999, with more than 40 000, its citation rate is 2.09 per publication. NAFTA, on the other hand, publishes one third less, with 31 000, but receives 3.38 citations per publication. NAFTA shows a slightly negative publication growth rate, however, compared to the growth rates in other regions, this confirms the overall negative trend in the production of scientific output. An interesting development is the growth of publications from China and Hong Kong. It is a similar development, for example, to biotechnology publications (cf. chapter 6, section 2). It seems that China and Hong Kong are focusing on and strengthening their knowledge bases, especially in key technologies – technologies that open up further technological opportunities (cf. chapter 6, section 3).

The trends seen in material sciences are similar to those seen in other scientific disciplines: NAFTA, or more specific the US, displays relatively low output levels and a negative growth rate, while the developed Asian countries, notably Japan, show increases in the range of 10%. The performance of the EU-15 is positive while the growth rates for China are outstanding.

[9] *Engineering as a field is difficult to evaluate by means of publications and citations. The reasons for this difficulty are manifold. First, in engineering sciences, research publications are often not considered of prime importance because of the focus on the technological aspects, in which engineers tend to produce designs and patents. Second, significant fractions of research in several engineering science fields are largely geographically bound. Researchers and engineers in this field are often more inclined to publish in their respective national languages, and are less inclined toward cross-border scientific collaboration and producing international co-publications. For the same reasons, citations of such research publications found in international literature are often relatively low, and restricted to a small community.*

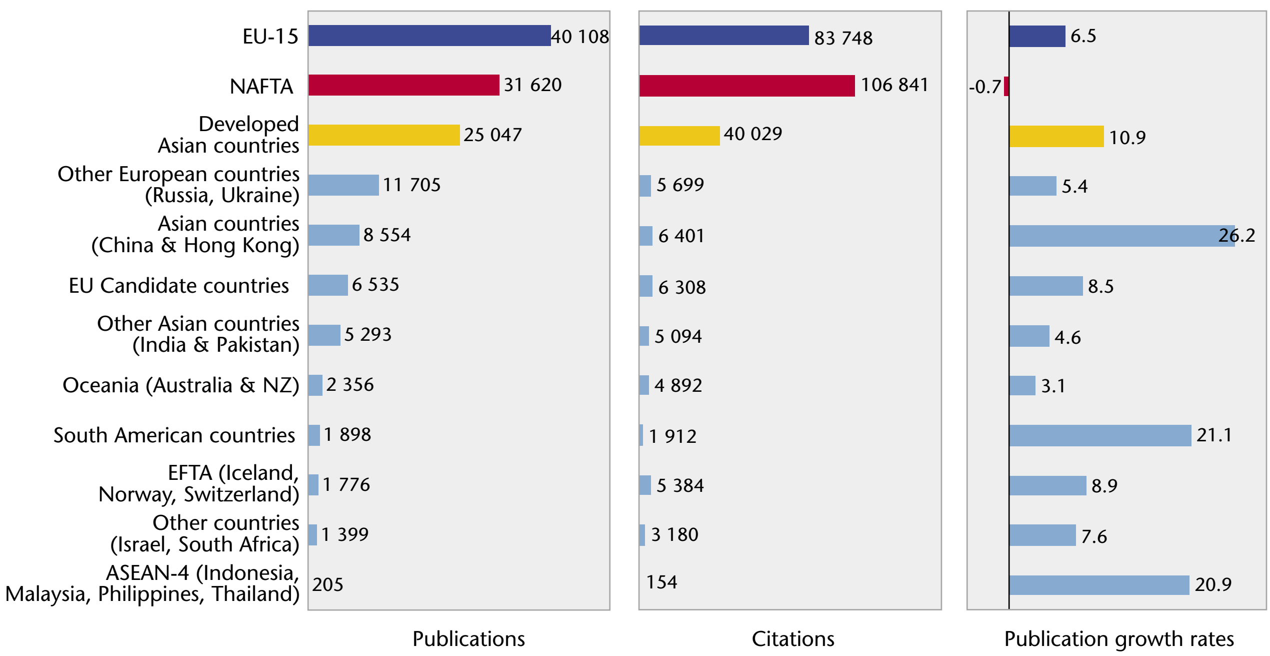
Figure 5.2.14 Average share of publications and growth rates (%) in the field of engineering (1995-1999, world)



Source: DG Research
Data: ISI, CWTS (treatments)
Note: The field "Other engineering sciences" covers ergonomics and operations research, the field labelled "instruments" also contains "instrumentation".

Third European Report on S&T Indicators, 2003

Figure 5.2.15 Publications (1995-1999), citations (1993-1999) and publication growth rates (%) in the field of material sciences by world regions



Source: DG Research
Data: ISI, CWTS (treatments)

Third European Report on S&T Indicators, 2003

Section III The scientific specialisation of the EU-15 Member States: diversity rules

While the two other main world regions are principally made up of a couple of dominant countries (the US in NAFTA and Japan in the Developed Asian countries), the two European regions, the EU-15 and the Candidate countries, consist of a larger number of countries performing very differently. One useful perspective is to see in which particular scientific fields countries specialise in, and if they have a particular scientific impact world-wide. That is the aim of this section, where the main focus is on the EU-15 Member States, but with references to other countries added when useful.

Specialisation profiles by country

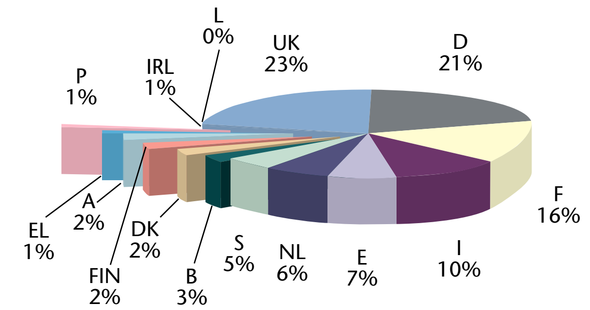
Each of the European Union's Member States not only has country-specific higher education and scientific training systems, but also individual industry structures, which are very often reflected by the science profile (cf. the example of computer sciences in the previous section). One should bear in mind that scientific fields have differing publication traditions. For example, in applied-oriented fields such as the engineering sciences, English-language research articles in scientific journals are not necessarily the main means of output. In others fields, researchers will tend to focus more on geographically specific issues or publishing in local journals or conference proceedings.

The other extreme example is given by the life sciences, where journal publications are very important and numerous, and the lingua franca is English. Given the number of different languages in Europe and the differences between countries in terms of their industrial specialisation patterns, as well as the specialisation of the ISI data base used for publication analysis, some EU countries will do better than others in terms of the number of journal publications. A country specialised in fields less represented in the data base and less likely to publish a lot, possibly in a language other than English, will have lower publication numbers than others. In the following analysis, only EU-15 publications between 1995-1999 have been taken as the basis for calculations of their absolute and relative contributions to the European and international science base.

Compared to their world shares, countries within the EU-15 appear in exactly the same order when measured by the size of their scientific publications output, as shown in figure 5.3.1. For example, while the largest European producers of scientific publications, the UK and Germany, have average world shares of 8.1% and 7.5% respectively, their intra-European shares are 22.5% and 20.8% respectively.

By calculating the numbers of publications by country and broken down by field, one will most likely find physics,

Figure 5.3.1 Scientific contribution by EU-15 Member States (1995-1999)



Source: DG Research
Data: ISI, CWTS (treatments)
Note: Scientific contribution takes only into account the publications that involve at least one EU-15 country. The number of these publications make the EU-15 total here and the shares by EU-15 country is then calculated.

Third European Report on S&T Indicators, 2003

chemistry and basic life sciences to be the largest fields. The simple reason for this uniformity is the sheer size of those fields and the fact that they belong to the ordinary canon of fields necessary in each country's science base and higher education system. In order to avoid reproducing such an obvious list, a scientific specialisation indicator - or 'research activity index' - has been calculated. The index takes into account the country's contribution by field, but ignores the size of its absolute number of publications.

Specialisation or relative activity can be measured in different ways, such as by relative shares of a country within a given field in the world total. Here, the specialisation profiles have been calculated considering only European publications. Tables 5.3.1 and 5.3.2 result from a calculation where first the numbers of European publications per field have been added for 1995-1999 and taken as the grand total. Second, the shares thereof per country have been calculated. Third, those ten fields have been taken for each country in which a country scored the highest shares.

This calculation method minimises the size effect of fields too. As the numbers of publications in physics and the life sciences are very high, and several countries would appear to be specialised in these fields if only the number of publications would have been taken into consideration, the field normalised shares have been taken instead. This alternative calculation results in some more interesting country patterns. It shows relative scientific strengths and weaknesses, and also which scientific fields are relatively predominant in Europe. In order to facilitate comparison, the different fields have been grouped and listed ranging from the life sciences, agriculture, and environmental sciences over engineering, chemistry, physics to mathematics, statistics and computer sciences in table 5.3.1.

Table 5.3.1 Relative specialisation profile by field and EU-15 Member States

	DK	S	FIN	IRL	B	A	E	F	I	UK	EL	NL	P	D
Basic life sciences		■		■	■	■		■						
Biological sciences	■		■	■	■	■	■							
Biomedical sciences	■	■	■		■	■								
Clinical medicine	■	■	■	■	■	■			■	■				
Dentistry	■	■	■	■						■	■	■		
Pharmacology		■	■		■		■		■					
Health sciences	■	■	■							■		■		
Food science & agriculture	■	■	■	■	■		■					■		
Earth sciences	■							■		■				
Environmental sciences	■	■	■				■			■		■		
Aerospace engineering				■				■	■					■
Electrical engineering				■	■				■	■	■			
Geological engineering									■	■	■			
Chemical engineering							■				■	■	■	■
Civil engineering	■	■	■							■	■	■	■	
Mechanical engineering				■				■		■	■		■	
Other engineering sciences				■	■	■				■	■	■	■	
Chemistry							■	■					■	■
Instruments & instrumentation					■	■			■				■	■
Materials science		■				■		■					■	■
Astronomy & Astrophysics							■	■	■			■		■
Physics						■		■	■					■
Fuels & energy								■					■	■
Mathematics				■		■	■	■	■		■		■	■
Statistical analysis & probability					■		■				■	■		■
Computer science			■			■			■		■	■	■	

Source: DG-Research
Data: ISI, CWTS (treatments)

Third European Report on S&T Indicators, 2003

From table 5.3.1 one can see a very similar activity pattern is apparent in Denmark, Sweden, and Finland. All of them are very active in the life sciences. Ireland, Belgium, and Austria are also relatively specialised in the life sciences but they display a more diversified pattern. Spain shows probably the most balanced pattern, being specialised in very different fields from the life sciences to physics and mathematics. So are France and Italy, but they show some preference for, or 'overrepresentation' in, physics. The UK is very much specialised in the life sciences and engineering sciences. Greece displays strengths in engineering sciences, mathematics, statistics and computer sciences. The Netherlands exhibits a diverse specialisation profile which lacks relative strengths in the life sciences. With a clear focus on engineering sciences and the natural sciences, a very similar pattern is shared by Germany and Portugal.

While this specialisation profile gives a limited picture of the European strengths, as only the European publications have been considered, the same pattern or strengths do not need to be the same at the world level.[10]

[10] *More importantly, even though a country might not boast high rates of specialisation in certain fields, they can still be quite active in those fields, and their science base may be of good or even excellent quality. Especially in the case of the smaller countries and fields, the specialisation profiles should be interpreted with caution.*

Table 5.3.2 Relative science specialisation profile of the EU-15 Member States (1995-1999): Share in EU-15 (%), number of publications (1995-1999) (P) and relative citation impact (1993-1999) (I)

Belgium	Share %	P	I
Other engineering sciences	4.2	231	1.24
Statistical analysis & probability	4.1	250	1.44
Instruments & instrumentation	4.1	323	0.82
Food science & agriculture	3.9	1 789	1.04
Electrical engineering	3.9	777	0.89
Biological sciences	3.7	1 880	0.97
Pharmacology	3.7	1 222	0.87
Basic life sciences	3.6	5 785	1.01
Biomedical sciences	3.4	4 234	1.02
Clinical medicine	3.2	8 887	1.19
Total all disciplines	3.2	42 248	

Spain	Share %	P	I
Chemistry	10.0	14 521	0.89
Food science & agriculture	9.5	4 314	0.74
Biological sciences	9.0	4 599	0.67
Mathematics	8.9	3 078	0.86
Chemical engineering	8.6	874	0.87
Astronomy & Astrophysics	7.9	2 136	0.84
Environmental sciences	7.7	1 800	0.83
Statistical analysis & probability	7.2	440	0.59
Basic life sciences	6.6	10 556	0.66
Pharmacology	6.6	2 197	0.65
Total all disciplines	6.7	89 750	

Denmark	Share %	P	I
Health sciences	4.9	547	1.02
Civil engineering	4.9	270	1.07
Food science & agriculture	4.3	1 950	1.21
Dentistry	4.2	266	1.15
Environmental sciences	4.2	974	1.22
Biological sciences	3.1	1 555	1.02
Basic life sciences	2.8	4 550	0.96
Clinical medicine	2.7	7 590	1.13
Biomedical sciences	2.7	3 315	0.84
Earth sciences	2.7	966	1.05
Total all disciplines	2.5	33 105	

France	Share %	P	I
Aerospace engineering	29.2	313	0.33
Mathematics	24.0	8 340	1.20
Earth sciences	21.8	7 857	1.03
Materials science	20.0	8 528	1.01
Fuels & energy	18.4	1 946	0.90
Mechanical engineering	18.1	2 800	1.20
Physics	17.9	33 634	1.12
Basic life sciences	17.1	27 508	0.98
Chemistry	17.0	24 669	1.03
Astronomy & Astrophysics	15.9	4 284	1.02
Total all disciplines	15.9	211 430	

Germany	Share %	P	I
Chemical engineering	27.9	2 840	0.63
Fuels & energy	27.8	2 949	0.93
Physics	27.4	51 401	1.24
Materials science	26.8	11 441	1.21
Chemistry	26.5	38 442	1.13
Instruments & instrumentation	25.3	2 002	1.07
Astronomy & Astrophysics	22.9	6 171	1.13
Aerospace engineering	22.0	236	0.41
Mathematics	21.5	7 481	0.99
Statistical analysis & probability	20.7	1 261	0.71
Total all disciplines	20.8	277 904	

Ireland	Share %	P	I
Food science & agriculture	2.1	947	1.02
Electrical engineering	1.0	208	1.00
Mechanical engineering	1.0	153	0.48
Mathematics	0.9	296	1.01
Clinical medicine	0.7	2 081	1.01
Basic life sciences	0.8	1 220	0.81
Biological sciences	0.8	384	0.69
Dentistry	0.8	48	0.81
Other engineering sciences	0.8	45	0.53
Aerospace engineering	0.8	9	0.42
Total all disciplines	0.7	9 656	

Greece	Share %	P	I
Geological engineering	6.5	24	0.33
Other engineering sciences	3.4	188	0.61
Civil engineering	3.2	178	0.53
Mechanical engineering	2.9	453	0.55
Electrical engineering	2.9	583	0.65
Chemical engineering	2.7	275	1.19
Computer science	2.6	671	0.59
Dentistry	2.2	137	0.66
Mathematics	2.0	683	0.58
Statistical analysis & probability	1.9	114	0.49
Total all disciplines	1.3	17 810	

Italy	Share %	P	I
Geological engineering	18.2	67	0.55
Aerospace engineering	15.4	165	0.56
Instruments & instrumentation	13.4	1 062	0.61
Electrical engineering	13.2	2 646	0.74
Pharmacology	12.8	4 243	0.66
Astronomy & Astrophysics	12.6	3 392	1.01
Mathematics	12.0	4 172	0.96
Computer science	11.9	3 052	0.82
Physics	11.5	21 580	0.98
Clinical medicine	11.1	31 301	0.92
Total all disciplines	10.1	135 162	

Luxembourg	Share %	P	I
Health sciences	0.1	7	0.93
Civil engineering	0.1	6	0.3
Chemical engineering	0.1	6	0.62
Biomedical sciences	0.0	53	0.45
Basic life sciences	0.0	47	0.36
Biological sciences	0.0	22	0.65
Pharmacology	0.0	15	0.38
Fuels & energy	0.0	4	0
Other engineering sciences	0.0	2	0.63
Statistical analysis & probability	0.0	2	0.26
Total all disciplines	0.0	317	

Netherlands	Share %	P	I
Health sciences	11.1	1 243	1.17
Other engineering sciences	10.6	581	1.10
Dentistry	9.0	563	1.18
Environmental sciences	8.2	1 910	1.26
Food science & agriculture	8.1	3 692	1.15
Statistical analysis & probability	7.9	480	0.87
Civil engineering	7.8	432	1.45
Astronomy & Astrophysics	7.7	2 071	1.17
Chemical engineering	7.5	765	1.65
Computer science	7.1	1 825	0.88
Total all disciplines	6.2	82 189	

Austria	Share %	P	I
Computer science	2.9	741	0.94
Clinical medicine	2.7	7 680	0.83
Biomedical sciences	2.5	3 114	1.09
Other engineering sciences	2.4	132	0.85
Materials science	2.3	975	1.10
Mathematics	2.2	766	0.97
Physics	2.1	3 981	1.15
Biological sciences	2.0	1 025	0.82
Basic life sciences	2.0	3 222	1.13
Instruments & instrumentation	1.9	153	0.96
Total all disciplines	2.2	28 839	

Portugal	Share %	P	I
Chemical engineering	2.2	224	0.75
Other engineering sciences	1.9	102	0.71
Materials science	1.5	648	0.70
Mechanical engineering	1.4	217	0.80
Computer science	1.2	299	0.66
Chemistry	1.1	1 571	0.73
Mathematics	1.1	375	0.81
Fuels & energy	1.1	121	0.59
Civil engineering	1.1	60	0.80
Instruments & instrumentation	1.0	83	0.47
Total all disciplines	0.8	10 241	

Finland	Share %	P	I
Health sciences	6.5	727	1.16
Dentistry	6.4	404	1.02
Environmental sciences	4.2	985	1.02
Food science & agriculture	3.2	1 464	1.10
Clinical medicine	2.7	7 583	1.27
Pharmacology	2.7	885	1.00
Computer science	2.5	651	0.99
Biological sciences	2.4	1 248	0.85
Biomedical sciences	2.3	2 870	0.89
Civil engineering	2.2	124	0.72
Total all disciplines	2.2	29 385	

Sweden	Share %	P	I
Dentistry	16.2	1 020	1.09
Health sciences	11.7	1 305	1.03
Environmental sciences	7.7	1 798	1.18
Civil engineering	6.8	377	1.14
Biomedical sciences	6.4	7 915	0.91
Pharmacology	5.6	1 849	1.25
Clinical medicine	5.5	15 511	1.15
Basic life sciences	5.3	8 483	1.02
Food science & agriculture	5.1	2 322	1.18
Materials science	5.0	2 130	1.19
Total all disciplines	4.9	65 113	

United Kingdom	Share %	P	I
Geological engineering	41.7	154	0.52
Civil engineering	33.1	1 836	0.90
Dentistry	32.7	2 055	0.78
Health sciences	30.0	3 352	0.97
Mechanical engineering	29.5	4 547	1.00
Other engineering sciences	29.1	1 592	0.75
Environmental sciences	28.2	6 602	1.04
Clinical medicine	26.9	75 544	1.11
Earth sciences	26.8	9 654	1.16
Electrical engineering	26.6	5 348	0.85
Total all disciplines	22.5	300 714	

Source: DG-Research
Data: ISI, CWTS (treatments)
Notes: (1) Concerns the citations received by articles in ISI-covered journals published in the years 1993-1999. Length of the citation period depends on the publication year. Includes only citations from other articles in ISI-covered journals. Excludes author self-citations.
(2) Citations are normalised against the world baseline, i.e. the absolute number of citations received ('actual') is divided by the 'expected' number of citations based on the world-wide citation levels in that discipline.
(3) The average normalised citation scores are equal to 1. Statistically significant high scores are typically above 1.15. They are marked in blue.
(4) Due to lack of statistical robustness for low numbers of papers, L has been omitted.

Third European Report on S&T Indicators, 2003

In table 5.3.2 the ten specialised fields are given with some more information. The first column gives the share of the field in the European range. For example, Austrian publications in computer science make up for 2.9% of the total of all European publications in computer sciences. The second column indicates the number of these publications. In the Austrian case, 741 publications in computer sciences have been published between 1995-1999. The third column gives the impact of these publications: The Austrian computer science publications scored a relative citation impact of 0.94. The last row gives the share and the number of Austrian publications in the European total. The share of 2.2% is the same as in figure 5.3.1.

One could assume that the citation impact of the specialised fields would be relatively high. This is indeed the case for several countries and for several fields as highlighted in the appropriate column in table 5.3.2. While the average normalised citation scores are equal to one, statistically significant high scores are typically above 1.15. Most countries score in at least one specialised field above average, others don't. In the following, two examples will be illustrated in more detail: aerospace engineering and basic life sciences.

Aerospace engineering

Aerospace engineering covers a total of 6 091 papers (including co-publications) from 46 countries, published between 1995-1999. The thirteen EU-15 countries have a share of 17%, while the US accounts for 57% alone. If the European share is calculated as the publication total, it appears as one of the main ten fields of activity or specialisation in France, Germany, Italy, and Ireland (tables 5.3.1 and 5.3.2). With a total of 313 papers, France is world-wide the third largest producer with a world share of 5%, while within Europe, it leads with a share of almost 30% (table 5.3.2), which is not surprising in view of the substantial French aerospace industry. Given this industry structure, one would expect that aerospace engineering belongs to the fields of scientific specialisation in France. However, it seems less likely so for Ireland, where aerospace engineering ranks number 10 within the Irish specialisation profile. The reason for this depends largely on the size of a field. If a field is very small, even a country that is small in terms of scientific output, can be among the group of countries publishing actively. In the case of aerospace engineering, Ireland only had a total of nine publications but in the world ranking it made it to number 30.

Aerospace engineering is a relatively small and applied field of science and has only a limited spillover potential for other fields. This renders this field less likely to receive many citations, especially from outside the field. Research articles published between 1993 and 1999 received on average only 1.1 citations. However, because the field is small, countries with a very low number of publications may have high impact scores. Due to lack of statistical reliability, these should not

Figure 5.3.2 Top 10 most actively publishing countries in aerospace engineering by number of publications (1995-1999)

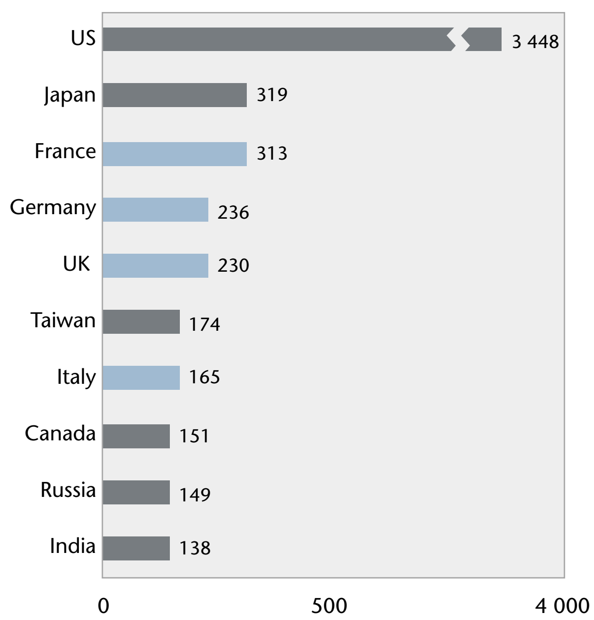
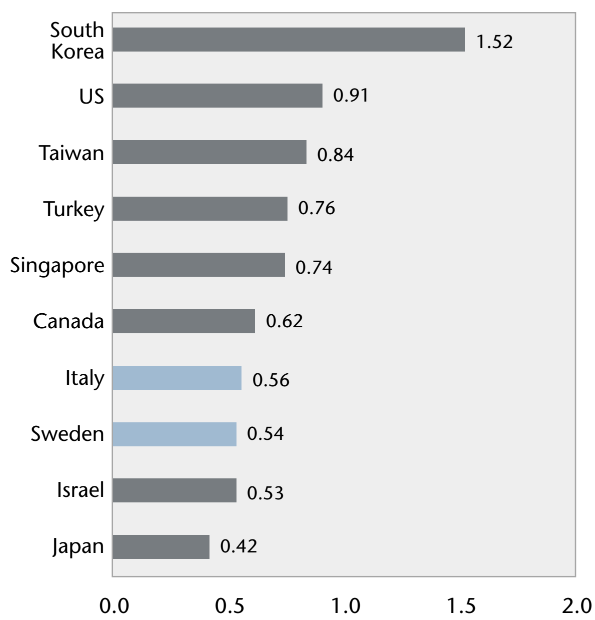


Figure 5.3.3 Top 10 highest citation impact countries in aerospace engineering by citation impact (1993-1999)



Source: DG Research
Data: ISI, CWTS (treatments)
Note: Figure 5.3.3 list countries with at least 20 publications.

Third European Report on S&T Indicators, 2003

be taken into account for calculations and rankings. A case in point is the performance of South Korea as shown in figures 5.3.2 and 5.3.3, which include only those countries that published at least 20 articles between 1995 and 1999. This is a very low threshold at country level. The discrepancy between activity and impact is clearly visible in the divergence of the countries being included as most active.

Basic life science

By comparison, basic life science is a large field with more than 377 000 publications between 1995 and 1999. The largest producer in the field of basic life science is the US with a publication share of 32.8%, followed by Japan with 8.8%, and the UK with 8.2%. The 'generic' field of basic life sciences contains a number of sub-fields that deal mostly with basic scientific research, and offer a high potential for citations, both from within and from outside the field (cf. methodological annex to chapter 5). The world average number of citations per paper in the basic life sciences from 1993 to 1999 is 4.96, almost five times the rate in aerospace engineering.

A total of 40 countries passed the threshold of 1 000 publications between 1993 and 1999. In figure 5.3.4, the 20 most active countries are ranked according to their publication size. Ten EU Member States make it into this ranking. Of course, all these countries have a fair amount of overall publication activity. Smaller countries, even those that specialise in life sciences, will not be represented according to this scale-dependent indicator.

The citation indicator is shown in figure 5.3.5, another scale-dependent indicator. Again, not surprisingly, the US dominates in terms of number of publications and citations. However, citations not only reflect reputation, impact, and influence, but they are sensitive to language. Different rankings show, for example, that Japanese publications receive fewer overall citations, causing Japan to drop from number 2 in terms of publications, to number 4 in terms of citations. There are also some new entries – Austria, New Zealand and Norway – which did not appear in the list of the 20 most active countries in terms of publications output. Korea and India, on the other hand, did not make it into the top 20 most cited countries. In total, 11 EU-15 Member States are ranked among the top 20 cited countries.

The number of average citations received by a publication leads to the statistics shown in figure 5.3.6. Poland and Slovakia are two countries that do not appear among the top 20, in either publications or citations. This shows that this indicator is less sensitive to the publishing size of a country. The fourth indicator – the mean field citation score – finally levels out the relative-size-of-countries problem. This is evident from the inclusion of Singapore, Ireland and Portugal, and the exclusion of larger countries such as Japan and India (figure

Figure 5.3.4 Top 20 in terms of number of publications in basic life sciences (1995-1999)

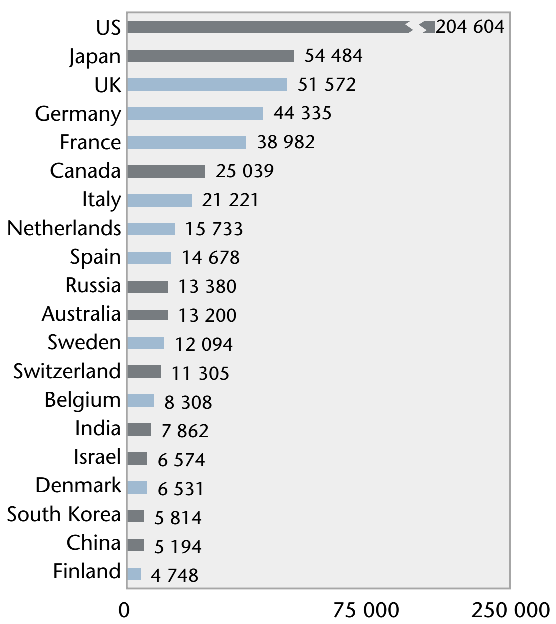
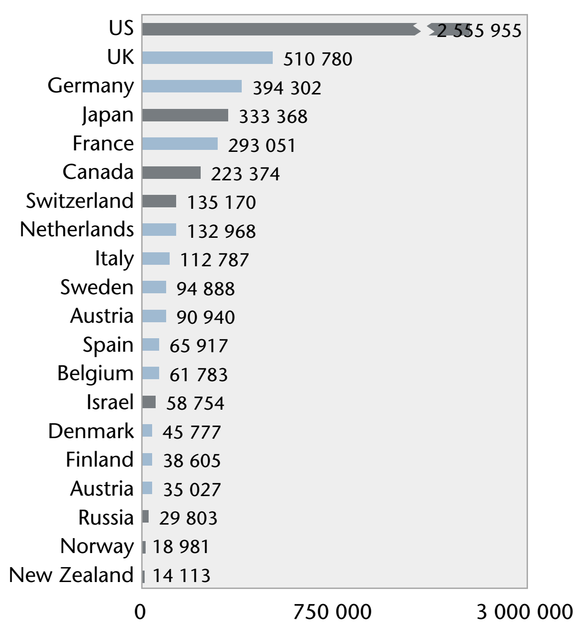


Figure 5.3.5 Top 20 in terms of number of citations in basic life sciences (1993-1999)



Source: DG Research
Data: ISI, CWTS (treatments)
Note: The threshold for inclusion in figure 5.3.4 is at least 1 000 publications from 1995-1999.

Third European Report on S&T Indicators, 2003

Figure 5.3.6 Top 20 in terms of citations per publications in basic life sciences (1995-1999)

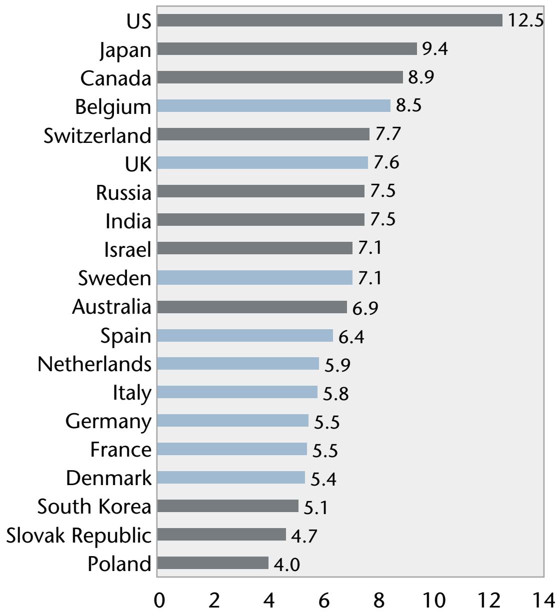
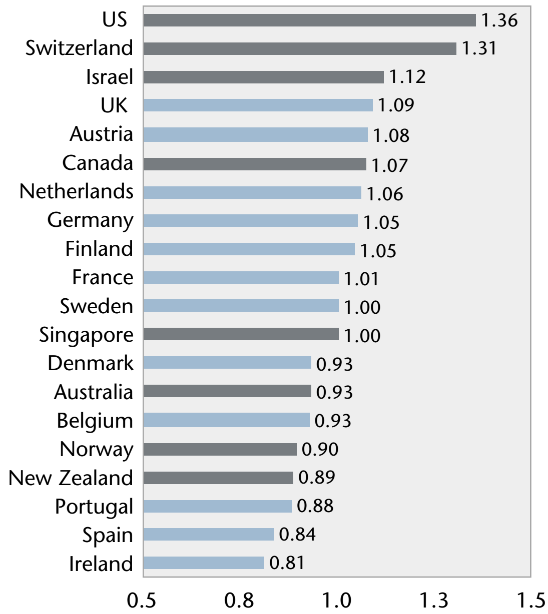


Figure 5.3.7 Top 20 in terms of number of mean field citation score in basic life sciences (1993-1999)



Source: DG Research
Data: ISI, CWTS (treatments)

Third European Report on S&T Indicators, 2003

5.3.7). This last indicator may be seen as the most accurate or meaningful one, levelling out several size distortions.

These examples show that the field of basic life science is a very important one for domestic science bases. All countries are active, but a rather smaller number of countries have very high scores across the various indicator categories; only 13 countries appear in all four categories. Eight of these are EU-15 members. Another 15 countries have been included in at least one category. Although the US is leading, a number of European countries, including EU-15 and EFTA countries, as well as Israel and Australia, are doing very well in terms of output levels and (relative) citation impact scores.

Section IV Patterns of scientific co-operation

In the past two decades there has been a strong trend towards greater scientific collaboration and resulting joint research publications. Co-authored publications ('co-publications' for short) have emerged in almost all scientific fields. While there has been a tradition of publishing multi-authored papers in physics and the life sciences, this pattern has evolved in all the natural sciences, engineering sciences, the social sciences, and the humanities. It was stated ten years ago already that co-publications across international borders would lead to more citations and higher relative citation impact rates (Lewison, 1991).

Many researchers are now actively involved in both domestic and international co-operation – as the data suggests. Between 1986 and 1997, the total number of articles in the ISI databases increased by 12%. The number of co-publications rose by 46% and international co-authored articles increased by almost 115% (National Science Board, 2000). While various different forms of co-publication are possible (cf. box), in this section the focus is on international co-publication patterns between world regions and between countries.

As science is becoming more and more complex and important findings result from cross-field or multidisciplinary research, most researchers are actively looking for co-operative research opportunities. However, co-publications are not only a means for disseminating important joint research findings, but research co-operation also enables learning within the different scientific communities and across geographical borders. In this respect, international co-publications are also a proxy of the mobility of researchers and an indicator of the globalisation of scientific research as a whole.

Co-publication analysis: notes on methodology

Co-publication analysis is one of the cornerstones of bibliometric analysis. There are three types of analysis:

Co-publications can involve domestic partners only. Depending on the institutional level of analysis, co-authored publications are produced when two scientists from the same research group or laboratory, or authors from two departments of the same main organisation (e.g. a university, government research laboratory, or company) publish together. Such intra-organisational co-publications are usually not regarded as domestic scientific co-operation.

Authors within the same country but from different main organisations – these are thought to constitute genuine domestic co-operation.

International co-publications, which involve authors from at least two different countries, as defined by research papers containing at least two authors' addresses in different countries.

An important methodological issue is the way in which a co-publication is quantified. The full counting method has been used in this instance, meaning that a single international co-published paper is assigned to more than one country of scientific origin. If, for example, the authors' addresses signal three different countries in the EU-15, the publication is counted three times – once for each country mentioned (cf. methodological annex to chapter 5 for further details). In a matrix of co-publications between countries, the number of publications mentioned is not an indicator of the number of publications being co-authored, but rather how often a country or region is involved in co-publications. The 'amount' of co-publications by a country or region, therefore, depends primarily on the overall scientific production, and secondly on the activity in fields with a high propensity for co-operation.

Co-publication data allow the analyst to approximate and compare countries' tendencies to be more open to scientific co-operation or to be more closed and/or less attractive to outside collaborators. Openness and attractiveness for international scientific collaboration will be affected largely by a common or different language, geographical proximity, and the attractiveness of a country's research facilities and activities. Scientific excellence and unique assets might be a very compelling incentive or 'attraction' for researchers to collaborate and co-publish their research results – in spite of language barriers and geographic distance.

1. World trends in scientific co-operation

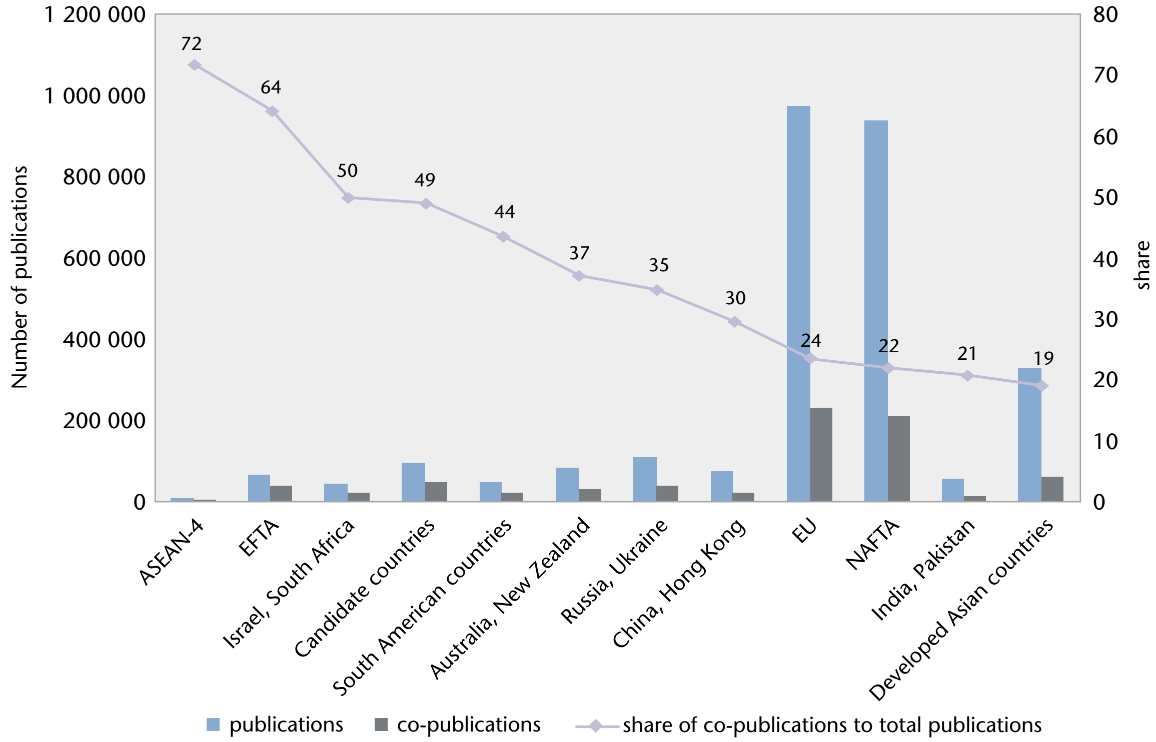
Figure 5.4.1 shows the total number of publications, the number of international co-publications and the ratio of co-publications to total publications by world regions for 1996-1999. During this period, more than 740 000 international co-publications were recorded. High ratios signalling large shares of co-publications to total publications are displayed in all smaller world regions. This would suggest that small producers of scientific knowledge have a high incentive for co-operation and co-publishing. In comparison, ratios for the large producers, EU-15 and NAFTA are relatively moderate, with co-publication ratios of 24% and 22% respectively.

The India/Pakistan region and the Developed Asian countries have a markedly low ratio of 21%. Why do these regions seem so 'inward-oriented'? There are two categories of reasons. Firstly, they are less prone to international scientific co-operation due to domestic science policies, areas of scientific specialisation, or cultural differences. This might well be the case for the Developed Asian countries. Secondly, the research systems of these countries are still in a catching-up phase and therefore not sufficiently active in international research projects, especially at the highly competitive level of leading-edge research topics. This might explain the situation in India and Pakistan.

By comparison, EFTA and Israel/South Africa have comparatively high shares with 64% and 50% respectively. There could be several explanatory factors for this discrepancy. In India and Pakistan, and to a certain extent in Israel, South Africa and in the EFTA countries, English is the common scientific language. Therefore, the argument of language as a hampering factor would be less valid here. Another factor could be that India and Switzerland are medium sized countries in terms of scientific production, and their domestic research systems for developing scientific knowledge at the international level are relatively limited.

However, compared to Switzerland or a country of similar size such as Sweden, which produced almost the same number of publications, with publication to co-publication ratios of 91% and 95% respectively, India has a low ratio of 23%. Again, these differences are relative, taking into account

Figure 5.4.1 Publications, co-publications and co-publication share by world regions (%) (1996-1999)



Source: DG Research
Data: ISI, CWTS (treatments)

Third European Report on S&T Indicators, 2003

Table 5.4.1 Matrix of co-publications by world regions in % of row totals (1996-1999)

	EU-15	Candidate countries	EFTA	NAFTA	ASEAN-4	Developed Asian countries	India, Pakistan	Israel, South Africa	Australia, New Zealand	Russia, Ukraine	China, Hong Kong	South American countries
EU-15		11.2	9.5	46.2	0.7	7.0	1.8	3.1	5.0	8.5	2.8	4.1
Candidate countries	53.4		4.4	23.0	0.1	4.9	0.9	1.8	1.4	7.7	0.9	1.4
EFTA	52.7	5.2		26.0	0.3	4.2	0.8	1.9	2.2	4.3	1.2	1.3
NAFTA	51.0	5.3	5.1		0.7	14.2	1.9	4.5	5.4	4.1	3.8	3.9
ASEAN-4	28.6	1.3	2.1	27.0		19.1	3.8	1.0	10.3	0.5	5.1	1.3
Developed Asian countries	25.5	3.8	2.8	47.1	1.7		1.8	1.3	3.9	4.0	7.1	1.1
India, Pakistan	35.4	3.8	2.8	34.6	1.8	9.8		1.4	2.9	2.7	2.7	2.0
Israel, South Africa	33.7	4.1	3.6	43.7	0.3	3.8	0.8		4.0	3.7	0.9	1.5
Australia, New Zealand	37.6	2.1	2.9	36.8	1.9	8.1	1.1	2.8		1.6	3.8	1.4
Russia, Ukraine	50.3	9.7	4.5	21.9	0.1	6.5	0.8	2.0	1.2		1.1	1.8
China, Hong Kong	29.1	2.0	2.2	35.2	1.3	19.9	1.4	0.9	5.1	2.0		1.0
South American countries	44.4	3.2	2.6	37.4	0.3	3.2	1.1	1.5	2.0	3.2	1.1	

Source: DG-Research
Data: ISI, CWTS (treatments)
Note: Whole counts of papers for pairs of countries in papers; de-duplication of country occurrence per paper

Third European Report on S&T Indicators, 2003

that a large proportion of Switzerland's and Sweden's publications is in the field of life sciences where co-publications are most common. Sweden manages almost 31 000 publications and Switzerland more than 24 000, while India accounts for 14 000 publications in the life sciences. All figures include the number of co-publications.

A much more detailed analysis of language factors, field-specific habits and geopolitical considerations would be needed to assess the various interrelated motives and incentives felt by researchers in certain countries to become involved in scientific co-publications.

The differences mentioned above reflect the meaninglessness of a simplistic comparison. There is probably never a single factor determining the openness and attractiveness of a region or country. It is a complex mix of the respective scientific and technological patterns, languages and cultures, government systems, funding mechanisms and criteria, scientific traditions, and means of communication.

The data in table 5.4.1 indicates the share of co-publications by world region. The table gives a matrix of co-publications by the main world regions; reading along the rows allows one to see the proportion of the total co-publications undertaken by that region in co-operation with the regions shown in the columns. It is apparent that the large regions of EU-15 and NAFTA are partners in a large proportion of all of the co-publications of the other world regions, which indicates their relative attractiveness. It is also clear that there are geographical clusters, for example Australia, New Zealand and the ASEAN-4. The Developed Asian countries of Japan, Korea, Singapore and Taiwan are important partners for the ASEAN-4, as are China and Hong Kong.

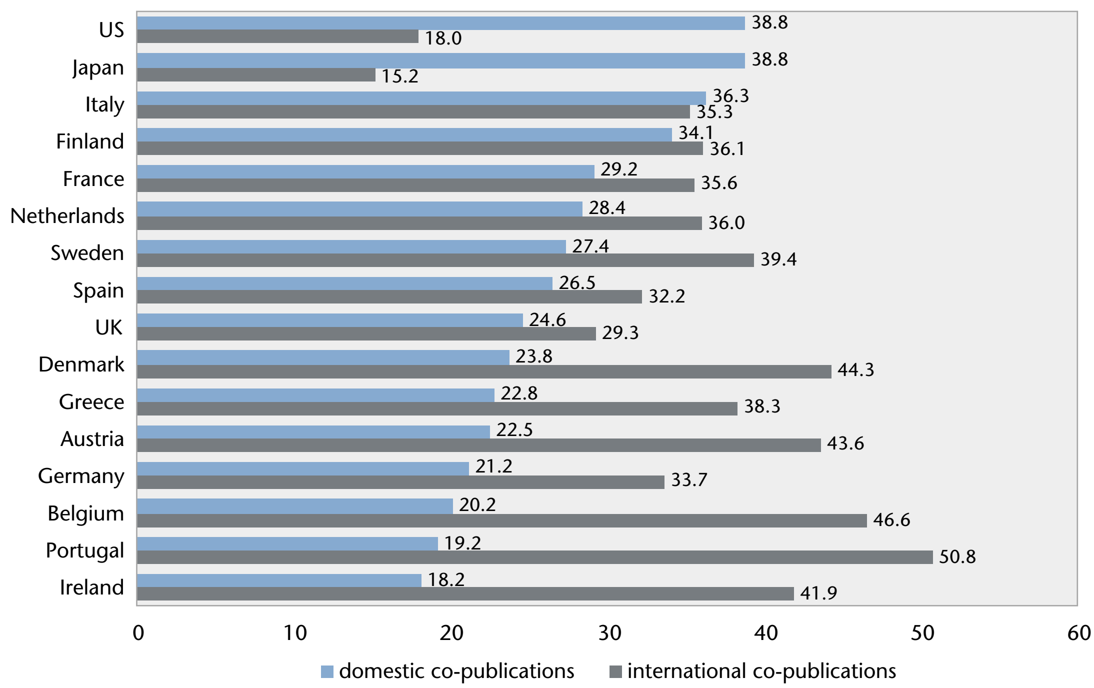
In the main, co-operation preferences seem to be driven predominantly by proximity, cultural similarities and national and international politics, rather than by scientific considerations such as benefiting from specific complementarities of scientific partners. Time will tell to what extent modern IT facilities and new policies will change these structural characteristics of the international landscape of science.

2. EU co-publishing with other regions

The propensity to co-publish varies between regions, countries and fields. An analysis of data published by the US National Science Foundation (NSB, 2000), particularly a more detailed comparison of the EU-15 and the US, facilitates some conclusions on this aspect. Despite the various similarities between their research systems, for example as indicated by publication size, co-publication patterns can be quite different. In order to arrive at a triadic comparison, data for Japan will be analysed on the micro level as well.

Figure 5.4.2 shows the share of total co-publications in all publications divided by domestic and international ones for

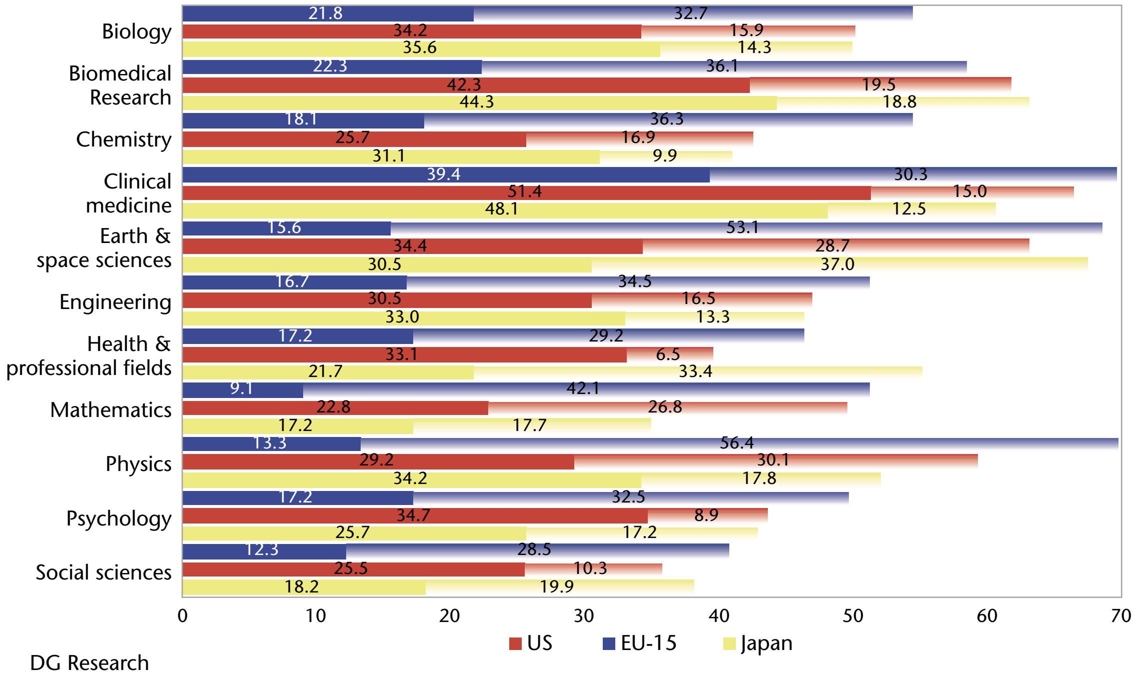
Figure 5.4.2 Domestic and international co-publication shares (%) by EU-15 countries, US and Japan (1995-1999)



Source: DG Research
Data: ISI, NSB 2000
Note: Sorted by decreasing share of domestic co-publications.

Third European Report on S&T Indicators, 2003

Figure 5.4.3 Domestic and international co-publication shares (%) by EU-15, US and Japan (1995-1999)



Source: DG Research
Data: ISI, NSB 2000
Note: share of domestic co-publications, the internationally co-authored publications by EU-15 (blue), US (red), and Japan (yellow). It should be read as follows: In the field of biology, Europe co-authors 21.8% domestically, i.e., within Europe. 32.7% of publications have a non-European partner involved.

Third European Report on S&T Indicators, 2003

each EU-15 country, the US and Japan. The upper blue bar shows the share of domestic co-publications, and the lower grey bar the percentage of international co-publications. The highest shares of domestic co-publications are found in the US, Japan and Italy. The lowest ones are in Ireland and Portugal. With regard to international co-publications, Portugal, Belgium and Denmark have the highest shares. Japan, the US, and to some extent the UK, have the lowest.

It is also instructive to analyse whether differing patterns of co-publishing can be found within broad scientific fields. Such an analysis is given in figure 5.4.3. Here, the EU average has been calculated, and the US and Japan totals have been included. Domestic co-publications within the EU-15, the US and Japan have high shares in clinical medicine and biomedical research and low ones in mathematics.

The shares for international co-publications are high in physics, earth and space sciences in both the EU-15 and the US. In Japan, the health and professional fields have the second largest share. At the lower level are the social sciences in the EU-15, chemistry in Japan and health and professional fields in the US. Despite some similarities, there are large differences between the shares within a field. One example is mathematics, where Europe has a very high international co-publication rate. Clinical medicine seems to be a predominantly 'domestic' field. In all countries the domestic shares are much higher than the international ones.

3. Internal co-publishing in the EU

The actual ratio of publications to co-publications by country reflects only one side of the picture, namely whether or not a country is involved in co-publications. As stated previously, the propensity to co-publish also depends on the size of a country's publication output. In order to analyse the co-publication patterns of EU-15 Member States, the expected co-publication ratios have been calculated. The logic is the following: country A has a certain amount of co-publications and there are a few prospective partnering countries. These candidates have equally different numbers of co-publications, depending to an extent on their total numbers of publications.

For table 5.4.2, the expected co-publication values have been tabulated. The colours signal whether country A has co-published more, less or as expected with different partners. The yellow fields indicate ratios below expectation, blue above expectation and grey indicates expected values. By looking along the rows, country A's partner preferences can be identified, while the columns indicate which other countries prefer country A as a partner.

Interesting preferences can be detected in related countries in terms of language as well as proximity. For example, Austria strongly favours Germany and vice versa. Belgium has strong ties with Luxembourg, the Netherlands, and France, while France has a preference for Belgium, Spain and Italy. Portugal

Table 5.4.2 Matrix of intra EU co-publication propensities (1996-1999)

	B	DK	D	EL	E	F	IRL	I	L	NL	A	P	FIN	S	UK
B		–				+			++	++	–		–		
DK	–			+		–	–		–				++	++	+
D	–	–		–	–		–	–		–	+	–	–	–	
EL		+	+			+	–	+	+		+	+			+
E						+	–	+	–		–	++		–	+
F	+	–			+		–	+		–	–		–	–	
IRL		–		–					++	+	–	+			++
I	–	–			+	+	–		–			–	–	–	
L	++		++	++	–	+	++				++	++			–
NL	++		+	–					–		–				+
A	–		++	+	–	–	–		+			–		–	–
P	+	+		++	++	+	+		+	+			+	+	+
FIN	–	+		–	–	–	–	–	–					++	
S	–	++		–	–	–	–	–	–		–		++		
UK	–						+		–		–		–	–	

Data: ISI, CWTS (treatments)
Note: less cooperation than expected; more cooperation than expected; cooperation as expected.

Third European Report on S&T Indicators, 2003

has a marked preference for neighbouring Spain, and vice versa. Other clusters are Sweden, Finland and Denmark, and the UK and Ireland. However, proximity and language can also explain differing patterns: Greece for example, with neither a direct border to another EU country nor any partner language-wise, shows above expected co-publishing ratios compared to a number of countries. This tendency can also be found for Portugal with the difference of having at least one direct neighbour.

For countries such as Germany and to a certain extent the UK, other features are evident. Apart from Germany's affinity to Austria, it shows no other preference. In fact, for most other European partners the ratios are below expectation. The UK shows an affinity for Ireland as opposed to the rest of Europe, which is either average or below expectation. This is a strong indication that both countries have preferred partners outside the EU.

Scientific and technological performance by gender

An analysis has already been made in chapter 4 and dossier III of the role of women in S&T, looking at the input side in terms of their participation in S&T education and careers. However, until now, there have been few reliable indicators of the output of women involved in S&T. A recent pioneering study carried out on behalf of the European Commission[11] assessed the feasibility of producing S&T output indicators by gender. Using patent and publication data for six EU countries, the study developed a unique methodology for indentifying the gender of authors and inventors, which allows us to see for the first time male/female differences in scientific and technological production.

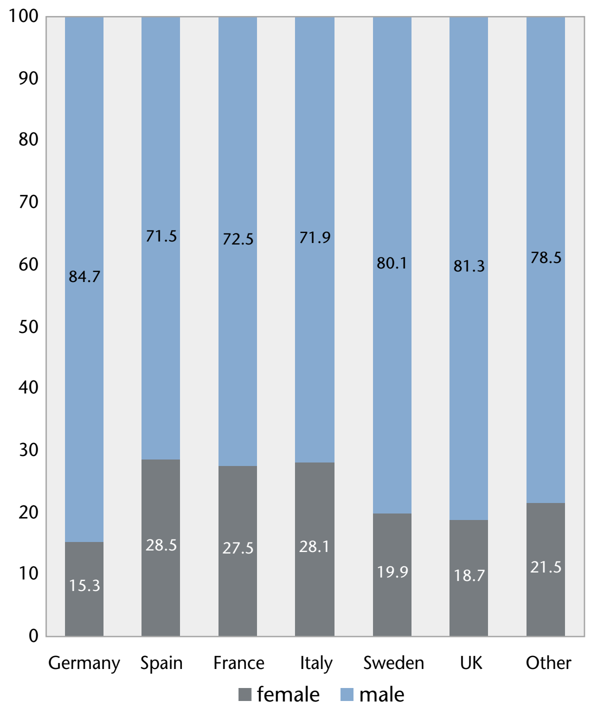
Such data are interesting when one talks about careers in S&T. We observe that, starting from almost the same base, the number of females in higher scientific and research positions is very low relative to the number of males. But what are the reasons for these differences? Are women less active or productive than men, or do they have to perform even better than men in order to reach the next career step? Genderized publication and patent indicators can help us to understand this better.

[11] *Naldi, F. and Vannini Parenti, I., Scientific and Technological Performance by Gender : A Feasibility Study on Patent and Bibliometric Indicators, project carried out for the European Commission under contracts ERBHPV2-CT-1999-14/15, Office for Official Publications, EUR 20309, Luxembourg, 2002.*

Main findings

Figure 5.4.4 shows scientific publications broken down by gender. Depending on the country, females represent between 15% and 29% of the analysed authors. Interestingly, we can identify a south-north bias with Spanish, Italian and French women more prominent than their Swedish, British and German counterparts. The data show that in some northern countries the share of women may be almost a half of that in southern countries. Still, even for the women in Spain, Italy and France equality is far from complete.

Figure 5.4.4 Number of authors of scientific publications by gender and country (%)

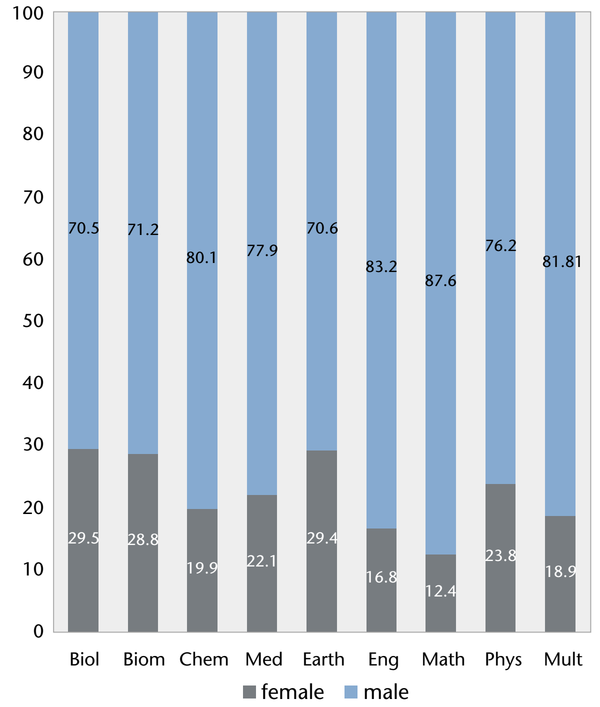


Source: Naldi and Parenti (2002)
Data: Sample of scientific journals
Third European Report on S&T Indicators, 2003

An analysis of authorship by scientific discipline (figure 5.4.5) exposes a pattern which has already been observed to a large extent from other statistical evidence such as numbers of researchers. Women are seen to be most active in the life sciences and much less so in mathematics and engineering.

Turning to data on patenting activity, the divergence between southern and northern European countries which was observed in figure 5.4.4 for authors of scientific publications can also be found in relation to inventors of patents. Figure 5.4.6 shows the results for male and female inventors of European patents, where one can observe even lower shares of female inventors than those in figure 5.4.4 for female authors.

Figure 5.4.5 Number of authors of scientific publications by gender and discipline (%)



Source: Naldi and Parenti (2002)
Data: Sample of scientific journals
Third European Report on S&T Indicators, 2003

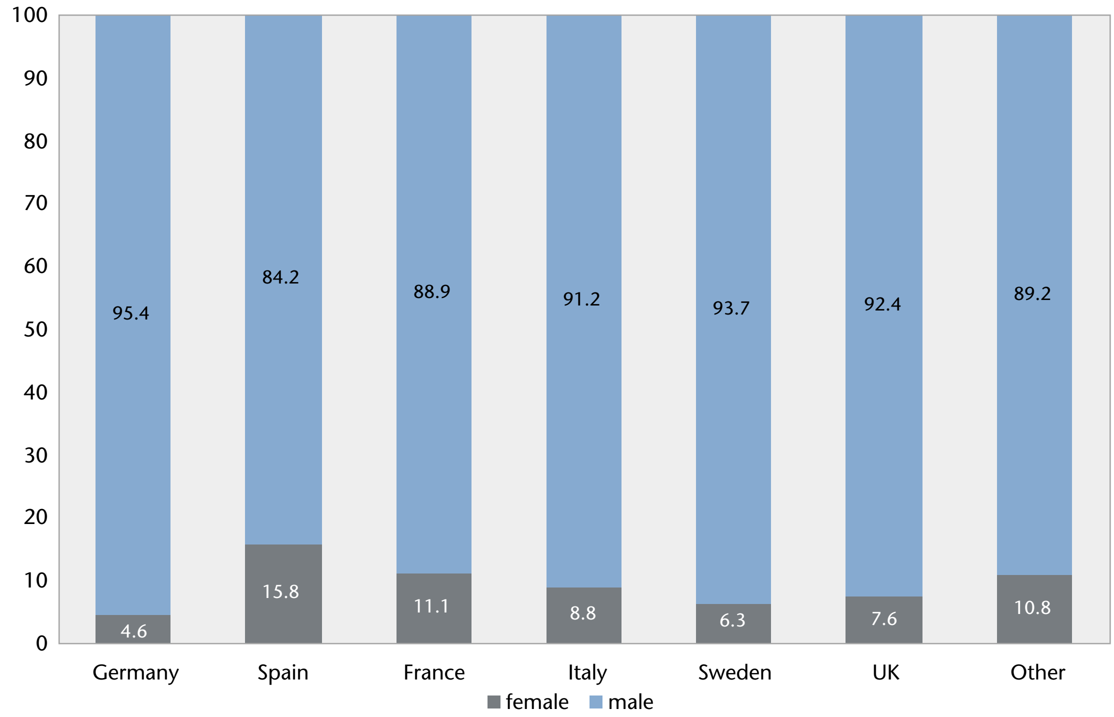
Only 15% of Spanish inventors are female, but even with this low share they come out at the top of the countries studied. Again the lowest share can be found in Germany, where less than 5% of inventors are female. The contribution of female inventors to technological progress would seem to be minor or even insignificant in the northern countries; applying for patents would appear to be an essentially male domain.

Gender distribution strongly depends on the field of technology. The study found that the fields with the highest contribution of female inventors were biotechnology (20.8 %), pharmaceutics & cosmetics (20%), food chemistry (13%), basic materials chemistry (12%) and organic fine chemistry (12%).

If one compares these data with the number of male and female researchers in the business enterprise sector (where most patented inventions originate), one observes some marked contrasts. For example, in Italy, while women represent around 16% of researchers in industry[12], they account for 9% of inventors of European patents. Similarly,

[12] *Source: Eurostat, Newcronos database*

Figure 5.4.6 Number of inventors by gender and country (%)



Source: Naldi and Parenti (2002)
Data: EPO

Third European Report on S&T Indicators, 2003

in Sweden some 25% of private sector researchers are female, but they represent only 6% of all inventors.

These figures raise a number of questions. Is the disproportionately weak presence of women among inventors due to their specialisation in fields of technology where patenting is less prevalent? This may be a factor, for while in the field of pharmaceuticals, for example, women account for 23% of European patents in Italy - compared with their overall presence of 16% of all business sector researchers - in the fields of transport and electrical engineering their share of patents falls well below 10%.

What is more difficult to detect is whether in some areas women face obstacles to advancing to positions where they may be centrally involved in patentable research and in the key R&D teams. To analyse this in more detail we would need gendered R&D personnel data by sector and by level of seniority (which are generally not available).

However, in order to derive robust and meaningful conclusions about the relationship between gender-specific activity and productivity, one needs to combine these data with structural input data such as the number of female and male scientists and researchers, their positions, and their motivations to publish or invent. This is an important area for future research, which will require further improvements in available statistics.

Methodology: Identifying the gender of authors and inventors

How does one identify the gender of authors and inventors in publications and patent documents? As there is no systematic recording of gender, and as the relevant datasets are extremely large, the only practical solution is to take the first names and to classify each name as female or male, or – in cases of ambiguity – as both. This was the approach used in this project, which created a database of over 30 000 first names used in 6 countries: UK, France, Germany, Italy, Spain, and Sweden. The classification was done by country/ language in order to minimize the number of ambiguous cases (e.g. Jean which is a male name in France, but a female name in UK). When applied to patent and publication data this approach successful identified the gender of authors and inventors in more than 90% of cases.

The patents were much easier to analyse than the publications because of the completeness of the relevant patent database in terms of coverage of patents and the provision of first names. In contrast, bibliometric databases generally contain no first names, and in many cases not even initials. Therefore a sample of publications had to be analysed in libraries in order to obtain the complete article with the full first names. However, about two thirds of the analysed journals still did not include the first names, and had to be excluded from the analyses. It was not possible to examine distortions due to this factor.

Section V The most actively publishing research institutions in the EU

It can be argued that quality has always been a key aim of researchers and scientists. Recently, however, the aim to produce quality research has become strongly coupled not only with innovation and prestige, but also with funding. With public funding getting more and more scarce, and scientific institutions, disciplines and technologies competing for funding, policy makers are now more interested than ever to know where the excellent research is being done and which are the future disciplines that should be promoted. While for the latter, technology foresight methods are applied in several countries (cf. also European Commission, 1997), various other policy instruments are being tested in the European Member States (cf. box). As seen in a previous part on scientific impact, the evaluation of research is becoming very important in various countries.

The indicators used for measuring research are numerous. With only two or three main indicators one can create a whole set of sophisticated ones which will give a very good picture of what has been done and, to a certain extent, the impact of some particular research. Most commonly, publications and citations are used as the basis for research evaluation, but the way these indicators are built varies. While the number of publications and citations are indicators which can be used as beforehand – showing countries' strengths and competencies, or lack of them – policy makers, scientists, and industry decision-makers are sometimes more interested to know where scientific excellence can be found at an institutional level.

If one takes the numbers of publications as the single main proxy for productivity and implicitly for quality, the analysis will tend to highlight only large institutions, which have the capacity to publish a lot, or institutions/disciplines with strong publication habits, such as the life sciences. As publication trends differ considerably between disciplines, institutions which are active in the life sciences tend to be more prominently represented in any activity list than smaller, more specialised institutions or technical institutions covering engineering or other more technical fields. In order to arrive at a more balanced view, a more sophisticated method has been used here for the identification of the institutions covered (cf. box and methodological annex to chapter 5). The study covers the most actively publishing institutions in the EU, using publication data from 1996-1999 and citation data from 1993-1999.

Instruments for fostering scientific excellence

A positive side effect on publications might be attributed to national science policies striving for scientific excellence. In several countries, both inside and outside the EU, national science policy has established specific programmes that try to foster excellence. The forms are manifold, ranging from specific funding for outstanding single scientists (e.g. the Spinoza prize in the Netherlands), funding for outstanding young researchers or research groups at universities (e.g. *Spezialforschungsbereiche* in Austria, *Sonderforschungsbereiche* in Germany). In several countries "Centres of Excellence" have been established and very often financed by public funding (for an overview, see Academy of Finland 2001).

For the latter, the promotion of research excellence is focused on specific disciplines and is often linked with efficient science transfer mechanisms. This indicates that while basic research is seen as important, the transfer of knowledge also needs to be a central part of the centres' strategies. Science policy makers use the "Centres of Excellence" instrument in quite flexible ways, depending on various goals. While basically all countries have the strengthening of scientific excellence as one of their main goals, some have experimented with different methods to achieve this. These include competitive funding, the mobility of researchers, or improving the research setting for young researchers.

In countries such as Finland and Denmark, Centres of Excellence are national programmes with no focus on a specific discipline. Therefore, centres can be found in disciplines ranging from the natural and medical to the social sciences. In Germany there is a focus on clinical research. In the UK, centres of excellence are awarded in combination with the outcome of the research assessment exercise (RAE). Canada is another example, where networks of excellence are promoted in which scientific excellence is only one of several goals. Pointing in the same direction, several countries have created the slightly different instrument of "competence centres". It is an instrument often intended for oriented research or technologies (e.g. the Kplus programme in Austria, BioRegio in Germany, or the national competence centres in Switzerland).

The European Commission is launching the "networks of excellence" instrument under the 6th Framework Programme. One of its main aims is to enable the networking of excellent research groups within the EU-15 and beyond by promoting the integration of these units (for further information see http://www.europa.eu.int).

In tables 5.5.1 and 5.5.2, the most active and important institutions have been compiled by country. There are several remarkable aspects worth focusing on. First, there is the publishing size of the institutions. In the larger Member States, one will find more institutions with large publication numbers, but also some with comparably low ones. In general the most productive institutions are specialised research institutions, or come from industry. In the smaller Member States, smaller numbers are more common. Here, one will find in general only one or two larger institution per country.

The second important feature is linked to the nature of the institution: one will find general universities as well as specialised ones – either technical, agricultural or veterinary universities. While roughly 51% are general universities, 15% are specialised ones. The second biggest group comprises research centres with 21%. The remaining 13% are hospitals, observatories, research councils, and companies.

Some differing patterns can be detected between countries. For example, the UK is dominated by general universities, but three firms also make it into the top 20 list of most actively publishing institutions in the UK.

In terms of quality, most of the institutions identified have aggregated field normalised citation impact scores above world average. This means that their research is highly competitive at the world level. Examining the evidence by fields, institutions show more variety. The yellow colour in table 5.5.1 and 5.5.2 shows in which fields institutions have published highly influential papers. One might be somewhat surprised finding primarily medical institutions also performing above average in engineering, or physics institutes performing in one of the life sciences fields. This is less surprising when one takes into account that a great part of research is interdisciplinary. Dentistry, for example, is more of a technical than medical field, and publications do not necessarily appear in specialised dentistry journals but also in engineering journals. Therefore, it comes to less of a surprise that the Dutch Academic Centre for Dentistry scores highly in the field of engineering despite the fact of being a centre for dentistry. The same is true for statistics, where several medical universities are strong. Of course, statistics is an important field for all epidemiological as well as clinical studies and therefore, these results will not only be published in medical but also in statistics journals. Still, one should bear in mind that sometimes only a very limited number of publications can outline excellence of an institution in a particular non-core sub-field.

Selection of institutions

The list of institutions covers various specialised and general universities as well as research institutes and firms. The selection criteria for these institutions and a further analysis of bibliometric indicators are based on a rather sophisticated choice: instead of adding all publications for a given institution, the publications have been broken down into 26 disciplines such as 'chemical engineering' or 'basic life science' (cf. the methodological annex to chapter 5). Within each of these fields, rankings have been produced. This method offers an advantage as it limits the bias towards large institutions (which tend to publish more than smaller or specialised ones). According to this method, an institution X can appear for example in discipline I as top performer, but in discipline II it does not appear at all, depending on its research focus. The calculations are based on publications in the period 1996-1999, and a lower threshold of 60 papers has been set per discipline in order to be included in the selection in these 26 disciplines. As one goal has been to identify the top performers at the national level, 20 institutions have been identified for the larger European Member States (D, E, F, I, NL, S, UK) and ten for the remaining smaller ones. For Luxembourg, no institute matched the selection criteria.

The absence of an institution's name in the final selection indicates that the institution is not amongst the most actively publishing in any discipline, or it does not meet the lower output threshold. This discipline-dependent selection criterion ensures that the larger institutions active in the less prolific disciplines (e.g. the engineering sciences) are also included. As the selection of these main research institutions has been based solely on their number of (co)authored research papers published in scientific and technical journals indexed by ISI, the institutions on this list do not necessarily have higher impact scores and/or higher productivity rates than those excluded from this selection.

In countries where research councils are strong, such as in France, Spain, and Italy, publications are frequently not attributed to the university but to the respective council. Especially in Spain and France, this tends to produce impressive numbers of publications for such research councils.

The method used has led to not only the large universities being mentioned as being among the most active ones, but also companies, specialised research centres and special universities. A glance at the names and types of institutions also reveals that the listed universities and research centres are not necessarily the largest ones within their countries, although they are of course of a certain size. Despite the fact of wide differences in terms of numbers of publications – the average publication figures for universities is more than ten times higher than those for research centres and firms – it is quite surprising that some companies made it into the group of most actively publishing institutions.

Table 5.5.1 Top 20 most important and actively publishing research institutions in large EU Member States

	Nr. of publications	Nr. of citations	Field norm. citation score	Agriculture & Food Sc.	Basic Life Sc.	Biological Sc.	Biomedical Sc.	Clinical Med.	Earth & Environ. Sc.	Engineering	Chemistry	Physics & Astronomy	Mathematics & Statistics	Computer Sc.
UK	P	C	I											
Astra Zeneca	1 846	11 732	1.36											
British Telecom	952	3 019	1.46											
Glaxo Wellcome Smithkline Beecham	4 395	49 550	1.93											
Loughborough Univ.	2 915	6 198	0.90											
NERC	1 809	10 378	1.33											
Rutherford Appleton Lab.	3 723	18 673	1.42											
Univ. Bristol	9 861	47 904	1.18											
Univ. Cambridge	26 486	197 887	1.55											
Univ. Edinburgh	13 818	89 077	1.35											
Univ. Glasgow	11 876	62 404	1.14											
Univ. Leeds	9 637	37 592	1.04											
Univ. London	85 182	550 278	1.29											
Univ. Manchester	16 816	76 277	1.03											
Univ. Nottingham	8 985	36 079	1.03											
Univ. Oxford	25 416	190 619	1.48											
Univ. Reading	4 604	14 888	0.95											
Univ. Sheffield	9 700	40 768	1.06											
Univ. Southampton	9 336	38 746	1.03											
Univ. Surrey	3 646	10 460	0.90											
Univ. Wales	14 029	49 505	0.90											
Germany	P	C	I											
DLR	1 707	4 252	1.00											
Free Univ. Berlin	10 830	55 210	1.00											
GSF-Res. Center for the Env. & Health	2 529	13 619	1.16											
GSI- Center for Heavy Ion Research	1 657	6 926	1.28											
Humboldt Univ.	8 947	31 676	1.01											
MPI for Extraterrestrial Physics	1 831	12 693	1.30											
Research Center Julich	6 301	28 812	1.34											
Siemens	1 100	2 380	0.98											
Tech. Univ. Aachen	7 946	24 648	0.95											
Tech. Univ. Munich	10 736	55 317	1.40											
Univ. Bielefeld	2 887	12 686	1.11											
Univ. Erlangen-Nurnberg	12 737	52 355	1.07											
Univ. Freiburg	9 476	63 142	1.34											
Univ. Heidelberg	13 111	86 313	1.32											
Univ. Karlsruhe	5 726	22 540	1.34											
Univ. Kiel	7 466	26 876	0.95											
Univ. Munich	16 208	83 477	1.05											
Univ. Stuttgart	5 083	17 183	1.24											
Univ. Wurzburg	9 210	49 742	1.11											
Vet. Med. School Hannover	1 515	3 445	0.67											
France	P	C	I											
CEA	14 782	72 269	1.21											
CNRS	23 784	130 105	1.19											
Ecole Natl. Vet. Toulouse	407	479	0.45											
France Telecom	1 142	4 740	1.56											
French Natl. Aerospace Research Off.	636	1 641	0.99											
INRA	11 428	42 148	0.86											
INSA	2 598	4 560	0.59											
INSERM	6 851	55 774	1.17											
Inst. Francais du Petrol	878	2 467	0.89											
Inst. Natl. Polytech. Lorraine	1 540	2 749	0.60											
Inst. Pasteur	7 249	79 379	1.39											

	Nr. of publications	Nr. of citations	Field norm. citation score	Agriculture & Food Sc.	Basic Life Sc.	Biological Sc.	Biomedical Sc.	Clinical Med.	Earth & Environ. Sc.	Engineering	Chemistry	Physics & Astronomy	Mathematics & Statistics	Computer Sc.
France	P	C	I											
Inst. Physique du Globe	880	4 179	0.96											
Observatoire Paris	2 594	12 301	0.94											
Univ. Grenoble 1	6 812	27 318	1.00											
Univ. Paris 11	16 265	75 822	1.06											
Univ. Paris 5	10 508	74 222	1.16											
Univ. Paris 6	22 154	100 372	0.98											
Univ. Paris 7	13 438	76 645	1.05											
Univ. Strasbourg 1	9 758	63 951	1.32											
Univ. Toulouse 3	7 493	28 941	0.92											
Italy	P	C	I											
CNR	18 833	66 626	0.85											
ENEA	1 313	2 400	0.62											
INFM	2 525	4 697	1.04											
INFN	9 199	38 311	1.17											
Inst. Natl. Super. Health	2 767	15 362	1.06											
Intl. School of Av. Studies, Trieste	1 715	8 243	1.17											
IRCCS	4 005	15 271	0.80											
Oberv. Astrophys. Arcetri	458	2 447	1.22											
Observ. Astronomy Rome	294	1 513	1.40											
Polytech. Milan	3 069	5 975	0.91											
Polytech. Turin	2 051	2 957	0.75											
Univ. Bologna	10 962	42 161	0.92											
Univ. Florence	8 209	35 149	1.04											
Univ. Genoa	6 617	24 003	0.84											
Univ. Milan	16 972	81 963	1.01											
Univ. Naples	9 789	32 813	0.74											
Univ. Padua	10 501	49 658	1.04											
Univ. Perugia	3 917	17 728	0.97											
Univ. Pisa	7 832	28 387	0.92											
Univ. Rome 1	13 402	47 422	0.81											
Netherlands	P	C	I											
Acad. Center for Dentistry, Amsterdam	491	1 662	0.94											
Catholic Univ. Nijmegen	9 648	50 840	1.05											
Delft Univ. of Technology	5 876	18 603	1.24											
Eindhoven Univ. of Technology	3 617	12 156	1.40											
Erasmus Univ.	8 995	65 171	1.32											
Free Univ. Amsterdam	8 689	51 638	1.22											
Leiden Univ.	12 585	86 682	1.25											
Nat. Ins. Physic. And High Energy Physics	873	6 219	1.87											
Natl. Inst. Public Health and Env.	1 991	12 137	1.30											
Netherlands Energy Res. Foundation	486	1 321	0.97											
Netherlands Institute Sea Research	698	3 238	1.31											
Philips	1 923	9 384	1.84											
State Univ. Groningen	10 257	57 480	1.18											
Tilburg Univ.	460	704	0.81											
TNO	3 079	17 709	1.05											
Univ. Amsterdam	12 851	77 345	1.25											
Univ. Maastricht	4 494	23 599	1.10											
Univ. Twente	3 182	10 506	1.34											
Univ. Utrecht	14 942	80 846	1.11											
Wageningen Univ. Research Center	9 556	40 850	1.17											

	Nr. of publications	Nr. of citations	Field norm. citation score	Agriculture & Food Sc.	Basic Life Sc.	Biological Sc.	Biomedical Sc.	Clinical Med.	Earth & Environ. Sc.	Engineering	Chemistry	Physics & Astronomy	Mathematics & Statistics	Computer Sc.
Spain	P	C	I											
Autonomous Univ. Barcelona	4 803	16 803	0.84											
Autonomous Univ. Madrid	6 723	32 918	0.99											
CSIC	16 133	50 681	0.86											
Hosp. San Pablo & Santa Cruz	870	3 264	0.84											
Inst. Astrofis. Canary Island	820	3 393	0.89											
Municipal Inst. Medical Investigations	250	803	0.93											
Polytech Univ. Madrid	1 953	3 475	0.75											
Polytech. Univ. Cataluna	2 476	4 558	0.85											
Res. C. for Energy and Env. Technology	635	3 928	1.99											
Univ. Zaragoza	3 807	8 655	0.76											
Univ. Barcelona	9 678	33 705	0.84											
Univ. Basque Country	3 564	7 789	0.68											
Univ. Carlos III Madrid	1 681	4 531	0.75											
Univ. Complutense Madrid	8 274	22 444	0.70											
Univ. Cordoba	2 194	4 919	0.58											
Univ. Granada	4 222	8 690	0.56											
Univ. Murcia	2 258	6 153	0.66											
Univ. Santiago de Compostela	3 866	8 983	0.69											
Univ. Sevilla	3 626	8 523	0.63											
Univ. Valencia	5 620	18 964	0.91											
Sweden	P	C	I											
Astra Hassle AB	597	3 040	1.11											
Chalmers Univ. of Technology	5 052	15 938	1.08											
Karolinska Inst.	15 434	116 900	1.22											
Lulea Tech. Univ.	903	1 505	0.97											
Nat. Vet. Inst.	389	1 302	0.96											
Onsala Space Observatory	141	669	0.96											
Orebro Hospital	555	2 801	1.03											
Royal Inst. of Technology	5 041	14 217	1.02											
Stockholm Observatory	206	924	1.18											
Swedish Inst. Space Physics	159	567	0.76											
Swedish Museum of National History	365	1 641	1.30											
Swedish Natl. Inst. for the Work. Life	338	338	0.76											
Swedish Pulp & Paper Research Inst.	235	409	1.02											
Swedish Univ. Agr. Sciences	4 537	15 781	0.97											
Umea Univ.	4 903	28 185	1.12											
Univ. Gothenburg	10 791	56 675	1.08											
Univ. Lund	16 341	83 179	1.07											
Univ. Stockholm	8 588	43 391	1.05											
Univ. Uppsala	13 438	70 035	1.08											
Uppsala Astronomical Observatory	178	1 286	1.35											

Source: DG-Research
Data: ISI, CWTS (treatments)
Note: Period for publications and citations 1993-1999, citations excluding author self-citations. The overall relative citation impact score represents the aggregate of all broad scientific fields. On the level of broad fields, only those institutions have been taken into account which surpassed an output threshold of at least 70 publications during the period. The colouring signals the following:

- most actively publishing institution in field by country
- at least 25 % of total publication output across the 11 broad fields is within the marked field
- highest number of citations in field by country
- impact above world average (≥ 1.20)
- highest impact score in country by field, but below 1.20

Third European Report on S&T Indicators, 2003

Table 5.5.2 Top 10 most important and actively publishing research institutions in smaller EU Member States

	Nr. of publications	Nr. of citations	Field norm. citation score	Agriculture & Food Sc.	Basic Life Sc.	Biological Sc.	Biomedical Sc.	Clinical Med.	Earth & Environ. Sc.	Engineering	Chemistry	Physics & Astronomy	Mathematics & Statistics	Computer Sc.
Belgium	P	C	I											
Belgian Nuclear Research Center	180	153	0.34											
Free Univ. Brussels (1)	10 538	53 564	1.07											
Inst. Tropical Med. Prince Leopold	702	3 640	1.28											
Interuniv. Microelec. Center, Leuven	959	1 917	0.88											
KUL Katholieke Univ. Leuven	15 420	68 876	1.07											
Limburg Univ. Center	765	2 527	1.04											
State Univ. Ghent	7 285	30 131	1.09											
UCL Univ. Catholique de Louvain	3 914	26 219	1.30											
Univ. Antwerp	5 133	25 083	1.20											
Univ. Liège	5 357	19 805	0.87											
Denmark	P	C	I											
Danish Inst. Agricultural Sciences	554	746	0.85											
Niels Bohr Inst.	1 311	7 193	1.42											
Riso Natl. Lab.	1 987	8 991	1.53											
Royal Danish School of Pharmacy	801	3 116	0.82											
Tech. Univ. Denmark	4 342	16 138	1.24											
Univ. Aalborg	986	2 299	1.06											
Univ. Aarhus	8 245	43 295	1.09											
Univ. Copenhagen	11 667	63 432	1.02											
Univ. South Jutland	3 425	17 204	1.04											
Vet. and Agr. Univ. Frederiksberg	2 716	8 415	0.92											
Finland	P	C	I											
Abo Academy Univ.	1 376	3 371	0.80											
Finnish Forest Res. Inst.	475	1 101	1.02											
Finnish Meterol. Inst.	306	1 020	0.92											
Helsinki Univ. Tech.	2 882	8 646	1.15											
Natl. Public Health Inst.	2 349	16 035	1.33											
Tampere Univ. Tech.	807	1 545	0.83											
Univ. Helsinki	13 446	81 531	1.29											
Univ. Jyvaskyla	1 677	3 997	0.82											
Univ. Kuopio	2 726	15 052	1.18											
Univ. Turku	5 948	25 876	0.95											
Austria	P	C	I											
Agro Univ. Vienna	1 224	4 527	1.02											
Tech. Univ. Graz	1 897	4 550	0.88											
Tech. Univ. Vienna	4 268	11 037	1.00											
Univ. Graz	4 383	17 698	0.89											
Univ. Innsbruck	5 505	27 342	1.03											
Univ. Linz	1 435	3 672	0.98											
Univ. Min. Metall Leoben	425	376	0.52											
Univ. Salzburg	703	2 229	0.73											
Univ. Veterinary Medicine Vienna	693	1 084	0.61											
Univ. Vienna	12 485	50 255	0.92											

	Nr. of publications	Nr. of citations	Field norm. citation score	Agriculture & Food Sc.	Basic Life Sc.	Biological Sc.	Biomedical Sc.	Clinical Med.	Earth & Environ. Sc.	Engineering	Chemistry	Physics & Astronomy	Mathematics & Statistics	Computer Sc.
Greece	P	C	I											
Agr. Univ. Athens	471	740	0.63											
Athens Natl. Observatory	183	304	0.53											
FORTH	1 403	4 609	0.88											
Tech. Univ. Athens	423	814	0.88											
NCSR Demokritos	1 601	4 509	0.90											
Univ. Athens	6 609	13 279	0.62											
Univ. Crete	2 044	6 763	0.76											
Univ. Ioannina	1 613	3 487	0.62											
Univ. Patras	2 576	4 451	0.54											
Univ. Thessaloniki	4 599	6 887	0.51											
Portugal	P	C	I											
Inst. Natl. Eng. Techn. Ind.	304	510	0.61											
Portuguise Inst. Oncology	166	463	0.64											
Tech. Univ. Lisbon	2 638	4 743	0.74											
Univ. Aveiro	802	968	0.71											
Univ. Catolica Portuguesa	233	300	0.55											
Univ. Coimbra	1 790	3 400	0.61											
Univ. Lisbon	2 141	6 338	0.88											
Univ. Minho	547	687	0.54											
Univ. Nova Lisbon	1 237	2 911	0.66											
Univ. Porto	2 422	6 183	0.74											
Ireland	P	C	I											
Beaumont Hospital	452	1 742	0.92											
Dublin City Univ.	908	2 926	1.00											
Dublin Inst. for Advanced Studies	288	858	0.74											
Limerick Univ.	314	431	0.70											
Natl. Univ. Ireland	5 054	14 842	0.88											
Royal College of Surgeons Ireland	427	2 014	1.11											
St. James Hospital	637	2 745	0.90											
St. Vincents Hospital	390	1 769	0.99											
TEAGASC	317	463	0.83											
Univ. Dublin	2 769	14 025	1.16											

Source: DG-Research
Data: ISI, CWTS (treatments)
Note: (1) Unfortunately, ISI makes no distinction in their database between the 'Université Libre de Bruxelles' and the 'Vrije Universiteit Brussel' . Both are categorised as the 'Free University Brussels' - despite the fact of being two separate universities. Therefore it is not possible to calculate separate publication figures for the two universities.
Period for publications and citations 1993-1999, citations excluding author self-citations. The overall relative citation impact score represents the aggregate of all broad scientific fields. On the level of broad fields, only those institutions have been taken into account which surpassed an output threshold of at least 70 publications during the period. The colouring signals the following:

- most actively publishing institution in field by country
- at least 25 % of total publication output across the 11 broad fields is within the marked field
- highest number of citations in field by country
- impact above world average (≥ 1.20)
- highest impact score in country by field, but below 1.20

Third European Report on S&T Indicators, 2003

European co-publishing top ten

The mentioned institutions were subjected to a further limited co-publishing analysis. The "universe" of possible co-publications was the whole group of 210 institutions. Results from table 5.5.3 confirm the assumption already outlined in section 4 that the size of a publishing institution matters a lot for the amount of co-publications. Only very large universities from four countries, the UK, France, Italy, and Sweden, make it into a European-wide list of top 10 institutions. Within the group of specialised universities, Swedish, German, Austrian, Dutch, and Portuguese universities are covered. While it gets even more international within the group of research institutes, it is the opposite for firms. Here only a limited number of multinational firms from the UK, Sweden, France, the Netherlands and Germany can be found.

Table 5.5.4 gives an overview of the largest actively publishing institutions in the Member States. This comparison reveals the different sizes very well: while the largest university in the UK is the University of London with almost 24 000 co-publications, the largest in Ireland, the National University of Ireland, reaches about 1 300 co-publications.

Table 5.5.3 Top 10 most actively co- publishing institutions in EU-15 by number of co-publications (1996-1999)

Universities	Nr. Co-P	Specialised Universities	Nr. Co-P	Research Centres	Nr. Co-P	Firms	Nr. Co-P
Univ London	23 898	Karolinska Inst	6 681	INFN Natl Inst Nucl Phys	15 967	Glaxo Wellcome SKB	1 666
Univ Paris 06	11 897	Tech Univ Aachen	4 953	Rutherford Appleton Lab	9 727	Astra Zeneca	797
Univ Oxford	11 399	Univ Karlsruhe	4 291	Nikhef	5 595	Philips	747
Univ Paris 11	10 864	Agr Univ Vienna	3 045	NCSR Demokritos	5 149	Astra Hassle AB	433
Univ Milan	10 619	Tech Univ Munich	2 715	Niels Bohr Inst	5 128	Siemens	227
Univ Bologna	10 198	Chalmers Univ Technol	2 394	CEA	5 059	France Telecom	194
Univ Paris 07	9 557	Wageningen Univ Res Ctr	2 360	Inst Pasteur	2 637	British Telecom	128
Univ Lund	8 931	Royal Inst Technol	1 833	Res CTR Julich	2 215		
Univ Padua	8 606	Tech Univ Lisbon	1 707	Inserm	2 149		
Univ Uppsala	8 280	Delft Univ Technol	1 510	Inst Natl Super Hlth	2 023		

Source: DG-Research
Data: ISI, CWTS (treatments)

Third European Report on S&T Indicators, 2003

Table 5.5.4 Most actively co- publishing institutions by Member State (1996-1999)

	Universities	Nr. Co-P	Specialised Universities	Nr. Co-P	Research Centres	Nr. Co-P	Firms	Nr. Co-P
B	Free Univ Brussels	7 126	Interuniv Microelect CTR	408	Inst Trop Med Prince Leopold	326		
DK	Univ Copenhagen	3 981	Tech Univ Denmark	1 128	Niels Bohr Inst	5 128		
D	Univ Heidelberg	7 153	Tech Univ Aachen	4 953	Res CTR Julich	2 215	Siemens	227
EL	Univ Athens	4 721	AGR Univ Athens	137	NCSR Demokritos	5 149		
E	Univ Valencia	4 059	Polytech Univ Cataluna	688	Inst Mun Invest Med	204		
F	Univ Paris 06	11 864	Ecole Natl Vet Toulouse	91	CEA	5 059	France Telecom	194
IRL	Natl Univ Ireland	1 328	Royal Coll Surgeons	393	Teagasc	128		
I	Univ Milan	10 619	Int Sch Adv Stud Trieste	1 055	INFN Natl Inst Nucl Phys	15 967		
NL	Univ Amsterdam	7 916	Wageningen Univ	2 360	Nikhef	5 595	Philips	747
A	Univ Innsbruck	2 957	Agr Univ Vienna	3 045				
P	Univ Lisbon	3 648	Tech Univ Lisbon	1 707	Inst Nacl Eng Tecn Ind	267		
FIN	Univ Helsinki	6 383	Helsinki Univ Technol	788	Natl Publ Hlth Inst	1 872		
S	Univ Lund	6 931	Karolinska Inst	6 681	Swed Natl Inst Working Life	307	Astra Hassle AB	433
UK	Univ London	23 898			Rutherford Appleton Lab	9 727	Glaxo Wellcome SKB	1 666

Source: DG-Research
Data: ISI, CWTS (treatments)

Third European Report on S&T Indicators, 2003

Conclusions

This chapter has considered the evidence on the production of scientific publications, and their impacts through citations. It has analysed developments in specific scientific fields, and has studied the patterns of cooperation across world regions and between countries. Finally, it has considered the issue of European scientific specialisation, and has investigated the most productive European scientific organisations.

What, then, can be concluded for worldwide trends? This concluding section provides a brief re-cap of the main trends by region.

Regional developments – a re-cap

The changes in numbers of publications and world shares signal significant changes in innovation systems worldwide:

EU-15

Although the picture across wider Europe is diverse, the EU-15 is now the best performing world region in terms of number of publications. In terms of numbers of publications as well as world share, the EU-15 have gained in the latter half of the 1990s, and surpassed NAFTA in 1997.

It is of course possible to challenge these conclusions by asserting that the enlargement of the EU to 15 Member States has had an effect on the number and share of publications. One might also add that changes to the SCI databases have proved to be positive for most countries other than the US, as the bias for the US is now becoming less and less strong.

It would be interesting to note whether the growth in European publication output coincides with an increase in citation impact. As indicated in the above discussion of US citation rates, the time lapse between publishing and receiving substantial numbers of citations must be considered. Depending on the field, this time lapse may vary from 2 to 10 years or more. Therefore, it remains to be seen if the surge in European publications will lead to a similar rise in citation impact scores in the long run.

Eastern Europe and EFTA

The picture is bleaker for the eastern European countries. While the world share of publications produced by Russia and the Ukraine decreased by 1.8% between 1995 and 1999, by contrast the candidate countries were able to increase their share by 4.3%. It seems that they are on their way to regaining their science base after the breakdown of the former Soviet Union and the loss of scientific partners in the late 1980s.

This gain may be attributed, to a large extent, to the European framework programmes and the ability for Candidate countries' to participate, whereas Russia and the Ukraine lack this possibility. Nonetheless, the candidate countries have smaller publication numbers and weaker relative citation impact scores than most Asian countries on the broad field level. Even compared to the India/Pakistan region, Russia and the Ukraine attain only low relative citation impact scores in most broad fields. This comparatively poor performance also stems from their traditional scientific culture, in which publishing in English-language international scientific and technical journals was a relatively novel phenomenon in the 1990s.

The other European extreme is EFTA. The particularly high citation impact in the life sciences stems predominantly from the Swiss research base (including its science-based pharmaceutics and chemicals industries), but may also be explained in part by the Icelandic push of R&D activities in the basic life sciences, especially genetics.

Asia

Asian countries are now proving to be willing and capable of conducting more basic research. It is evidenced by their numbers of scientific publications, which increased both in absolute terms during the 1990s, and generally at high rates of growth, particularly in the second half of the 1990s. Barring Japan, all the Asian contributors have relatively small publication bases and are thus more easily capable of realising very high growth rates.

The four developed Asian countries (Japan, Korea, Singapore and Taiwan) form the third largest regional bloc in terms of world publication output. The ASEAN-4 countries (Indonesia, Malaysia, the Philippines and Thailand), along with China and Hong Kong, generally show very high publication growth rates, while those of India and Pakistan remain relatively small. The impact of publications is fairly high in most broad fields of the developed Asian countries. While the developed Asian countries still have a strong engineering basis, their scientific trajectories have begun to broaden from the more applied to the more basic-oriented fields.

North America

The picture is diverse for the Americas. Traditionally the most self-contained research system, the US has been losing ground in recent years in terms of total publications output. It is losing world share, and has surprised with its overall growth rate of around zero. Canada's share is also declining, while Mexico's very small share is rising.

This rather bleak picture changes when looking at performance in individual scientific fields, and at citation impact. Here, the US decline in the number of publications has not been coupled with a decline in citations, as it scores impressive relative citation rates in almost all fields. However, some of this can be put down to the high levels of indigenous citations. Moreover, the US remains the most attractive scientific partner for almost all other countries and in most disciplines.

The explanations for the changes in US data are numerous. One such explanation is that the number of citations and the citation impact depend to a larger extent on older papers. For this analysis the citation window has been rather long dating back to 1993-1999, allowing for a larger number of citations for older papers – and of course the number of publications from the first half of the 1990s is comparably high.

Changes in science and technology policies may also have had a significant impact: a policy of more restricted public funding, the drive from basic research to basic-oriented research, and the financial implications of a vigorous technology transfer policy are all incentives for applications. In turn they can lead to higher citation rates. This shift can be observed, in particular, in the surge of clinical research within the life sciences and in the overall increasing figures for university patents. However, these incentives may have had a negative impact on the publication habits and actual output figures in these disciplines, where patenting is a more attractive option. Changes in public R&D funding may be another reason for the changes in US data. It is most likely that all the above factors have an impact. Their various degrees of impact are yet to be analysed.

Australia and New Zealand

Australia and New Zealand form another world region, which is relatively small in terms of world publication share. While the publication growth rate remains below 1%, the scientific impact of publications from Oceania is relatively high. Despite a geographically peripheral location, Australia and New Zealand's scientific publications may profit from a language advantage, given the predominance of English-language journals in the database and easy access to scientific networks in the major English-speaking scientific nations, such as the US, the UK and Canada.

Selected Bibliography

Arora, A. et al. (1999) 'The Indian software services industry', *Heinz School working paper*, 99/19**,** Carnegie-Mellon University, Pittsburgh, November 1999.

D'Costa, A. P. (2001) 'Asia, Asian Diaspora, and the Digital Divide', *Paper presented at the 2001 Internet Political Economy Forum (IPEF) Conference*, National University of Singapore, Singapore, September 14-15, 2001.

deB Beaver, D. (2001) 'Reflections on scientific collaborations (and its study): Past, present and prospective', *Scientometrics*, 52**,** pp. 365–377.

deB Beaver, D., Rosen, R. (1979) 'Scientific co-authorship, research productivity and visibility in the French elite', *Scientometrics*, 1, pp. 133–149.

deB Beaver, D., Rosen, R. (1978) 'Studies in scientific collaboration, Part I. The professional origins of scientific co-authorship', *Scientometrics*, 1**,** pp. 65–84.

European Commission, Directorate-General for Research (1997) *Second European Report on Science and Technology Indicators*, Report EUR 17639, OPOCE, Luxembourg.

European Commission (EU) (2001) '*Benchmarking industry-science relations – the role of framework conditions*', Reasearch Project commissioned by EC, Enterprise DG and Federal Ministry of Economy and labour, Austria, Final Report, Vienna/Mannheim.

Glänzel, W. (1995) 'International scientific collaboration in a changing Europe, A bibliometric analysis of coauthorship links and profiles of 5 East-European countries in the sciences and social sciences, 1984-1993', *Science and Science of Science*, 4**,** pp. 24-31.

Henderson R., Jaffe A.B., Trajtenberg, M. (1998) 'University patenting amid changing incentives for commercialization', in: *Creation and transfer of knowledge. Institutions and incentives*, Navaretti G.B. Barba, Dasgupta P., Mäler K.-G. and Siniscalco D. (eds), Springer, Berlin, 1998, pp 87-110.

Katz, S. (2000) 'Scale dependent indicators and research evaluation', *Science and Public Policy*, 27, 1**,** 2000, pp. 23-36.

Lewison, G. (1991) 'The advantages of dual nationality', *New Scientist*, 4.5.1991.

Luukkonen, T., Persson, O., Silvertsen, G. (1992) 'Understanding patterns of international scientific collaboration', *Science, Technology & Human Value*s, 17, pp. 101-126.

Malkamäki, U. et al. (2001) *Centre of excellence policies in research, Aims and practices in 17 countries and regions*, Academy of Finland, 2/01, Finland.

May, R. (1997) 'The scientific wealth of nations', *Science*, 275, 7 February 1997, pp. 793-796.

Moed, H.F. , De Bruin, R.E. and van Leeuwen Th.N. (1995) 'New bibliometric tools for the assessment of national research performance: database description, overview of indicators and first applications', *Scientometrics*, 33 (3), pp. 381-422.

National Science Board (NSB) (2000) *Science and Engineering Indicators, 2000*, National Science Foundation, Arlington VA (NSB-00-1).

Okubo, Y. (1997) *Bibliometric indicators and analysis of research systems: methods and examples*, STI Working Papers 1997/1, OCDE/GD(97)41, Paris.

Pritchard, A. (1969) 'Statistical bibliography or bibliometrics', *Journal of Documentation*, 24, pp. 348-349.

Schubert, A., Braun, T. (1990) 'World flash on basic research: International collaboration in the sciences, 1981-1985', *Scientometric*s, 19, pp. 3-10.

van Leeuwen, Th.N. , Moed H.F. , Tijssen R.J.W., Visser M.S. and van Raan A.F.J. (2001) 'Language biases in the coverage of the Science Citation Index and its consequences for international comparisons of national research performance', *Scientometrics*, 51 (1), pp. 335-346.

van Raan, A.F.J. (1996) 'Advanced bibliometric methods as quantitative core of peer review based evaluation and foresight exercises', *Scientometrics* 36 (3), pp. 397-420.

Weinstock, N. (1971) 'Citation indexes', in: *Encyclopedia of Library and Information Science*, Kent, A. (ed.), Marcel Dekker, New York, Vol. 5, pp.16-41.

DOSSIER IV
The importance of Nobel Prizes as S&T indicators

The second European Commission Report on S&T Indicators included a quantitative analysis of Nobel Prize awards. On the occasion of the 100th anniversary in 2001 of the Nobel Prizes, the Commission decided to incorporate in this report a qualitative analysis of Nobel Prizes in science in order to determine whether the system used over the past 100 years for awarding these Prizes could be used as an indicator of the state of S&T worldwide.

The concept of the Nobel Prize reflects European ideas of the late nineteenth century, rather than the twentieth. Alfred Nobel was a man of his time, and his will of 1895 consolidated in legal form a number of ideas on progress, science and culture, which have been carried through the twentieth century into the twenty-first century. Now, a hundred years on, these *fin de siècle* ideas are still strong and vivid, largely due to the annual award of the Nobel Prizes. Despite other prizes, such as the Japan Prize, the Balzan Prize, le prix Goncourt, the Pulitzer Prize, the Fields Medal, the MacArthur Fellowship and others, which have tried to emulate it, the Nobel Prize has retained its prestigious position, and has been called "the strongest brand name in the world".

The Nobel Prizes are prestigious for a number of reasons: firstly, they are international; secondly, the extensive nomination and evaluation process has created credibility, not least because international expertise is employed for both nomination and evaluation; thirdly, the first prizes were awarded to accredited and renowned scientists, which gave the prizes a good reputation from the outset. The prizes generally have – whatever the critics may say – "a good track record". Winning the Nobel Prize means that one's name is added to a list that becomes more distinguished with each passing year. Today it includes such giants as Albert Einstein, Marie Curie, Barbara McClintock, Linus Pauling, James D. Watson and Richard Feynman. Fourthly, the prizes have been large. The only prize that exceeds a Nobel Prize in value today is the Le Prix Louis-Jeantet de Médecine, instituted in 1952, which in 2001 was worth $1.04 million. It, however, is a single prize per annum, unlike the five Nobel Prizes[1].

Section I Nobel prizes as S&T indicators

A closer look at the history of the science Nobel Prize awards might contribute to developing a methodology for evaluating the awards as an indicator of the state of S&T worldwide. Such a methodology might prove valuable in the shaping of future decisions concerning European science policy, and, in particular, in enhancing the scientific excellence of European human capital. The point of departure for the following qualitative discussion is a description of the system of nominating, evaluating and selecting Nobel Laureates in the sciences. The basic assumption is that any attempt to develop a methodology for using Nobel Prizes as S&T indicators must be based on a full understanding of how this system works; if not, the use of Nobel Prizes as S&T indicators might prove to be counterproductive.

The information conveyed in the announcement of a Nobel Prize in the sciences is, "Professor X from the University of Y has been awarded the Nobel Prize in Physics for his outstanding contributions to the field of Z". This merely indicates that at a specific moment an individual, working at a specific institution in a specific nation, has been awarded the highest scientific recognition for his or her contributions to a specific field of Physics (or Chemistry, or Medicine). What general conclusions can be drawn from this information when all these awards are studied together over a longer period? Firstly, it appears likely that it would be possible to identify which scientific fields are the most dynamic at present, information which might be useful in deciding on the allocation of R&D resources. Secondly, it may also be possible to identify which nations are the most advanced and successful in R&D, thus enabling an analysis of the reasons for their success to be carried out with the hope of replicating them.

[1] *A list of all the Nobel Symposia and their proceedings can be found at: www.nobel.se/nobel/nobel-foundation/publications/symposia/complete-list.html*

SECTION II THE NOBEL SYSTEM: AN OUTLINE

During the first hundred years of the Nobel Prize (1901–2001), 685 Prizes were awarded to individuals or institutions. Despite the statutes allowing both the Physics and the Chemistry Nobel Prize to be given to an institution, for example, CERN in Geneva, the only Prize that has been awarded to an institution is the Peace Prize, which has been given to bodies such as the Red Cross, the United Nations and the Campaign to Ban Land Mines. During the years 1969–2001, 49 individuals have also received the Bank of Sweden Prize in Economic Sciences to the Memory of Alfred Nobel (usually referred to as the "Economics Prize"). The total sum of Prizes so far is thus 734.

The Nobel Foundation, established in 1900, is a private institution, and its main task is the financial management of the Nobel capital. However, the Foundation is not involved in either the nomination and evaluation process, or the final choice of the Laureates. These are the responsibilities of the Prize Awarding Institutions, and these institutions are entirely independent of all Swedish and Norwegian governmental and non-governmental agencies and organizations – including the Nobel Foundation. The autonomy of the Prize Awarding Institutions is of crucial importance to the objectivity of their prize decisions, and hence also to the prestige of the Nobel Prize. The Nobel Foundation and the Prize Awarding Institutions together constitute what is usually referred to as "the Nobel System". The Prize Awarding Institutions for the science prizes are the following:

– The Royal Swedish Academy of Sciences, which was founded in 1739 on the model of the Royal Society in London, and which today has about 350 Swedish members. It awards the Nobel Prizes in Physics and in Chemistry and, has in addition, since 1969, been entrusted with awarding the Economics Prize;

– The Nobel Assembly at the Karolinska Institute (the medical school in Stockholm, founded in 1810), which has 50 members, awards the Nobel Prize in Physiology or Medicine (usually referred to as the "Nobel Prize in Medicine").

For their preparatory work, the Prize Awarding Institutions have special Nobel Committees, each consisting of five members (i.e., for the science prizes: a Physics Committee, a Chemistry Committee, and a Medicine Committee).

SECTION III THE AWARDING PROCESS: NOMINATIONS AND EVALUATIONS

Every year, each Committee sends out personal invitations to thousands of individuals all over the world asking them to nominate candidates for the Nobel Prize for the coming year. These individuals are university professors, members of academies and learned societies, and other scholars, as well as all previous Laureates. About half of those invited in any one year are approached to submit nominations every year, and about half are new. The nominations must reach the Nobel Committees before 1 February in the year for which the nomination is being made. Only persons who have been nominated by this process may be awarded a Nobel Prize.

The nominations are then evaluated by the Committees with the help of specially appointed Swedish and foreign experts, thus making the selection of Nobel Prize Laureates truly international. Not only is the nomination process international, but international experts are also used to evaluate the merits of different candidates and to compare their achievements. This aspect of the Nobel Prizes makes them useful as an indicator of the state of S&T worldwide, as they reflect an international assessment.

The Nobel Committees for the science prizes do not evaluate achievements in only one field of a particular discipline each year. Their deliberations involve a continuous process of monitoring and evaluating several fields at the same time. The Prize for a specific year will be awarded on the basis of the highest merit in one of the most important and dynamic current fields.

When the various Nobel Committees have decided who the candidates are, how the Prizes should be divided between them and how the citations should read, their recommendations are presented to the Prize Awarding Institutions, who take the final vote. In the case of the Physics Prize and the Chemistry Prize, the recommendations of the Committees are first discussed in the Physics class and the Chemistry class of the Royal Swedish Academy of Sciences. The members of the Academy gather in early October each year to cast their votes on the Laureates in Physics and Chemistry (as well as in Economics), and during the same week the members of the Nobel Assembly at the Karolinska Institute cast their votes on the Laureate in Medicine. After the votes are counted, the slips are burned and no records are kept of the numbers or of any discussions preceding the final vote. This is so that when the current year's selection of Nobel Laureates is announced to the media, the Prize Awarding Institution's decision appears to be unanimous.

There have been occasions when the Prize Awarding Institution has overruled the proposal of the Committee. The 1912 Physics Prize, for example, was awarded to the Swedish inventor Gustaf Dalén, whereas the Physics Committee had suggested that it should be awarded to the Dutch physicist Heike Kamerlingh Onnes (who received it the following year). These cases have become known through sources other than the archives of the Nobel Committees (e.g. leakage through private correspondence in a public archive).

Section IV Nobel prizes as an indicator of dynamic fields

The description of how the Nobel Laureates are nominated, evaluated and selected is of crucial importance to a discussion on the potential usefulness of Nobel Prizes as S&T indicators, especially if they are to be used to identify the most dynamic fields. As mentioned above, the various Committees examine a number of fields simultaneously in the area of their prize (i.e. Physics, Chemistry or Medicine). The identity of these fields, the nominators, the nominees and the evaluation experts will, unfortunately not be revealed until the archives of the Nobel Committees are opened to scholars 50 years from now, at a time when this information is no longer of any interest to present-day policy makers.

It is thus not possible on the basis of the awarding of a Nobel Prize in a specific field in any one year to conclude that this is currently *the* most dynamic of all fields in the discipline. Instead, the awarding of a Nobel Prize within a specific field merely tells us that this is one of several dynamic fields studied closely by the Nobel Committee, and one in which the questions of merit and priority have been evaluated to the satisfaction of the Committee and the Prize Awarding Institution. Nevertheless, taken over a five-year period, the fields in which Prizes have been awarded during this time should give a fair indication of which the most dynamic fields are.

Another complication is that the Nobel Prizes in science are usually awarded 10 to 20 years after the research breakthroughs have been made, an interval that has been subject to some criticism. The delay in recognising outstanding research reflects a natural caution on the part of the Nobel Committees not to reward anything of dubious merit. It often takes some time to confirm new findings, or their significance does not become clear until much later. Recently, the interval between a breakthrough and a Nobel Prize award has been increasing, a trend that reflects the growth and specialization of science during the 20th century.

The time lag between the achievement and the awarding of the Nobel Prizes further diminishes their usefulness as an S&T indicator so that they cannot form the basis for short-term policy decisions on which sub-fields to support. However, if the shift between larger areas over a 10- or 20-year period is studied, the Prizes for Physics, Chemistry and Medicine may be useful S&T indicators for more general policy-decisions.

A positive aspect of the Nobel Prizes which serves as a possible indicator of where the most dynamic fields are to be found is the 5 or 6 annual *Nobel Symposia* (NS) supported by the Nobel Foundation since 1965. These are devoted to areas of science "where breakthroughs are occurring", or deal with other topics related to the Prizes in Literature, Peace and Economics. They are small, international symposia to which 25 to 30 of the leading experts in a field are invited, and whose proceedings are as a rule published within a year.

The Nobel Symposia are part of the larger screening process engaged in by the Nobel Committees, and as a Nobel Prize is often awarded within a field that was the topic of a Nobel Symposium 3–4 years earlier, it is rare for anyone invited to a Nobel Symposium not to attend. Scientists who have benefited from these symposia include Ahmed H. Zewail, who received the 1999 Nobel Prize in Chemistry "for his studies of the transition states of chemical reactions using femtosecond spectroscopy" following a Nobel Symposium on Femtochemistry and Femtobiology in 1996; and Zhores I. Alferov and Herbert Kroemer, who received the 2000 Nobel Prize in Physics "for developing semiconductor heterostructures" following a Nobel Symposium on "Heterostructures in Semiconductors" in 1996. The recent Nobel Symposia could therefore be used as S&T indicators of which scientific fields are the most dynamic today and this information would probably be more up-to-date than the Nobel Prizes themselves.[1] The following is a list of the topics dealt with by the Nobel Symposia in Physics, Chemistry and Medicine during the period 1995–2001, including the Nobel Centennial Symposia (NCS) during the centennial year 2001.

- Physics
  "Barred Galaxies and Circumnuclear Activity" (1995, NS 98)
  "Heterostructures in Semiconductors" (1996, NS 99)
  "Modern Studies of Basic Quantum Concepts and Phenomena" (1997, NS 104)
  "Particle Physics and the Universe" (1998, NS 109)
  "Quantum Chaos Y2K" (2000, NS 116)
  "Condensation and Coherence in Condensed Systems" (NCS 2001-1)
- Chemistry
  "Catalytic Asymmetric Synthesis" (1995, NS 97)
  "Femtochemistry and Femtobiology: Ultrafast Reaction Dynamics at Atomic-Scale Resolution" (1996, NS 101)
  "Frontiers of Molecular Science" (NCS 2001-2)
- Medicine
  "The Nature - Nurture Controversy" (1995, NS 94)
  "Functional Organization of the Eukaryotic Cell Nucleus" (1996, NS 100)
  "Towards an Understanding of Integrative Brain Functions. Analyses at Multiple Levels" (1997, NS 103)
  "Intracellular and Persistent Infections" (1998, NS 106)
  "Schizophrenia: Pathophysiological Mechanisms" (1998, NS 111)
  "Estrogens and Women's Health - Benefit or Threat?" (1999, NS 113)
  "Prevention and Treatment of Tuberculosis in the Coming

Century" (2000, NS 114)
"Global HIV Therapeutics - HIV Vaccines" (2001, NS 119)
"Beyond Genes" (NCS 2001-3)

– Interdisciplinary
"The Physics and Chemistry of Clusters" (2000, NS 117)

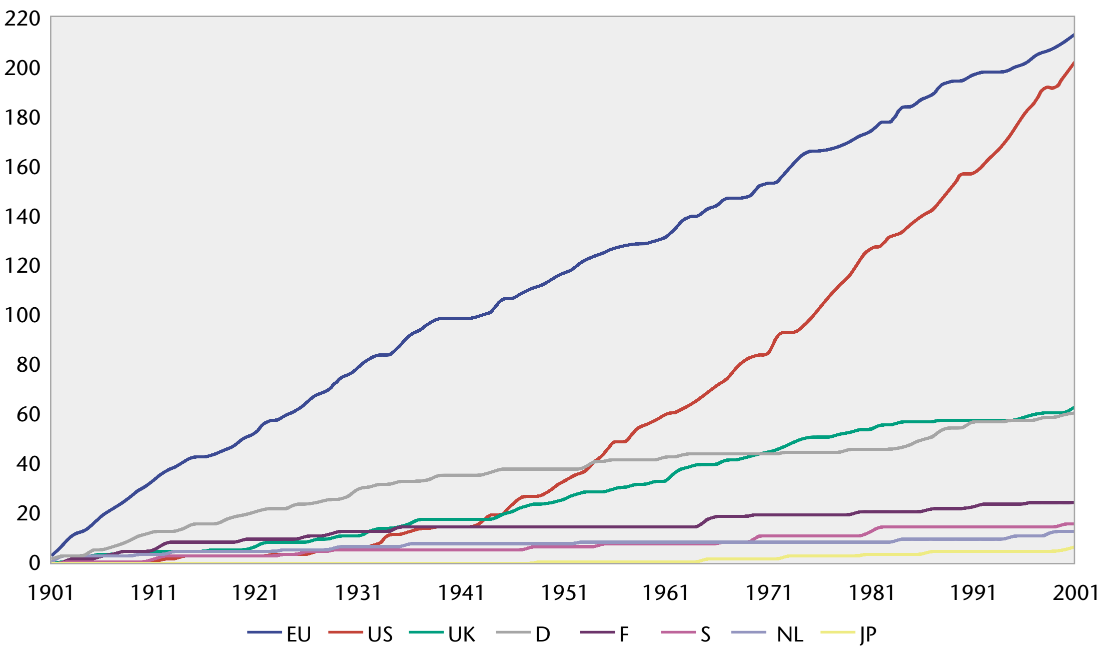
Section V Nobel prizes as S&T indicators of national merit: brain drain vs. brain gain

The Nobel system has always been opposed in principal to national comparisons. However, since their inception, the Nobel Prizes have been regarded in the same way as the great World Exhibitions and the Olympic Games, where the number of gold medals is totalled to give a ranking order among nations. This is hardly surprising, because these institutions spring from the same conceptual world of the late 19th century. In some countries, Nobel Prizes are treated as a yardstick of the country's scientific and cultural level. For example, in the new Science and Technology Basic Plan, adopted by the Japanese Government in 2000, it was stated quite unambiguously that the aim was to strengthen government investment in basic research so that Japan would gain at least 30 Nobel Prizes in the next 50 years. Malaysia set a more modest goal in 2001, when the Prime Minister challenged the scientific community to produce a Nobel Laureate in science by the year 2020.

More than three-quarters of all Nobel Laureates in the sciences have come from the US, the UK, France or Germany (cf. figures D4.5.1 – D4.5.4). This does not mean, as some critics have claimed, that the Nobel system has consciously ignored Africa, Asia and Latin America. It has simply tried to observe the provision of the will, that "no consideration be attached to any sort of national allegiance so that the most worthy receives the prize, whether he is a Scandinavian or not".

The geographical distribution of the science Nobel Prizes largely reflects the distribution of the great research centres of the 20th century. Some interesting changes during that century included a shift in emphasis from a European-dominated research environment (until the late 1930s), to the rise of the US (from about 1940 onwards).This swing was due to the wave of refugees fleeing to the US prior to the outbreak of World War II. This pattern has become less distinct in recent decades, beginning with the award of the first Nobel Prize to Japan in 1949 (in Physics to Hideki Yukawa). Changes in the geographical distribution of the Nobel Prizes in the 20th century are worthy of a major research project in themselves.

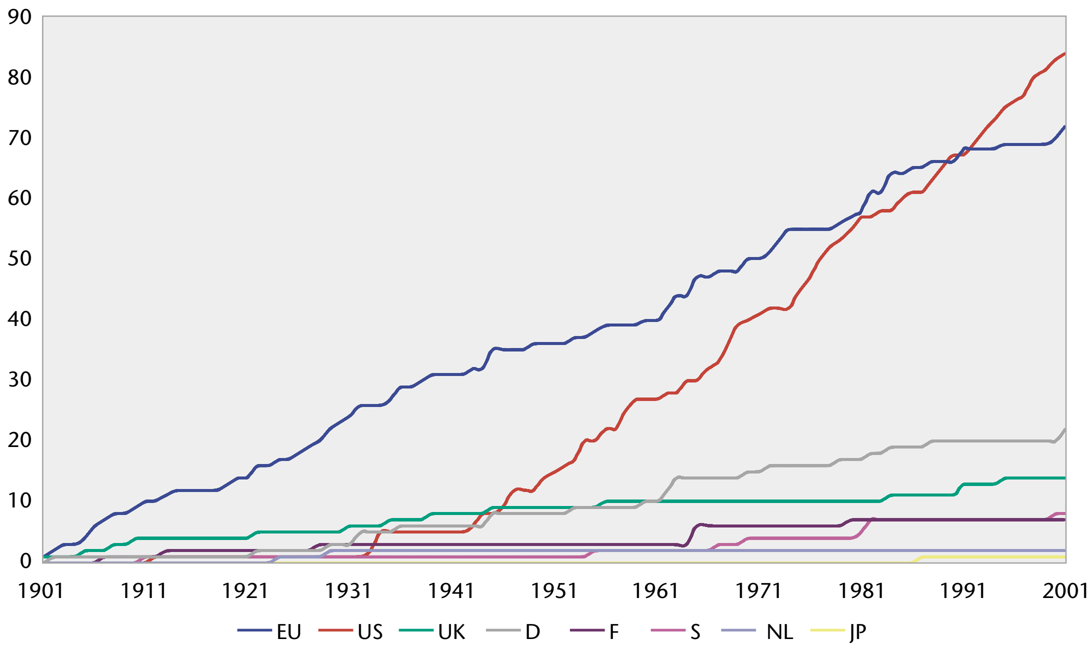
Figure D4.5.1 Distribution of Nobel Prizes in three scientific disciplines (Chemistry, Physics and Medicine) by selected countries (1901-2001) – cumulative total



Source: DG Research
Data: Nobel Prize Foundation
Note: No Nobel Prizes have been awarded between 1940 to 1942.

Third European Report on S&T Indicators, 2003

Figure D4.5.2 Distribution of Nobel Prizes in Medicine by selected countries (1901-2001) – cumulative total



Source: DG Research
Data: Nobel Prize Foundation
Note: No Nobel Prizes have been awarded between 1940 to 1942.

Third European Report on S&T Indicators, 2003

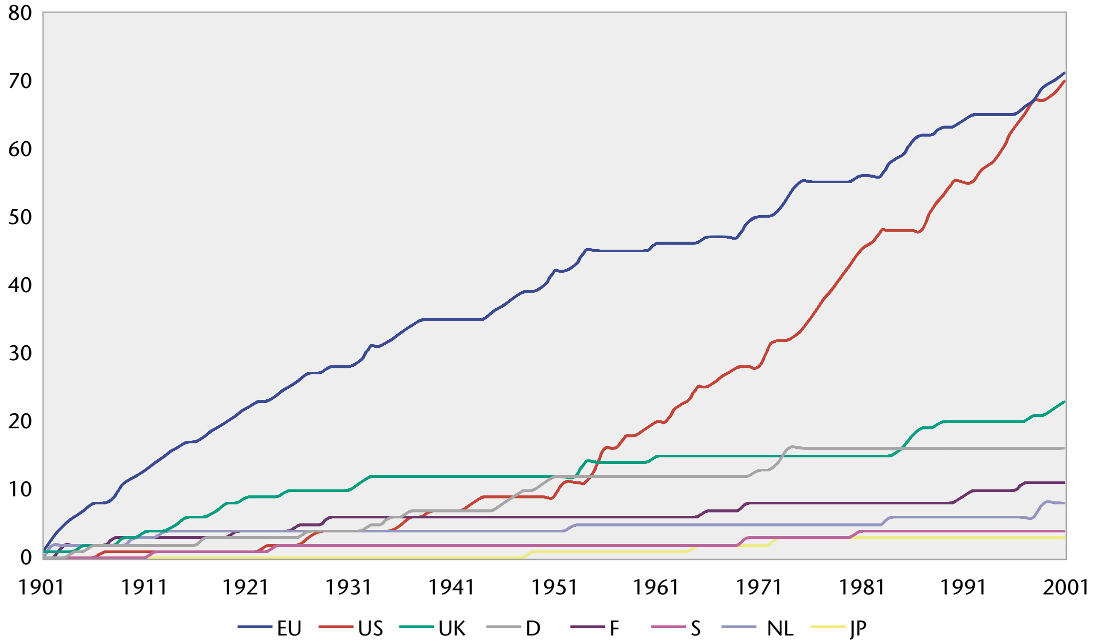
As part of the Nobel Centennial Exhibition "Cultures of Creativity", the Nobel Museum, in co-operation with the Department of Human Geography at Lund University, produced a database containing the biographical details in *Les Prix Nobel* on the mobility of all Nobel Laureates (year and place of birth, education, university education and academic positions). Although major patterns, such as the shift from Europe to the US in the late 1930s, can be illustrated by this database, the biographical information is too inconsistent to form the basis for any more substantial analysis.

Using the nationality of Nobel Laureates to make deductions about S&T indicators is fraught with difficulty, as many of the recipients have had different nationalities during their careers. (The Nobel Foundation, wisely perhaps, only acknowledges nationality at birth and nationality at the time the prize is awarded). In many cases, a scientist was born and received his or her early education in one nation, received a university education in another, done ground-breaking work in a third, and been in a fourth when the Prize was awarded. Ernest Rutherford (Nobel Prize in Chemistry, 1908) and Albert Einstein (Nobel Prize in Physics, 1921) are good examples. Rutherford was born and educated in New Zealand, did much of his most important work in Montreal and in Manchester, before moving to Cambridge in the UK. The four universities he attended all claim him as their Nobel Laureate. Einstein was born and received his early education in Germany; went to university in Switzerland, where he also did much of his important early work; resigned his German citizenship to become a Swiss citizen; became a Professor in Prague, then a Professor at ETH in Switzerland; and later a Professor in Berlin. When he received the Nobel Prize, although a native German working in Germany, he was a Swiss citizen. He left Germany for the United States after the Machtübernahme in 1933. Retaining his Swiss citizenship, he later became a US citizen and spent his last 22 years in that country.

Nationality, on its own, is therefore in many cases of little use as an S&T indicator, and although the nation where the award-winning work was done must receive due recognition, other criteria, such as scientific training, university education and early education obtained in other nations, should also be taken into account.

Although there appears to be a fairly simple correlation between a nation's wealth and/or the percentage of the GNP spent on R&D and the number of Nobel Prizes in science awarded to its citizens, this is not always the case. Japan, for example, is a nation which in spite of its heavy investment in R&D has comparatively few science Nobel Laureates. The educational system, cultural traditions and social climate of a country obviously also play an important role. Economic resources are (or at least were) no guarantee of scientific achievements worthy of a Nobel Prize, as illustrated by the relatively simple equipment and meagre resources with which some of the Laureates did their ground-breaking work,

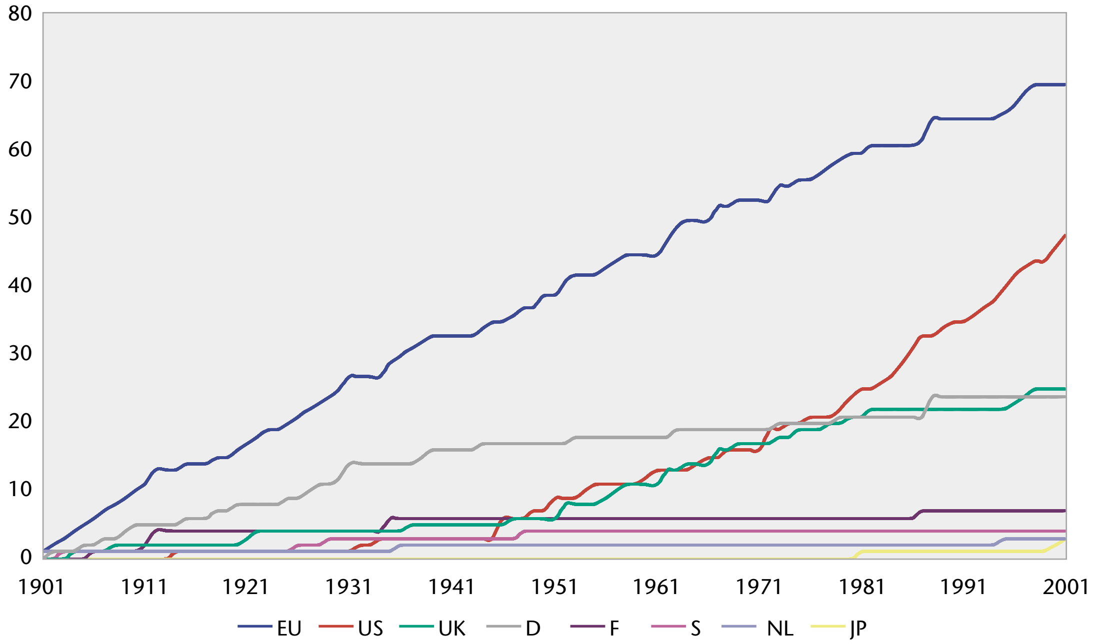
Figure D4.5.3 Distribution of Nobel Prizes in Physics by selected countries (1901-2001) – cumulative total



Source: DG Research
Data: Nobel Prize Foundation
Note: No Nobel Prizes have been awarded between 1940 to 1942.

Third European Report on S&T Indicators, 2003

Figure D4.5.4 Distribution of Nobel Prizes in Chemistry by selected countries (1901-2001) - cumulative total



Source: DG Research
Data: Nobel Prize Foundation
Note: No Nobel Prizes have been awarded between 1940 to 1942.

Third European Report on S&T Indicators, 2003

e.g., Rita Levi-Montalcini (Medicine 1986), Barbara McClintock (Medicine 1983) and George A. Olah (Chemistry 1994).

Another aspect of the Nobel Prizes is that they are awarded for one original contribution, regardless of previous work, rank or age, and not for lifetime achievement. Many renowned and honoured scientists, are therefore not on the list of Nobel Laureates. Likewise, the annual announcement of the Laureates may sometimes surprise the national scientific community. The focus on original, creative discoveries is one of the attractive features of the Nobel Prizes, but it is also an aspect that makes them less useful as an S&T indicator.

Given the international character of the scientific enterprise, the mobility of individual scientists across national borders is to be expected and ought to be encouraged. From a European or any non-US national perspective, this is, however, often regarded negatively as "brain drain". The lesson from the history of the Nobel Prizes as far as the scientific excellence of European human capital is concerned, is the importance of providing material resources, social conditions and a cultural climate which attracts the best scientists from all over the world to European universities and research institutions, as the US has been able to do for the last 70 years. This may seem a trivial conclusion, as this is an issue which European policy makers are well aware of and have been working on. The history of the Nobel Prizes may, however, be useful in focusing on the importance of fostering a cultural tradition, a social climate and an educational system which not only favours higher education and research, but which is open to radical creativity and mobility, thus promoting a European "brain gain".

NOBEL PRIZES AS S&T INDICATORS: CONCLUSIONS

The history of the science Nobel Prizes offers interesting potential as an S&T indicator, and efforts should be made to develop a methodology by which this rich source of information can be fully utilized. There are, however, some difficulties in using the material at present. These include the following:

- the 10- to 20-year time-lag between the ground-breaking research and the award, which makes it difficult to formulate decisions on short-term policy;
- many scientists who have made major contributions over a life-time are excluded, as Laureates are awarded the Prize for one original contribution only;
- a geographical analysis of the awards is constrained by many Laureates having carried out their research in more than one country;
- an analysis of the awards by nationality of the recipient is subject to a similar constraint;
- there is no clear correlation between the amount spent by a country on R&D and the number of Nobel Prizes awarded to its citizens.

In spite of the above constraints and challenges, much can still be learned from a careful analysis of individual cases and of the more general trends (e.g., shifts between nations and fields). One of the most positive sources of S&T indicators arising from the Nobel System, for example, are the Nobel Symposia, which in many cases have identified important fields and led to participants receiving the Nobel Prize itself shortly afterwards.

One difficulty is that the material is still rather limited, although the Nobel Prizes have been awarded for 100 years and no less than 734 Prizes have been awarded in total. Both the number and the time span may seem large enough for a statistical analysis from which to draw general conclusions and on which to base policy decisions. However, the most interesting material is contained in the archives of the various Nobel Committees, and these are opened to scholars only after 50 years. Thus we have at the moment access to detailed information only for the first 50 years of the Nobel Prize.

A further complication is that the biographical material regarding the various Nobel Laureates is highly disparate. In order to provide the basis for statistical analysis, the biographical data in e.g. Les Prix Nobel (also at www.nobelprize.org) has to be supplemented, verified and standardized. This can only be done in careful studies on the individual level (especially regarding the mobility of Laureates between institutions and nations), and there is thus a need for scholarly biographies of all the Nobel Laureates, written by professional historians of science using primary sources: biographies which are critical in the true sense of the word. As the field of history of science continues to develop (being, as it is, still a comparatively rather young academic discipline), more biographies will, of course, be published. The life and work of the Nobel Laureates will always attract historians, and it is therefore likely that most of the Laureates will one day have been the subject of a proper scholarly biography. But in order for these biographical studies to be enlightening on questions relating to the work that led to the awarding of the Nobel Prize to the Laureate in question (nominations, nominees, evaluations et cetera), the historians must have access to the archives of the Nobel Committees. We cannot thus expect to have complete biographies of any Nobel Laureate who was awarded the Prize later than some 50 years ago.

The gloomy conclusion from this might be that we cannot expect to have any substantial material covering the first 100 years of the history of the Nobel Prize of a quality that could be used as the basis for a more penetrative analysis, until, say, 60 years from now (the 50 years rule of the Nobel Committees for archival access plus some 10 years for research, writing and publication). In turn, the conclusion from this would be that one might as well sit back and wait for another 60 years before any attempt should be made to use the history of the first 100 years of the Nobel Prize for studies that might lead to more substantial policy recommendations.

This is, however, not the case. Much can still be learned from a careful analysis of individual cases and of the more general trends (e.g. shifts between nations and fields). It would be most useful to pursue this discussion in order to develop the concepts which could lead to a methodology for utilizing this valuable material for policy decisions.

Selected Bibliography

Crawford E. (ed.) (2002) *Historical studies in the Nobel archives: The Prizes in science and medicine*, Universal Academy Press, Tokyo, 161 pp.

Crawford, E. (2002) *The Nobel population 1901–1950: A census of the nominators and nominees for the Prizes in physics and chemistry*, Universal Academy Press, Tokyo, 420 pp.

Feldman, B. (2002) *The Nobel Prize: A history of genius, controversy, and prestige*, Arcade, New York, 489 pp.

Friedman, R. M. (2001) *The politics of excellence: Behind the Nobel Prize in science*, Freeman, New York, 327 pp.

Hargittai, I. (2002) *The road to Stockholm: Nobel Prizes, science, and scientists*, Oxford University Press, Oxford, 342 pp.

Hillebrand, C. D. (2002) 'Nobel century: A biographical analysis of physics laureates',in *Interdisciplinary Science Reviews*, Vol. 27, No. 2.

Larsson, U. (ed.) (2001) *Cultures of creativity: The Centennial Exhibition of the Nobel Prize*, Science History Public., Canton, Mass., 228 pp.

Levinovitz, A. W. & Ringertz, N. (eds.) (2001), *The Nobel Prize: The first 100 years*, Imperial College Press., London, 2001, 235 pp.

Nielsen, H. & Nielsen, K. (eds.) (2001) *Neighbouring Nobel: The history of thirteen Danish Nobel Prizes*, University Press, Aarhus, 624 pp.

Widmalm, S. (2001) 'Perspectives on the Nobel Prize', in *Minerva*, Guest Editor No. 4, Special isssue.

www.nobelprize.org (Web site of the Nobel Foundation).

Zuckerman, H. (1996) *Scientific elite: Nobel laureates in the United States*, Transaction Publishers, New Brunswick, N.J., New York, 1996, 335 pp.

CHAPTER 6
Europe's technological competitiveness

Introduction

Maintaining a strong science base and sustained investment in research and development, although they are important components of the modern economy, is not an end in itself. The knowledge that is created also needs to be exploited to the benefit of society – to enhance the competitiveness of industry, to promote growth, employment and higher living standards, and to improve the quality of life in terms of health and environment. At the beginning of the 21st century, there is a perception that Europe still falls behind its main competitors in transforming knowledge into economic growth and welfare for its citizens, and that it can and must do better.

In this context technology plays a crucial role. Countries must be successful in creating, exploiting and commercialising new technologies if they are to remain competitive in the modern global economy. Technology provides a crucial vehicle for improving economic growth and productivity. Technological innovation helps to generate new products and processes, which in turn open up new business opportunities and new markets. Sales of high-technology products have become an important and dynamic component of many countries' export performance, while the high-tech industries that manufacture these products are associated with high added value and well-paid jobs. As well as contributing to competitiveness, it should not be forgotten that new technologies can also have an important impact on society and the environment (e.g. health and environmental technologies).

However, it is far from easy to evaluate how well countries perform in developing and commercialising technology. The national systems of innovation that underlie and help to explain these performances involve complex phenomena that are difficult to measure and analyse. As a result, relevant and internationally comparable data are not easy to find.

Outline of this chapter

This chapter adopts a focused approach in seeking to explore Europe's technological competitiveness. Sections I and II report on two important indicators – patenting activity and high-tech trade. Section I examines Europe's performance in technological output as measured by patents. These data are valuable since they capture new technical inventions. A significant number of such inventions may lead to the development of innovative products or better manufacturing processes, resulting in economic benefits in the form of competitive advantage and increased market share. Certain inventions may even lead to the creation of entirely new markets or industries.

Section II moves closer to the market and analyses trends in the trade in high-tech products. These products represent the leading edge of science-based trade. They often result from significant research and development (R&D) investment, and are associated with industries which have high levels of productivity and high wages. As will be seen, high-tech trade has grown more rapidly than trade in other products, and has some of the most globalised markets.

Section III examines Europe's performance in two technologies that hold much promise for the future: biotechnology and nanotechnology. The chapter concludes with a dossier analysing the interaction between science and technological invention.

Other indicators

The indicators used here give only a partial picture. Other complementary indicators exist or are being developed, but generally they pose problems in terms of availability, comparability and interpretation. For example, data on the technology balance of payments (TBP) capture international trade in technical knowledge and services (e.g. sales of patents, licences for patents, know-how, models and designs, trade marks, technical services). These data are extremely valuable and shed important light on a country's ability to sell its technological know-how, or conversely its dependence on importing foreign technology. It is an important indicator of the international diffusion of technology. However, TBP data are not available for many countries, and require further harmonisation efforts.

Useful data do exist on the innovation activities of firms collected through the Community Innovation Survey (CIS). However, at present the survey is only carried out every four years, and the latest statistics from the second CIS (CISII) relate to the period 1994-1996. Figures for 1998-2000 will be available soon from the most recent survey which is being carried out at the time of writing. The available innovation data from CISII are now rather old, and have already been well analysed in many reports and articles (including the last edition of this report). As a result, they have not been included in this chapter.

Section I The competition for invention in world markets

Introduction: patents as an indicator of invention

The creation and use of technological knowledge are the key drivers of the modern economy. New technologies can stimulate innovation and competitiveness by improving the quality of products, or by incorporating them in entirely new products. They may also contribute to improving processes, and act as a factor in increasing productivity. Technological change also plays an increasing role in helping to bring about improvements to the quality of life, for example through developments in biotechnology and environmental technology.

Europe's success in the knowledge economy will therefore be enhanced not only by its capacity to create technological knowledge, but also by its ability to commercialise technologies, and to absorb and exploit knowledge created elsewhere.

This section focuses upon an important element in this picture: the generation of technological knowledge codified in patents. Patents represent an outcome of technologically oriented inventive activity. Moreover, since firms invest considerable amounts of time and money to obtain patent protection, the existence of a patent is usually a sign of expectation that such investments will bring a return to compensate for this investment. They represent an important source of data which can help to shed light on patterns of technological change.

Patents may also involve important transfers of knowledge, both in terms of the dissemination of information about the patented invention, and through the use of other scientific and technological knowledge to produce the patented technology.

It should be understood that not all inventions or innovative activities result in a patent, and that not all patents are exploited economically (cf. box "the interpretation and limits of patent data"). Nevertheless, patents are a rich source of data, allowing us to trace technology dynamics in detail and over long time periods.

The interpretation and limits of patent data

Certain of the characteristics of patents necessitate some care in interpreting patent data:

The usefulness and value of patents vary greatly. Many of them do not give rise to any innovation, while some represent major advances. Patents do not measure innovation per se, but rather the existence of knowledge which has the potential for innovation; these two things are very different.

An organisation filing a patent application may be the registered office or holding company whose location may have been determined by financial or even tax considerations. It may not be the location where the knowledge has actually been generated (e.g. the R&D laboratory). Accordingly, in the data presented here patents are systematically assigned to the country of residence of the inventor, rather than that of the applicant.

There is no strict proportional relationship between the generation of knowledge in an organisation and the number of patents it applies for. In some cases, it may decide not to patent the technological knowledge generated and to adopt, for example, a policy of secrecy. Conversely, an organisation may file applications for patents purely with a view to blocking the activities of its competitors. Such strategic factors on a micro scale are largely eliminated when working on a macro or meso scale – i.e. over a very large number of organisations, the law of large numbers will tend to even out these "micro" peculiarities. However, the objection is valid where the indicator is based on a very small number of patents and organisations. Thus, below a certain number of patents, the meso/macro interpretation has to give way to a micro interpretation.

Certain industrial sectors, by the very nature of the knowledge they produce, generate more patents than others, all other things being equal. For example, it is "easier" to file patent applications in the field of mechanical engineering than in aerospace. There are even sectors where the filing of patent applications is limited by definition (e.g. defence activities). Most innovation and invention in the service sector is not captured by patents, since relatively few service companies patent compared with manufacturing firms. When comparing countries' patenting levels, differences in their industrial structure must be taken into account. This effect can be eliminated by looking at individual technological or industrial sectors.

Finally, there tends to be a "home advantage" effect in patenting. For example, US inventors will have a dominance in the US patent system because it is their home market, while European inventors will tend to be the dominant players in the European patent system. Nevertheless, it is interesting to analyse patenting by Europeans in the US, and by Americans in Europe, since they represent economically strategic foreign markets.

Home advantage also affects the interpretation of specialisation patterns in patent data. Typically, a country will have a more even distribution of patents across technology fields in its home patent system than it will in a foreign system. Furthermore, products with a lower technology intensity, such as consumer goods, are primarily offered by local companies. This is why European countries have a specialisation on consumer goods at the European Patent Office while US companies have a strong specialisation in this area at the USPTO (US Patent and Trademark Office). For Japan, the US and EU markets are both foreign. Therefore it is less specialised in consumer goods at both offices.

1. Overview of performance in the different patent systems

This section gives an overview of trends in the main patenting systems, which are in Europe, the US and Japan. Also included are the 'Triad patents' – those taken out in all three of the main patent systems.

Patent indicators: the different patent systems

Inventors apply for patents in those countries where they seek protection of their inventions. Applications for patents are made to national patent offices, or sometimes through so-called "regional" patent offices such as the European Patent Office.

Three sets of indicators are analysed here because they cover three of the most important international markets where intellectual property rights are of strategic significance:

1. European patents, i.e. patents applied for at the European Patent Office (EPO);
2. US patents, i.e. patents granted by the US Patent and Trademark Office (USPTO);
3. "Triad" patents, i.e. the set of patented inventions for which protection has been sought at all three major patent offices of the Triad – at the EPO, at the USPTO and at the Japanese Patent Office (JPO).

The advantage of Triad patents is that they can eliminate the "home advantage" effect (cf. previous box). They may also be associated with patents of a higher expected commercial value, since it is costly to file through three patent systems. However, it is also likely that they tend to reflect the patenting activity of larger companies who seek, and can afford, broader international protection.

The European patent system

Europe still has the highest share of patents at the European Patent Office but the US has increased its presence over the past decade. The US is gaining on the EU in terms of percentage of patent applications filed at the European Patent Office (EPO). The gap between the EU and the US was almost 17% in 1992, compared with only 10% in 2001. In 2001, the EU was responsible for 42.2% of patents applied for at the EPO, the US for 32.4% and Japan for 14.6% (figure 6.1.1). Over the period 1992 to 2001, the US managed to increase its share by more than 4.2%, while the EU's share fell by 2.6% and Japan's by 4.9%.

Within the EU, Germany with 17.9% is by far the top country in terms of share of patents applied for at the European Patent Office – nearly three times more than France on 6.1%, or the UK on 5.3%. Italy has 3.1% of EPO applications, followed closely by the Netherlands (2.5%) and Sweden (2.2%). With between 1% and 1.5% are Finland (1.2%) and Belgium (1.1%), while Austria, Denmark and Spain are just below 1%. Greece, Ireland, Luxembourg and Portugal have less than 0.3% of all European patents.

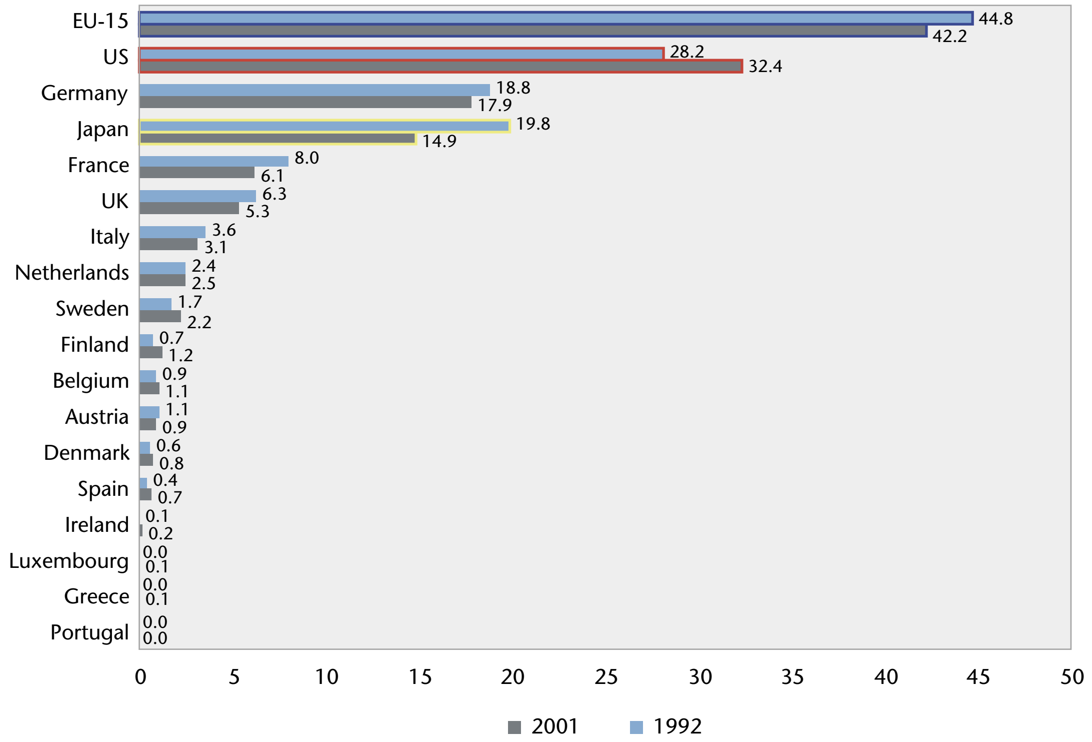
Examining the changes in shares of European patents during the period from 1992 to 2001 (figure 6.1.2), one sees that the four largest EU countries (Germany, France, UK, Italy) all lost ground in terms of their shares of European patents, while the fifth, the Netherlands, maintained its position.

However, the shares of all other EU countries (except Austria) rose during the same period. Portugal, Ireland, Finland and Spain posted the highest growth rates, leading to an increase in their shares of over 50% from 1992 to 2001, followed by Greece, Luxembourg and Denmark who increased their share by more than 30% in total over the same nine year period.

In absolute terms, numbers of patents have grown strongly across all EU countries since the 1990s, part of a worldwide surge in patenting activity. The countries with decreased patent shares were those whose growth rates, while relatively high, were still lower than the global rise in patenting volumes.

As shown in table 6.1.1, among the 20 organisations that applied for the most patents at the EPO, eight are from EU countries. European companies also occupy the top three positions. US firms hold seven of the top 20 spots, and Japanese companies five.

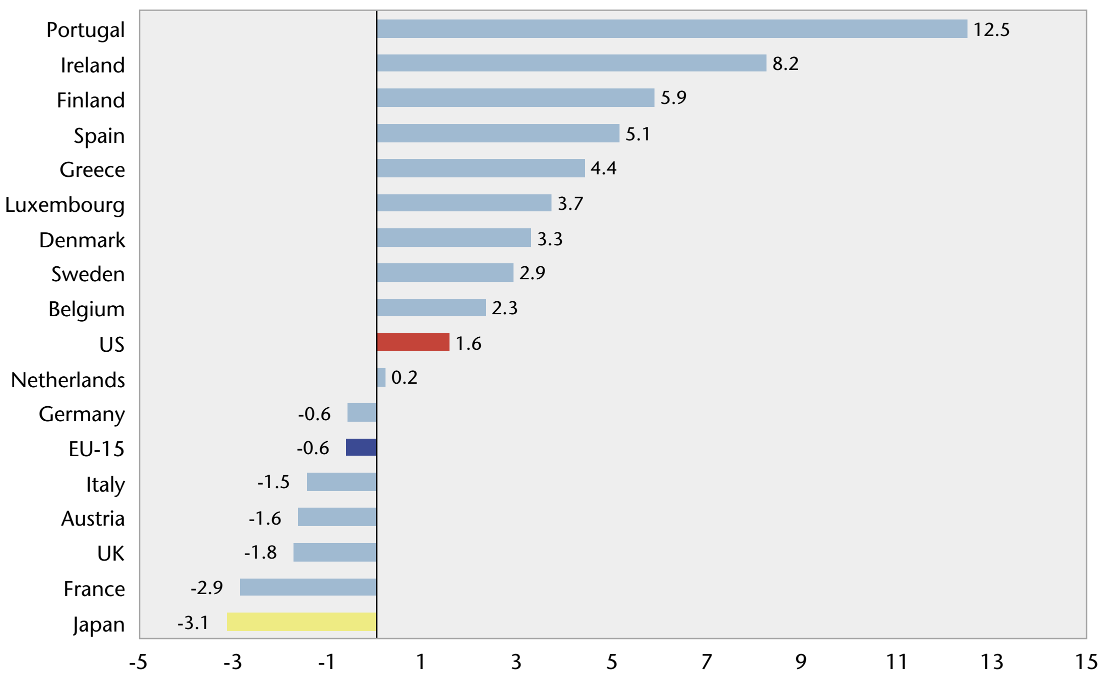
Figure 6.1.1 Share of European patents (%)



Source: DG Research
Data: EPO; data processed by OST

Third European Report on S&T Indicators, 2003

Figure 6.1.2 Annual growth in shares of European patents by country (1992-2001) %



Source: DG Research
Data: EPO, data processed by OST
Note: Growth rates are calculated as the average annual compound growth of the share between 1992 and 1999.

Third European Report on S&T Indicators, 2003

Table 6.1.1 Top 20 applicants at the European Patent Office

	Applicant	Country	Patent numbers
1	SIEMENS AKTIENGESELLSCHAFT	Germany	1 944
2	ROBERT BOSCH GMBH	Germany	983
3	N.V. PHILIPS' GLOEILAMPENFABRIEKEN	Netherlands	884
4	MATSUSHITA ELECTRIC INDUSTRIAL CO. INC.	Japan	836
5	THE PROCTER & GAMBLE COMPANY	US	819
6	CANON KABUSHIKI KAISHA	Japan	736
7	TELEFONAKTIEBOLAGET LM ERICSSON	Sweden	713
8	NEC CORPORATION	Japan	692
9	BASF AKTIENGESELLSCHAFT	Germany	658
10	LUCENT TECHNOLOGIES.	US	569
11	ALCATEL	France	534
12	HEWLETT-PACKARD COMPANY	US	489
13	MINNESOTA MINING AND MANUFACTURING COMPANY	US	467
14	BAYER AG	Germany	420
15	SONY CORPORATION	Japan	411
16	EASTMAN KODAK COMPANY	US	397
17	DAIMLER-BENZ AEROSPACE AIRBUS GMBH	Germany	362
18	FUJITSU LIMITED	Japan	335
19	E. I. DU PONT DE NEMOURS AND COMPANY	US	326
20	MOTOROLA	US	311

Source: OST
Data: INPI, EPO and OST; data processed by OST
Note: Patents have been aggregated at firm level only, and have not been consolidated at industrial group level. Data relate to all types of applicants, including public research centres.

Third European Report on S&T Indicators, 2003

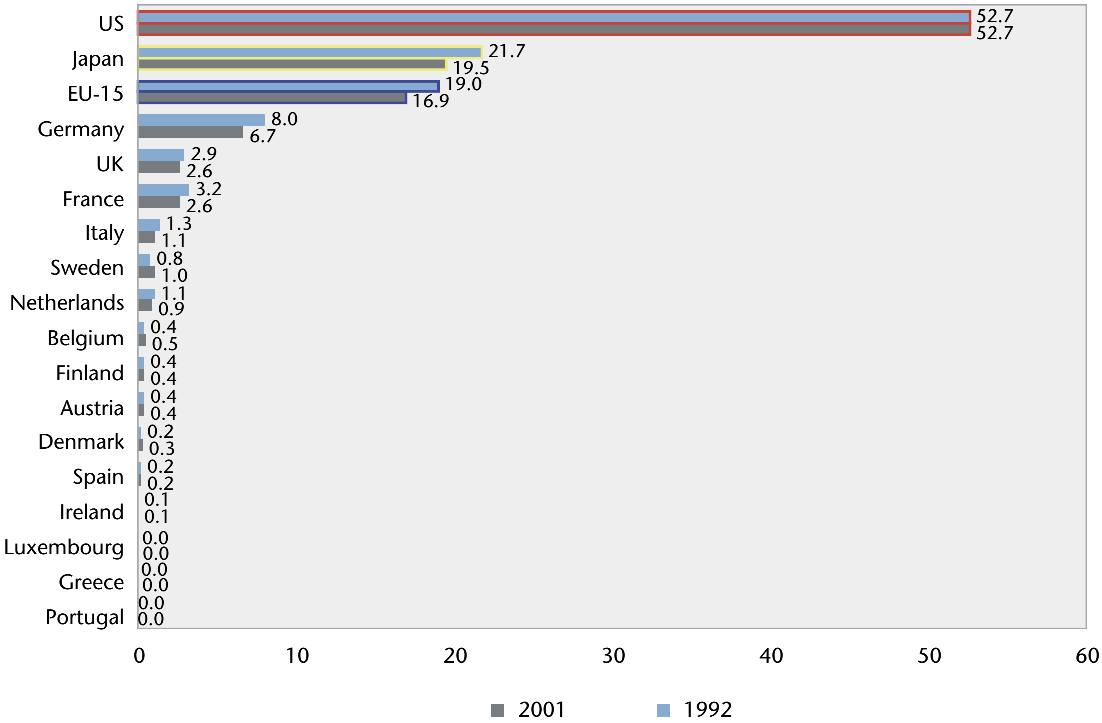
US Patents

Europe's share of US patents fell from 1992 to 2001, with some consolidation towards the end of the period. The EU's share of US patents was 16.9% in 2001, compared with 19% in 1992 (figure 6.1.3) However, Europe seems to have stemmed this trend during the second half of the period, registering a fairly stable share since 1996. The US maintained its position at 52.7%, while Japan's was 19.5%, slightly below its 1992 share. As will be seen later, much of the change in shares over this period is attributable to the fast rising shares of the other Asian economies.

The evolution of the EU-15 share of US patents was mainly attributable to the dynamics of those Member States with the highest patent shares. Between 1992 and 2001, Italy's share fell by an average of 2.4% per year, France's by 2.3%, Germany's by 2.1%, the Netherlands by 1.7% and the UK's by 1.3%. (figure 6.1.4). Since 1996 the trend has slightly improved, with all five countries posting better growth rates, and the UK, Germany and the Netherlands in particular registering positive increases in their shares of US patents.

Trends in the other EU countries in 1992-2001 have generally been positive, with Denmark, Ireland, Greece, Portugal, Sweden, Belgium, Spain and Finland all increasing their shares of US patenting by between 2.5% and 5% per year.

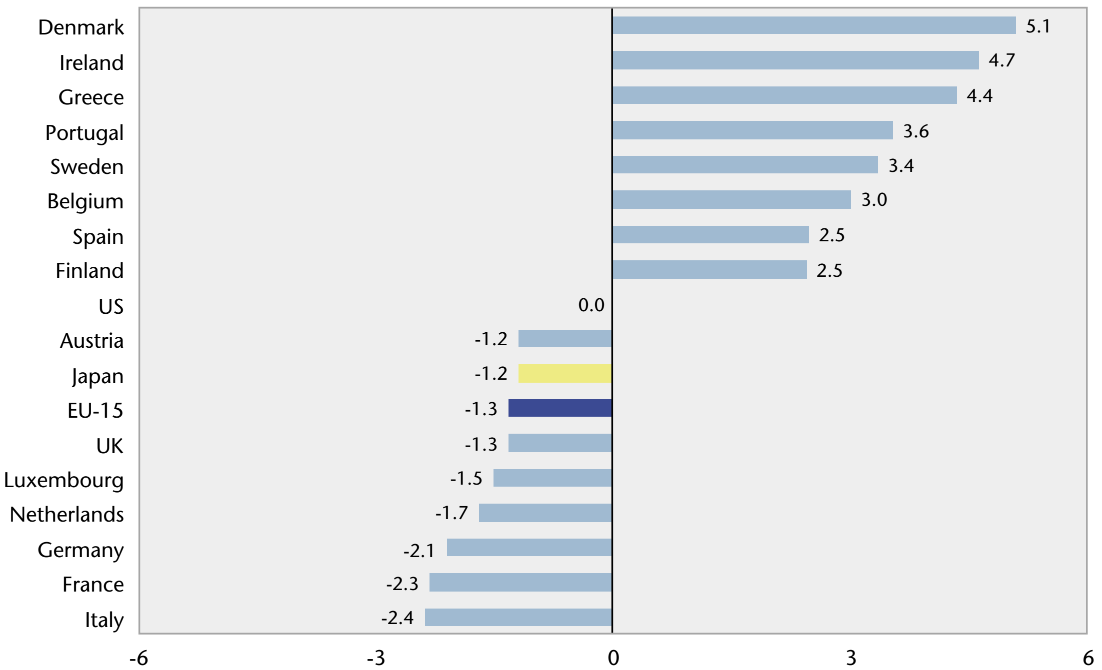
Figure 6.1.3 Share of US patents (%)



Source: DG Research
Data: USPTO; data processed by Fraunhofer-ISI

Third European Report on S&T Indicators, 2003

Figure 6.1.4 Annual growth in shares of US patents by country (1992-2001) %



Source: DG Research
Data: USPTO; data processed by Fraunhofer-ISI
Note: Growth rates are calculated as the average annual compound growth of the share between 1992 and 1999.

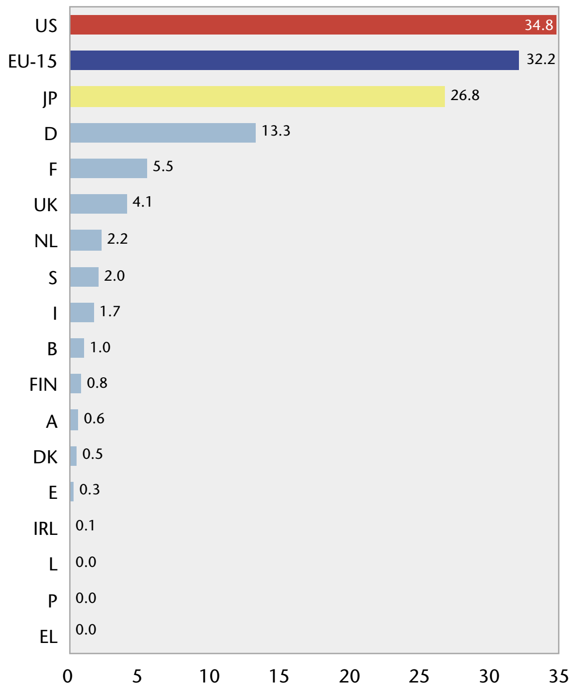
Third European Report on S&T Indicators, 2003

Triad patents: a different picture?

Looking at Triad patents – that is, those patents applied for at all three major patent offices of the Triad (the EPO, the USPTO and the JPO) – one gets a rather different impression of the relative shares of the EU, the US and Japan. As shown in figure 6.1.5, Europe has a share of 32% of this special subset of patents. It is slightly below that of the US, which holds almost 35% of Triad patents, while Japan has just under 27%. Although the reference years for this data are slightly different from those analysed in the previous section[1], they suggest that Europe is reasonably well positioned among those inventors who file economically valuable patents at all three major offices.

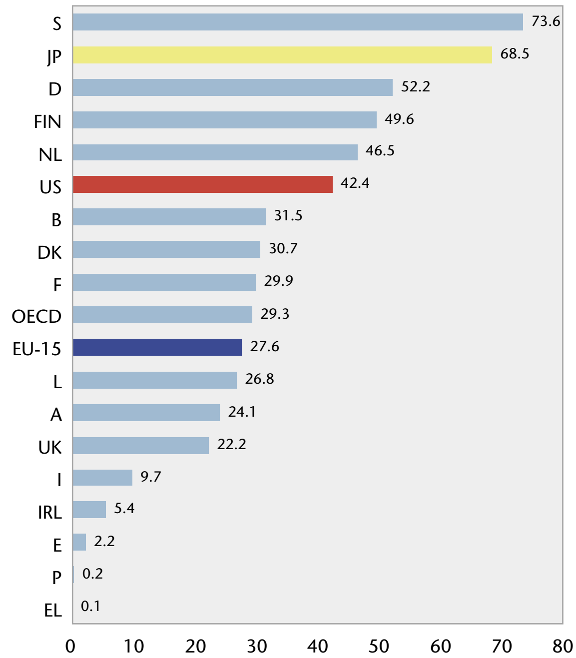
The situation is somewhat different with regard to Triad patents per capita (figure 6.1.6). Here the EU has slightly fewer than 28 patents per million population which is well behind the US (42) and Japan (69).

Figure 6.1.5 Share of Triad patents % (1995)



Source: DG Research
Data: OECD from EPO, USPTO and JPO
Note: Data for 1995 priority year.
Third European Report on S&T Indicators, 2003

Figure 6.1.6 Number of Triad patents per million population (1995)



Source: DG Research
Data: OECD from EPO, USPTO and JPO
Note: Data for 1995 priority year.
Third European Report on S&T Indicators, 2003

The most dynamic patenting countries worldwide

While the large economies of Europe, the US and Japan have the dominant shares of European and US patents, one must generally look elsewhere to identify those countries that have displayed the largest growth in patenting activity over the last ten years. Starting from a low base, South Korea and Singapore have increased the size of their share of patents in the US and Europe by well over 20% a year since 1992. These two countries are leading in terms of growth rate of their US patents share, and occupy second and third position in the European patent system. China has displayed the strongest dynamics in the latter system, with its share of European patents expanding by nearly 25% per year between 1992 and 1999. However, China started from a relatively low base level of patenting activity of around 30 patents in 1992, rising to more than 200 in 1999.

[1] *Triad patents have been counted according to the earliest priority date (first filing worldwide) which is closest to the invention date and important for data comparability. This introduces a time-lag in the data, as does the delay in the US patent system due to publishing patents only when they are granted. For these reasons, 1995 is the latest year available.*

Leading the EU countries in terms of growth of patent shares, are the smaller Member States, notably Finland and Denmark. Since the early 1990s, Finland has achieved the fastest growing share of European patents (nearly 8% per year), with a particularly strong performance in the field of Electricity/Electronics, while Denmark has had the strongest increase in US patent share (almost 7% annually) across a range of different technology fields. The high-tech boom of the 1990s in Ireland is reflected in its sound growth rates in both European and US patent shares.

Table 6.1.2 Fastest growing countries worldwide and in the EU (average annual growth in patent share, 1992-1999)

	European patents	Share %	US patents	Share %
	Top 10 worldwide			
1	China	24.4	S.Korea	26.0
2	S.Korea	23.5	Singapore	22.9
3	Singapore	21.2	Malaysia	15.9
4	New Zealand	18.4	Taiwan	12.7
5	Mexico	15.7	India	11.3
6	Israel	12.6	Argentina	8.5
7	Brazil	11.7	Hong Kong	8.0
8	Finland	7.8	New Zealand	7.3
9	India	7.6	Denmark	6.8
10	Ireland	7.6	Israel	6.1
	Top 5 European Union			
	European patents	**Share %**	**US patents**	**Share %**
1	Finland	7.8	Denmark	6.8
2	Ireland	7.6	Belgium	3.9
3	Sweden	6.1	Spain	2.9
4	Greece	6.0	Finland	2.7
5	Spain	5.6	Ireland	2.5

Source: DG Research
Data: EPO, USPTO; data processed by OST and Fraunhofer-ISI
Notes: Countries with fewer than 50 patents in 1999 have been excluded from the tables to avoid high growth rates associated with small numbers of patents.
Growth rates are calculated as the average annual compound growth of the share between 1992 and 1999.

Third European Report on S&T Indicators, 2003

Policies to encourage patenting and the exploitation of inventions

There has been an increasing awareness in recent years that the ownership of knowledge, and the appropriation of the economic benefits associated with it, are key factors behind innovation and competitiveness. In particular, strengthening the management and protection of intellectual property has become a major concern of policy makers in most countries.

While an array of intellectual property rights (IPR) measures have been implemented by national and, in some cases, international authorities, two broad areas have been the focus of attention: improving the protection and exploitation of research results emanating from public research organisations, and stimulating the use of IPR in small to medium sized enterprises.

Promotion of the protection and exploitation of IPR in public sector research institutes

Governments have become increasingly interested in developing better measures to exploit the fruits of basic research generated by universities and public research centres. There is a perception of a significant, and still largely untapped, potential for commercial exploitation of scientific findings which are not yet protected by IPR. The number of patents applied for by public organisations, while increasing, is still perceived to be too low. This is attributed to the high costs and lengthy procedures associated with patenting, and in some cases inadequate information and expertise regarding patenting. As a result, many countries have introduced measures to make it easier for public institutes to patent, and to help them actively pursue the commercialization of scientific research. Some examples are given below.

Germany: Commercialisation of Intellectual Property from Public Science

This measure aims at strengthening the use of IPR at universities and other public science organisations. It will improve technology transfer to the enterprise sector, by (i) creating a professional patenting and commercialisation infrastructure, (ii) promoting the use of patents for protecting research results, (iii) increasing further education in the field of IPR, and (iv) building up a network of commercialisation units at public science organisations. A main feature is the creation of partnerships between universities and private patent agencies.

Denmark: Act on Inventions in Public Research

In 1999, the Danish parliament adopted new legislation on inventions in public research. Under the new act, public research organisations are entitled to claim IPR for the inventions of their own employees, in the same way as private enterprises.

The Danish IPR act offers an incentive for all parties to generate and exploit scientific inventions by dividing the revenue from IPR contracts between the inventing researchers and the organisations. By offering a clear legislative framework on IPR, the act facilitates co-operation contracts between academia and industry. Furthermore, the IPR act promotes the creation of new innovative enterprises by allowing universities and other public research organisations, within certain limits, to become shareholders in spin-off companies.

Austria: Technologiemarketing Austria (TecMa)

TecMa was established to promote commercial applications for intellectual property developed by Austrian scientists. TecMa locates industrial partners, provides financial assistance during the patenting phase and offers consulting services for the exploitation of R&D results.

In general, applicants have to pay for the various services of this programme. The fee depends on the revenue the applicant gains from his invention and on the service the applicant receives. The programme is partly integrated with other schemes offered by the Innovation Agency. The Agency delivers assistance in patenting and commercialising inventions and helps to finance the patent application.

Encouraging small and medium enterprises to apply for patents

The second group of actors targeted by public measures to promote IPR are small and medium enterprises (SMEs). It is widely perceived that SMEs are more likely than large firms to be deterred from patenting because of the prohibitive cost associated with the patent process (application, maintenance, litigation), and because the procedures are so complex. It is also thought that many SMEs suffer from a lack of awareness of the strategic interest of patenting, coupled with inadequate information on and expertise in seeking protection.

Government policies have focused on raising the IPR awareness of SMEs and reducing the barriers (including cost) to their applying for patents. Such policies are also aimed at improving the conditions for litigation, and stimulating the exploitation of protected inventions (e.g. through contact with business experts). Some examples of national initiatives are given below.

Germany: NSTI – SME patent initiative

This programme provides subsidies for SMEs in six areas to increase the use of IPR and to stimulate inventions by SMEs:

- information search on the state of art in technology;
- cost-benefit-analyses of inventions;
- patent applications;
- preparation activities for commercialising an invention;
- using IPR abroad;
- technical permission of inventions.

The programme aims to:

- reduce barriers in SMEs with respect to the use of patents as a source of information and an instrument to protect property rights, and to improve the innovation capability of SMEs;
- increase the number of qualified patent applications by SMEs;
- improve the conditions at SMEs for the commercialisation and use of patents.

Overall, the programme should help to foster an innovation-friendly climate in Germany, promote a rapid and comprehensive commercialisation of R&D results into innovations, and increase the awareness of IPR among SMEs.

United Kingdom: Abolition of patent fees

Introduced in 1998, this initiative is part of a package of measures designed to improve the competitiveness of British industry, and especially that of small firms. Several changes have been introduced to assist entry into the patent systems and encourage their use by small firms and private individuals. There are three main measures:

- abolition of the patent application fee;
- a 20% reduction in the costs of Patent Office services;
- making the patent application form available on the Internet.

Savings to industry are estimated at £12 million, or 20% of the Patent Office's fee income. There are also cuts in patent renewal fees by an average of 18%. The greatest savings will be in patent renewals in the earlier years, when companies are frequently still in the phase of product development and have yet to make a return on their investment.

France: INPI's innovation awards

Every two years, the National Institute for Intellectual Property (INPI) organises its innovation awards to promote SMEs and research institutes which have successfully used patents for business or innovation development. The number of employees or researchers must not exceed 1 000. The measure aims at promoting best practices, both in SMEs and research institutes in IPR strategies.

Each award ceremony serves as an exchange of best practices in IPR strategies. The winners can exchange information about a variety of aspects, such as their practices, the challenges of IPR, technology watch, and pirating.

2. Technology fields and their dynamics

Patent shares by field of technology

Europe's performance in patenting varies quite significantly according to the field of technology. This section therefore presents data on patents broken down according to the main technology fields to which the patents relate.

Looking first at patents applied for at the European Patent Office, figure 6.1.7 gives a breakdown of patents by technological field and country. Those fields in which it has the highest share of European patents are Processes, Mechanics and Consumer Goods, where the EU has between 50% and 55% of patents. The US is relatively weak in these fields, with a share of less than half of the EU's (around 24%).

Conversely, in the fields of Electricity/Electronics, Instruments and Chemistry, the EU has around 36% of the world share, well below the EU average across all fields. These are the three fields in which the US is strongest.

Japan has a share of more than 20% in Electricity/Electronics, the field in which it is very highly specialised. It is a little below 15% in other fields, except Consumer Goods, where it is under 6%.

Turning to US patents, as shown in figure 6.1.8, the EU once again has its smallest shares in the fields of Electricity/Electronics and Instruments. In particular, its share of only 10.7% in Electricity/Electronics is well below Japan's share of 27.8%. However, the EU is ahead of Japan in the fields of Chemistry, Processes and Mechanics where its share is more than 20%.

In the field Consumer Goods, the EU at 12.1% is also ahead of Japan, whereas in Instrumentation, Japan is strongly specialised with a world share of 23% of all US patents, compared with 13.8% for the EU.

The US has a fairly stable profile across different fields, with shares consistently between 50% and 55%, except in Consumer Goods where it has more than 66% of all patents.

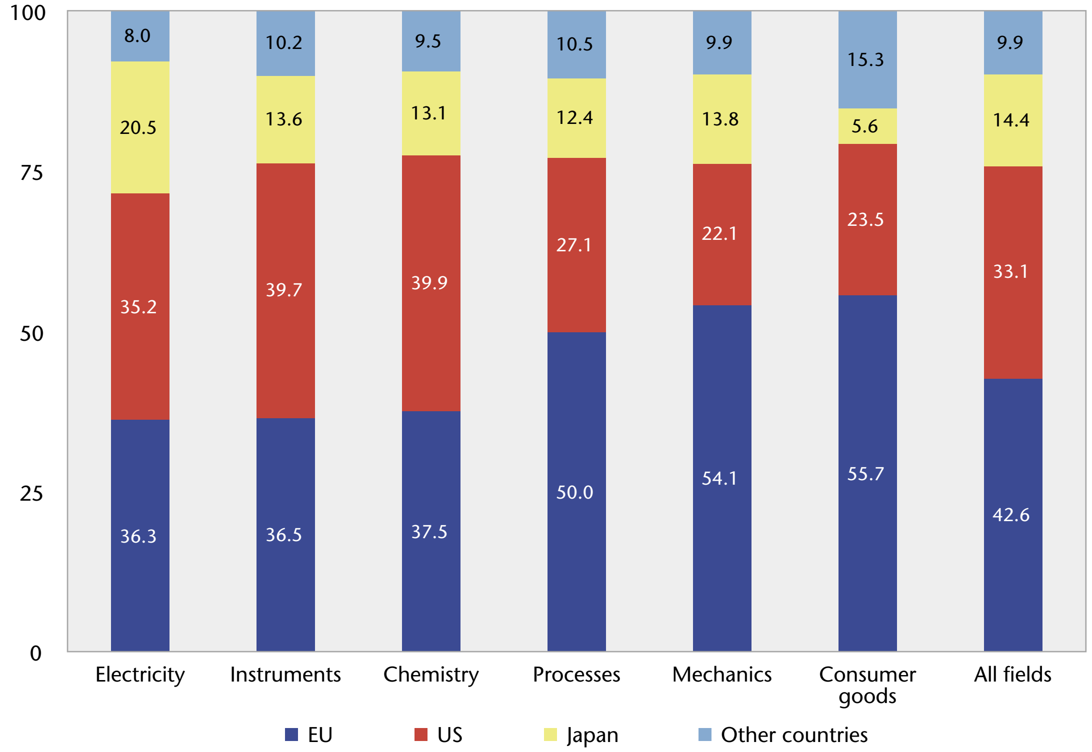
To summarise, in Electricity/Electronics and in Consumer Goods, US inventors have five US patents for every one granted to an EU inventor, while in most other fields the US generates 2.5 times as many patents as the EU.

However, within this technological performance profile for the EU as a whole, there is considerable diversity in the shares of the Member States (tables 6.1.3 and 6.1.4). There are two broad effects. Firstly, there is an obvious country size effect, so that Germany, France, UK and Italy hold the largest shares for each field at both the EPO and the USPTO. Secondly however, the data also suggest important differences in technological specialisation.

Germany, Austria, Spain, France and Italy have the same specialisation profile in European patents, with weaknesses in Electricity/Electronics, Instruments and Chemistry, balanced by better positions in Processes, Mechanics and Consumer Goods. This is broadly true for patents taken out by these countries in the US as well, except that their position in Chemistry is relatively stronger and in Consumer Goods relatively weaker.

Belgium, Denmark and the UK have good positions in chemistry. While the EU as a whole has its lowest patent share in the field of Electricity/Electronics, this is an area of strength for Finland, the Netherlands and Sweden. Sweden and the UK are also well placed in Instruments.

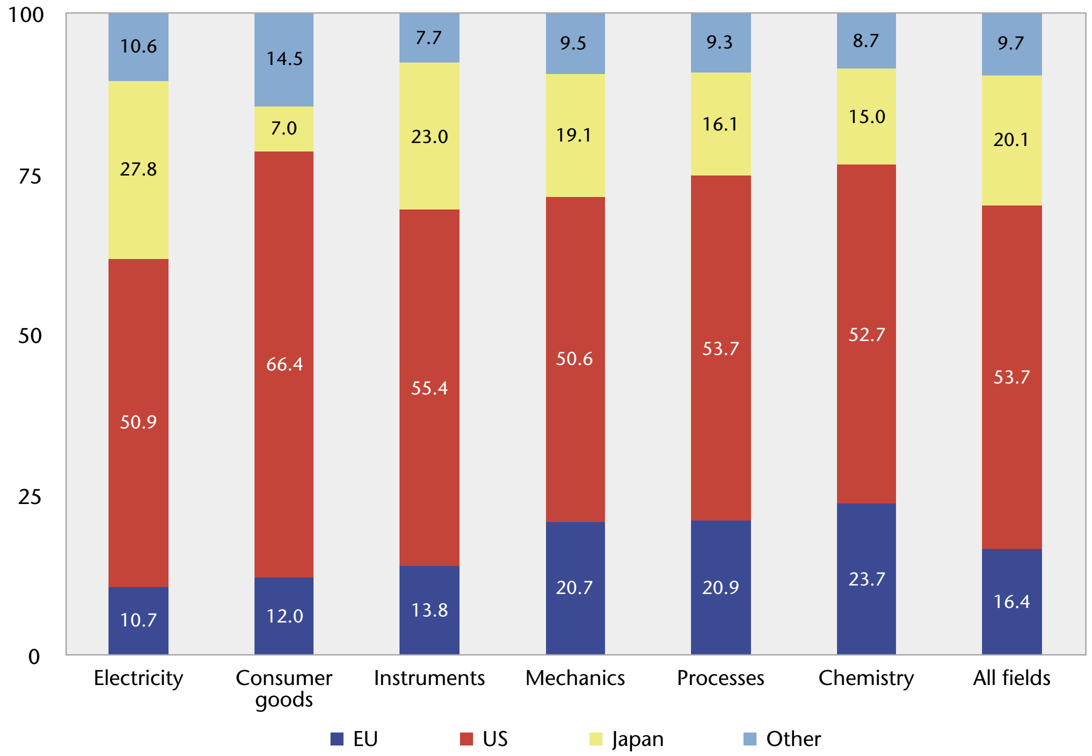
Figure 6.1.7 Shares of European patents by technology area in % (1999)



Source: DG Research
Data: EPO, data processed by OST

Third European Report on S&T Indicators, 2003

Figure 6.1.8 Shares of US patents by technology area in % (1999)



Source: DG Research
Data: USPTO; data processed by Fraunhofer-ISI

Third European Report on S&T Indicators, 2003

Table 6.1.3 Share of European patents by technology field, % (1999)

Countries/Groups	Electricity	Instruments	Chemistry	Processes	Mechanics	Consumer goods	All fields
European Union	36.3	36.5	37.5	50.0	54.1	55.7	42.6
Belgium	0.6	1.0	1.6	1.5	0.7	1.0	1.1
Denmark	0.4	0.7	1.1	1.1	0.8	1.1	0.8
Germany	13.7	14.5	14.8	20.2	27.6	21.3	17.6
Spain	0.3	0.5	0.6	0.9	0.7	1.5	0.6
France	5.6	5.5	5.6	6.3	8.1	8.9	6.3
Italy	1.8	2.2	2.5	4.6	3.9	5.8	3.0
Netherlands	3.3	2.0	2.1	3.1	1.5	2.7	2.5
Austria	0.5	0.6	0.6	1.3	1.5	2.0	0.9
Finland	2.1	0.7	0.7	1.9	0.8	1.0	1.2
Sweden	3.1	2.7	1.3	3.1	3.2	2.9	2.6
UK	4.7	5.8	6.4	5.7	5.0	6.8	5.6
US	35.2	39.7	39.9	27.1	22.1	23.5	33.1
Japan	20.5	13.6	13.1	12.4	13.8	5.6	14.4
World	100	100	100	100	100	100	100

Source: DG Research
Data: EPO; processed by OST

Third European Report on S&T Indicators, 2003

Table 6.1.4 Share of US patents by technology field, % (1999)

Countries/Groups	Electricity	Instruments	Chemistry	Processes	Mechanics	Consumer goods	All fields
European Union	10.7	13.8	23.7	20.9	20.8	12.1	16.4
Belgium	0.2	0.6	1.2	0.7	0.3	0.2	0.5
Denmark	0.1	0.2	0.8	0.4	0.3	0.2	0.3
Germany	3.3	5.1	8.5	8.9	10.9	3.9	6.3
Spain	0.1	0.1	0.3	0.3	0.2	0.3	0.2
France	2.0	2.2	4.1	2.6	3.0	2.0	2.7
Italy	0.7	0.7	1.5	1.8	1.2	1.2	1.1
Netherlands	0.9	0.9	1.2	1.1	0.4	0.5	0.9
Austria	0.1	0.2	0.5	0.6	0.4	0.5	0.3
Finland	0.5	0.3	0.3	0.8	0.4	0.3	0.4
Sweden	0.7	0.9	0.8	1.1	1.2	0.7	0.9
UK	1.9	2.5	4.2	2.5	2.3	2.1	2.6
US	50.9	55.4	52.7	53.7	50.7	66.6	53.7
Japan	27.8	23.0	15.0	16.2	19.1	7.0	20.1
World	100	100	100	100	100	100	100

Source: DG Research
Data: USPTO; processed by Fraunhofer-ISI

Third European Report on S&T Indicators, 2003

Growth in patent shares by field of technology

The 1990s represented a decade of contrasting halves as regards Europe's shares of patents at the European and US patent offices. After a sharp decline in the early 1990s across most technology fields, Europe has stabilised its shares of patents since 1996, notably in the US patent system. The period 1992-1995 was one of rapidly declining shares across most broad technology fields, most acutely in terms of US patents, but also European patents (figures 6.1.9 and 6.1.10).

Since 1996, the EU has managed to arrest or at least lessen the fall in European patent shares, except in the fields of Chemistry and Consumer Goods/Construction. It has also reversed the trend in US patents where all fields except Electricity showed modest growth between 1996 and 1999.

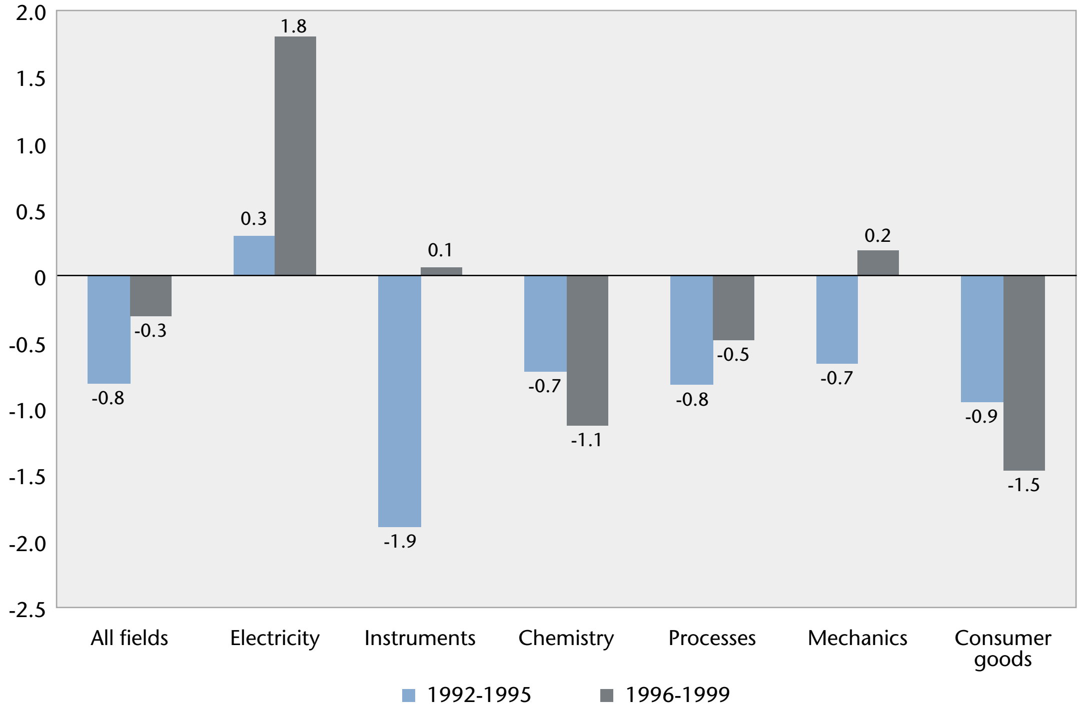
The US has experienced a stabilisation and even a small decline in its shares during the latter period (with the exception of Chemistry, and Electricity/Electronics in European patents) in contrast to the rapid expansion of its shares across all technology fields in the first half of the 1990s (table 6.1.5). The fall in Japan's shares in the European patent system softened towards the end of the decade, but its US patent shares continued to fall in most fields, with a steepening decline in Electricity/Electronics and Chemistry.

Table 6.1.5 Growth in shares of patents at the European and US patent offices %

	European Patents					
	European Union		United States		Japan	
	1992-1995	1996-1999	1992-1995	1996-1999	1992-1995	1996-1999
All fields	-0.8	-0.3	4.2	-0.5	-6.3	-1.5
Electricity	0.3	1.8	4.0	-1.7	-6.9	-2.7
Instruments	-1.9	0.1	6.0	-0.6	-7.5	-4.1
Chemistry	-0.7	-1.1	3.3	0.3	-6.2	-2.6
Processes	-0.8	-0.5	3.8	-0.1	-3.7	-0.5
Mechanics	-0.7	0.2	3.9	-2.6	-6.3	2.5
Consumer Goods	-0.9	-1.5	3.1	1.9	-4.0	-3.1
	US Patents					
	European Union		United States		Japan	
	1992-1995	1996-1999	1992-1995	1996-1999	1992-1995	1996-1999
All fields	-4.5	0.1	1.2	-0.5	-0.3	-1.6
Electricity	-7.2	-0.9	0.8	0.9	-0.2	-4.4
Instruments	-3.9	0.3	2.1	-0.9	-2.9	-0.2
Chemistry	-2.7	0.9	1.1	0.7	-0.4	-6.0
Processes	-3.2	0.5	0.8	-0.9	1.0	0.5
Mechanics	-3.0	2.3	2.4	-2.5	-4.9	3.0
Consumer Goods	-6.7	1.4	0.9	-1.0	-1.9	-0.6

Source: DG Research
Data: EPO, USPTO; data processed by OST, Fraunhofer-ISI
Note: Growth rates are calculated as the average annual compound growth of the share between 1992-1995 and 1996-1999.
Third European Report on S&T Indicators, 2003

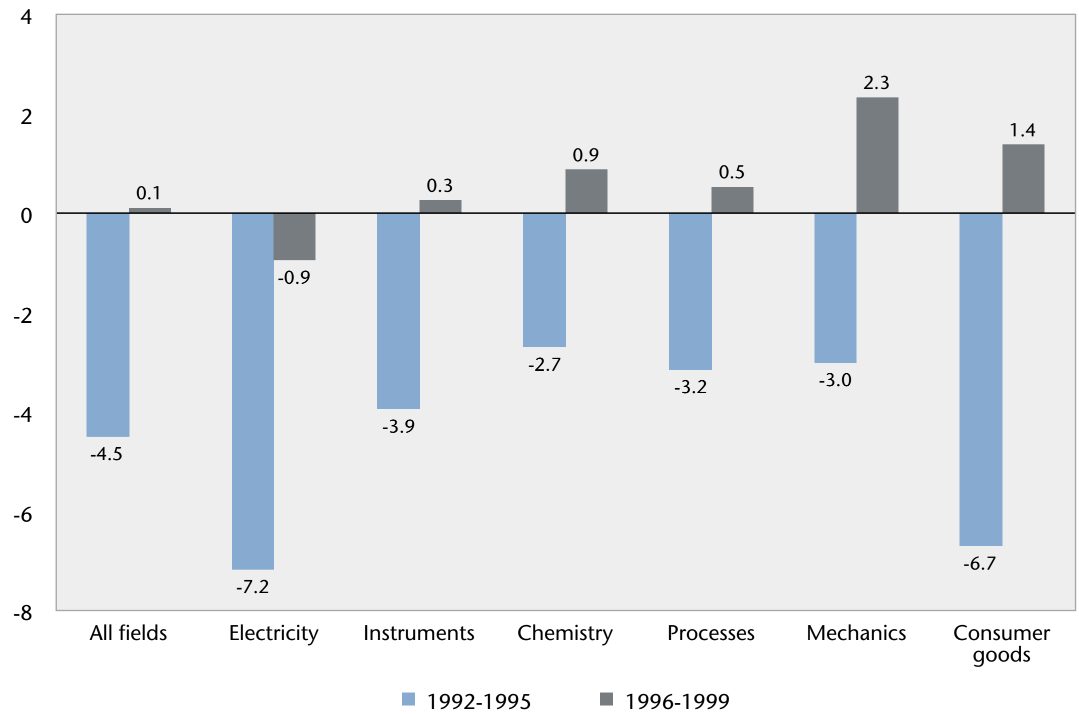
Figure 6.1.9 Growth in EU shares of European patents (%)



Source: DG Research
Data: EPO; data processed by OST
Note: Growth rates are calculated as the average annual compound growth of the share between 1992-1995 and 1996-1999.

Third European Report on S&T Indicators, 2003

Figure 6.1.10 Growth in EU shares of US patents (%)



Source: DG Research
Data: USPTO; data processed by Fraunhofer-ISI
Note: Growth rates are calculated as the average annual compound growth of the share between 1992-1995 and 1996-1999.

Third European Report on S&T Indicators, 2003

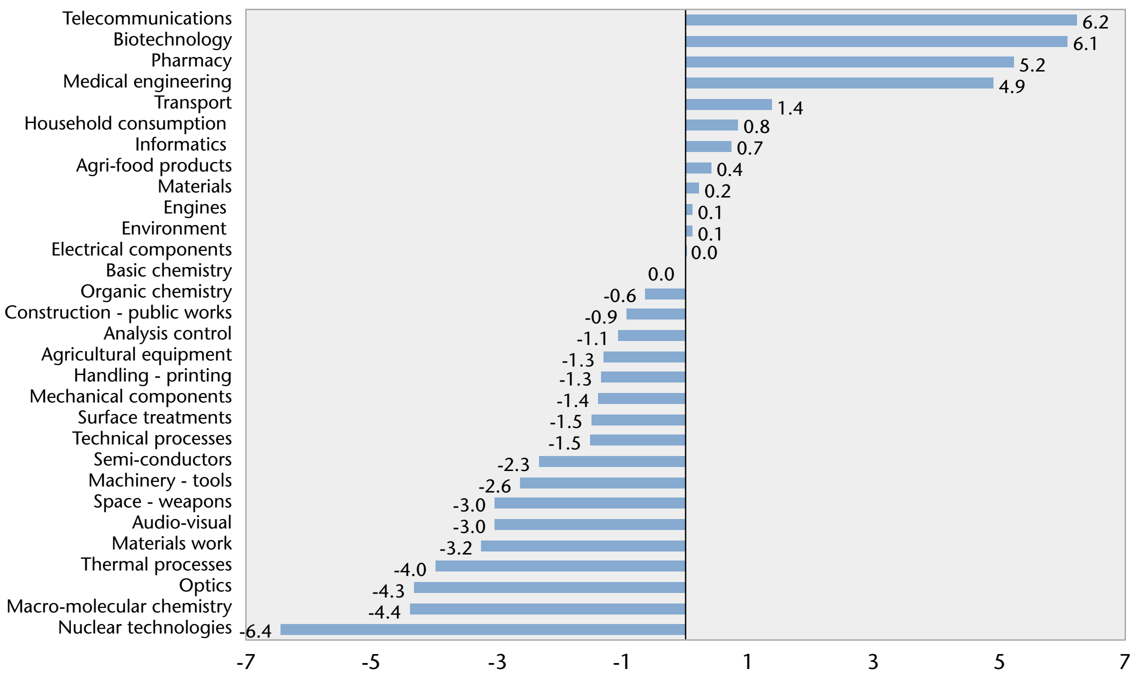
Which technology sub-fields reflect the fastest patenting growth?

Patent statistics can provide some useful insights into the pace of technological change in particular fields. Statistics of patents taken out by all countries provide a global indication of those fields of technology that are expanding rapidly, as well as some pointers towards new or emerging technology areas.

An analysis of patterns of patenting in technology sub-fields facilitates a more detailed understanding of growth. Figure 6.1.11 shows the growth rates for 30 technology sub-fields during the period 1992-1999.

The sub-fields of Biotechnology, Telecommunications, Pharmacy and Medical Engineering experienced spectacular growth during the 1990s in both absolute numbers of patents and in terms of their share of total patents. However, in technological subareas such as Audio-visual, Semi-conductors, and Analysis/Measurement the number of patent registrations rose more slowly than average, despite substantial technological activity.

Figure 6.1.11 Which technology sub-fields are the most dynamic?
Average annual growth in share of European patents (1992-1999) %



Source: DG Research
Data: EPO; data processed by OST
Note: Growth rates are calculated as the average annual compound growth of the share between 1992 and 1999.

Third European Report on S&T Indicators, 2003

The most dynamic patenting countries by technology field

Worldwide, the top countries in terms of growth of patent share are from the developed Asian economies (South Korea, Singapore and Taiwan). South Korea in particular is among the top five dynamic countries in all six broad technology fields analysed here (table 6.1.6), and is the fastest growing country in the world (for both European and US patents) in the areas of Instruments, Processes and Mechanics. China and Hong Kong have also expanded their shares significantly during the 1990s. The emergence of New Zealand as a dynamic patenting force is also evident.

In the EU, it is the smaller Member States (in terms of patent share) that have exhibited the strongest growth in the last decade, which are also by and large those countries that have seen the higher rates of growth of R&D expenditure (cf. chapter 3). Finland's rapidly rising share of patents in Electrical/Electronics technologies serves to underline its strong performance in the Telecommunications sector over the last decade. However, it should be noted that Finnish shares in Chemistry and Processes have also increased rapidly. Sweden, which has been strong in Electricity/Electronics, features in the top five across a range of technology fields, as do Denmark, Ireland, Belgium and Spain.

The strong performance of these Member States, which have some specialisation in information and communication technologies (ICT) and in life sciences, may be partly explained by the general dynamism of these technology fields during the 1990s. In the 1990s, the breakdown in the total number of European patents registered by the technological sector changed significantly: Telecommunications technology jumped from 5.8% of patents in 1990 to 8.9% in 1999, a relative increase of more than 50%. Similarly, the proportion of patents in the fields of Biotechnology, Pharmacy and Medical engineering rose from 9.8% to 14.1%, a jump of 44%. There are three reasons for the increase in the relative number of patents in ICT and life science: the relative increase in the share of R&D in these fields, a broadening of the scope of patentable inventions in these areas, and their "technological fecundity", which are teeming with opportunities for invention.

The influence of globalisation should not be overlooked either. Among the patented inventions of Ireland, Belgium and Spain are many which belong to foreign-owned multinationals whose affiliates carry out R&D in these Member States (this issue will be discussed in more detail in the following section).

Table 6.1.6 Top countries worldwide and in the EU in terms of growth of patent share (Average annual growth in patent share, 1992-1999) (%)

Electricity

	European patents		US patents	
Top 5 worldwide				
1	Finland	22.7	Singapore	20.7
2	China	22.5	S.Korea	19.9
3	Sweden	20.0	Taiwan	18.7
4	Singapore	19.5	Finland	15.5
5	S.Korea	18.8	Israel	12.6
Top 5 European Union				
1	Finland	22.7	Finland	15.5
2	Sweden	20.0	Sweden	8.8
3	Spain	9.3	Spain	3.9
4	Denmark	8.4	Ireland	1.0
5	Ireland	6.4	Belgium	-0.7
EU, US and Japan				
	US	1.7	US	0.8
	EU-15	0.9	Japan	-2.4
	Japan	-5.6	EU-15	-3.5

Instruments

	European patents		US patents	
Top 5 worldwide				
1	S.Korea	27.6	S.Korea	33.1
2	N. Zealand	23.4	Argentina	14.2
3	China	21.3	Taiwan	13.5
4	Israel	18.0	Belgium	11.8
5	Ireland	13.7	N. Zealand	11.0
Top 5 European Union				
1	Ireland	13.7	Belgium	11.8
2	Denmark	6.1	Denmark	5.0
3	Sweden	6.0	Ireland	3.5
4	Belgium	5.1	Sweden	3.1
5	Spain	4.4	Netherlands	1.0
EU, US and Japan				
	US	2.9	US	0.5
	EU-15	-0.7	Japan	-1.5
	Japan	-6.6	EU-15	-1.6

Chemistry

	European patents		US patents	
Top 5 worldwide				
1	China	26.2	S.Korea	21.6
2	S.Korea	25.2	Singapore	18.8
3	Brazil	20.3	Poland	17.6
4	N. Zealand	16.9	Taiwan	16.8
5	Mexico	12.6	India	12.9
Top 5 European Union				
1	Ireland	6.4	Denmark	12.7
2	Spain	6.2	Spain	6.3
3	Denmark	6.2	Finland	5.6
4	Finland	4.6	Belgium	5.5
5	Sweden	3.8	Sweden	5.2
EU, US and Japan				
	US	2.2	US	0.7
	EU-15	-1.1	EU-15	-0.6
	Japan	-5.0	Japan	-3.3

Processes

	European patents		US patents	
Top 5 worldwide				
1	S.Korea	31.8	S.Korea	22.5
2	China	27.0	Hong Kong	17.8
3	Brazil	17.7	N. Zealand	13.1
4	N. Zealand	16.3	Taiwan	12.2
5	S.Africa	11.5	Brazil	12.0
Top 5 European Union				
1	Ireland	6.6	Ireland	8.2
2	Spain	6.3	Denmark	6.9
3	Finland	4.8	Austria	4.7
4	Sweden	3.1	Spain	3.8
5	Belgium	2.9	Belgium	1.7
EU, US and Japan				
	US	2.4	Japan	0.5
	EU-15	-0.8	US	-0.1
	Japan	-2.5	EU-15	-1.1

Mechanics

	European patents		US patents	
Top 5 worldwide				
1	S.Korea	28.8	S.Korea	30.6
2	China	21.5	Taiwan	8.3
3	N. Zealand	20.0	Norway	6.4
4	Czech Rep.	14.9	Spain	6.2
5	Brazil	9.9	Denmark	4.9
Top 5 European Union				
1	Denmark	8.1	Spain	6.2
2	Sweden	4.2	Denmark	4.9
3	Spain	3.6	Belgium	4.0
4	Belgium	2.3	Sweden	1.4
5	Germany	1.2	Germany	0.4
EU, US and Japan				
	US	1.3	US	0.0
	EU-15	-0.4	EU-15	-0.5
	Japan	-2.0	Japan	-1.4

Consumer goods

	European patents		US patents	
Top 5 worldwide				
1	N.Zealand	20.5	S.Korea	29.1
2	S.Korea	20.3	Hong Kong	10.9
3	Brazil	17.1	Taiwan	8.9
4	China	14.0	Denmark	7.1
5	Ireland	11.9	Finland	5.6
Top 5 European Union				
1	Ireland	11.9	Denmark	7.1
2	Spain	6.4	Finland	5.6
3	Denmark	4.2	Spain	0.5
4	Finland	0.9	Sweden	-0.5
5	Netherlands	0.8	Netherlands	-1.6
EU, US and Japan				
	US	3.0	US	0.0
	EU-15	-1.3	Japan	-2.2
	Japan	-3.6	EU-15	-2.7

Source: DG Research
Data: EPO and USPTO; data processed by OST and Fraunhofer-ISI
Note: Countries with fewer than 20 patents in 1999 have been excluded from the tables to avoid high growth rates associated with small numbers of patents. Growth rates are calculated as the average annual compound growth of the share between 1992 and 1999.

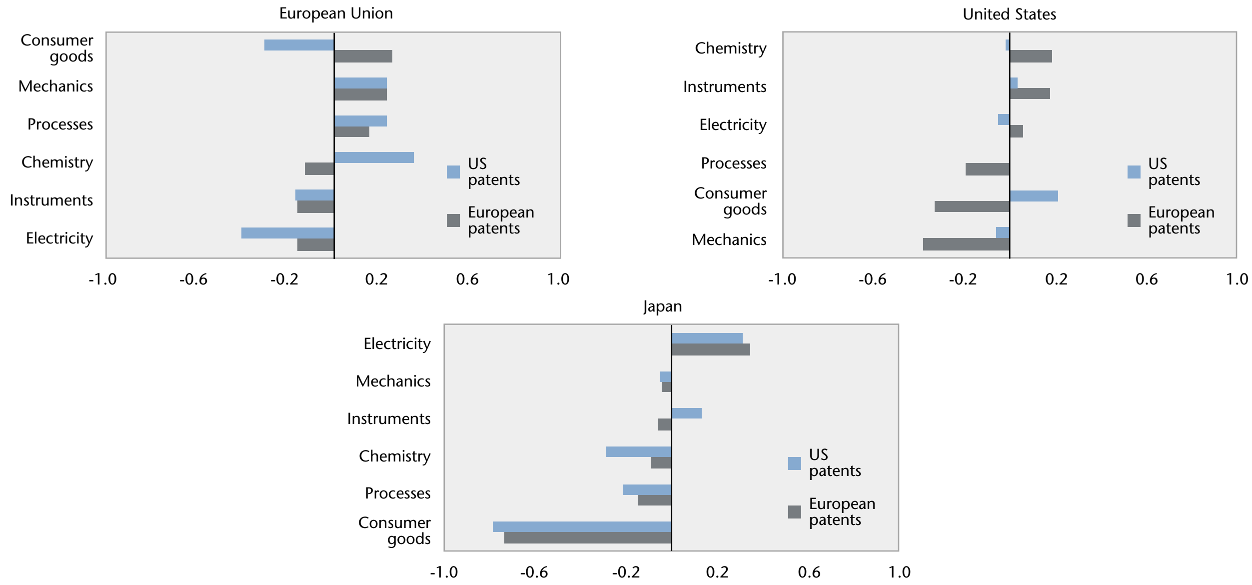
Third European Report on S&T Indicators, 2003

Technological specialisation

Figure 6.1.12 compares the technology specialisation of Europe, US and Japan. As can be seen, Europe's areas of specialisation are Mechanics and Processes, while its weakest specialisation areas are Electricity/Electronics and Instruments. The fields of Chemistry and Consumer Goods show patterns of both greater and lesser specialisation, depending on whether one looks at European or US patents[2].

The US is strong across all main technology fields in terms of US patents, hence its lack of specialisation in any specific field[3]. In its European patents it specialises in Chemistry and Instruments, but is weaker in Mechanics, Consumer Goods and Processes. Japan's strength in Electricity/Electronics is evident, but it lacks specialisation in other fields.

Fig 6.1.12 Technological specialisation of the EU, US and Japan (1999)



Source: DG Research
Data: EPO, USPTO; data processed by OST and Fraunhofer-ISI

Third European Report on S&T Indicators, 2003

The relative specialisation index

The relative specialisation index allows one to identify technology areas in which a country is relatively specialised (when the index is positive) or despecialised (when it is negative).

The index is relative in the sense that it refers to the average position of the country. In other words, a very small country may have a high value of the index for a particular technology area in which it has its highest world share of patents, even though it may have a very low absolute share of world patents in that area.

The index equals zero when a country's share of patents in a particular technology is the same as its overall share of patents for all technologies combined. The index will be positive if the share of the technology is above the country's overall average share (and will tend towards +1 the higher above the average it is). Conversely, the index will be negative if the share of the particular technology is below the overall average (tending towards –1 the lower this share is below the average).

The formula is $RSij = [A_{ij}^2-1] / [A_{ij}^2+1]$, where A_{ij} is the share of country i in technology j divided by the share of country i for all technologies combined.

[2] *For Chemistry the sign of the specialisation indices is systematically the reverse between European and US patenting (figure 6.1.12). This field is similar to Consumer Goods/Construction, where the same phenomenon occurs, but the other way round for each index. This can be explained as follows: Consumer Goods/Construction is the technological field in which the proportion of SMEs is the greatest, and small firms often do not extend their European patents to the US system. This explains the large difference between European patenting (the "local" patent for firms in EU countries) and US patenting in this field. The opposite extreme is found in Chemistry, which includes pharmacy: the major firms dominate here, and a patent is the normal means of protection. Hence, most of the European patents of firms in EU countries will be extended automatically to the US system. Therefore, in terms of relative value, the EU share in Chemistry will be much greater in US patenting than it is in European patenting, while the opposite holds for Consumer Goods.*

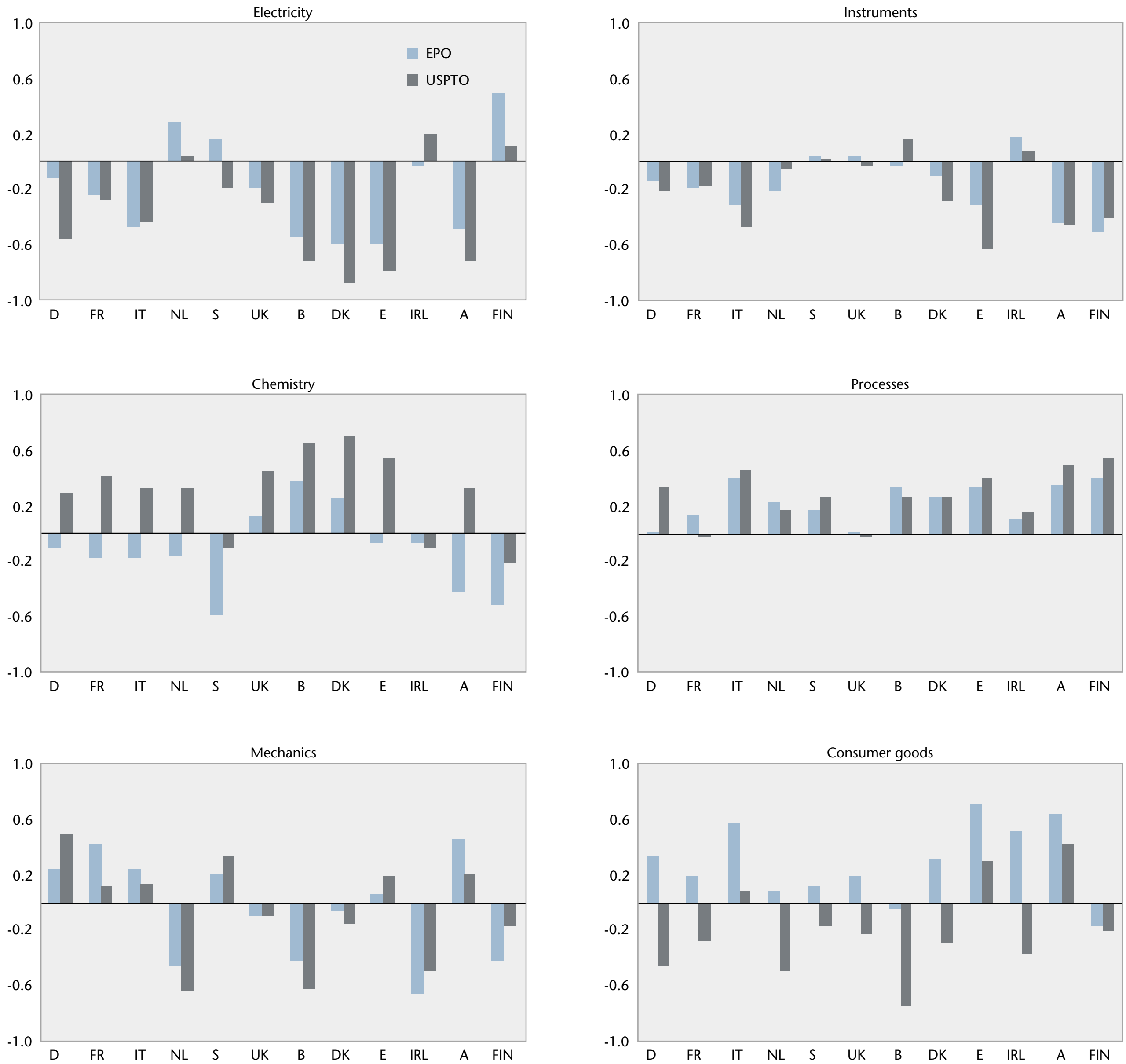
[3] *A country will tend to have a more even distribution of patents across technology fields in its own national patent system than it does in patent offices abroad. When using these data to compare countries' specialisation (and technological competitiveness) it is therefore more revealing to look at their foreign rather than domestic patenting: i.e. to look at EU patents in the US, and US patenting at the European Patent Office.*

Specialisation in EU Member States

Specialisation patterns differ significantly between EU Member States, as shown in figure 6.1.13. Not surprisingly, the overall EU positions are largely reflected in the specialisation profiles of the biggest EU patenting countries (Germany, France, UK and Italy). The UK exhibits a slightly stronger specialisation than the other three in Chemistry, and weaker specialisation in Processes and Mechanics.

Among the other countries the picture is rather different. Finland and the Netherlands have a high positive specialisation in Electricity/Electronics (as do Sweden and Ireland, though to a lesser extent). In Chemistry, while most Member States have a strong degree of specialisation in the US patent system and weaker specialisation in the European system, Belgium, Denmark and the UK appear to be highly specialised in both. Mechanics is an area with two distinct groupings: the smaller countries whose specialisation lies elsewhere (Netherlands, Belgium, Ireland and Finland), and the countries for which this is an area of relative strength, dominated by the larger Member States (Germany, France and Italy), but including Austria, Sweden and Spain.

Figure 6.1.13 Technological specialisation of EU Members States (1999)



Source: DG Research
Data: EPO; data processed by OST

Third European Report on S&T Indicators, 2003

Performance in advanced technology fields

The analyses in the previous section have traced some important developments in patenting across six broad technology fields, which include both traditional technologies and some more advanced technology areas. The following tables narrow the focus to the high-tech end of patenting, using data on Europe's patenting activity in eight technologically advanced sub-fields. These include some of the sub-fields where technological dynamism is the greatest.

Table 6.1.7 Shares of European patents (%) for advanced technological sub-fields (1999)

Country groups	Audio visual	Telecom-munications	IT	Semi-conductors	Analysis-Control	Pharma-ceuticals	Biotech-nology	Materials
European Union	28.6	37.9	26.9	29.2	43.7	35.7	28.3	55.1
Belgium	0.4	0.6	0.4	0.7	0.6	1.0	1.1	1.0
Denmark	0.6	0.4	0.3	0.1	0.7	1.2	1.7	1.3
Germany	9.3	10.8	8.6	13.6	19.5	10.8	7.7	23.5
Spain	0.3	0.2	0.2	0.1	0.5	0.6	0.5	0.9
France	4.0	5.4	4.6	4.5	6.0	7.4	4.2	7.6
Italy	1.2	1.2	1.6	2.4	2.1	2.7	1.1	6.1
Netherlands	5.5	3.5	2.5	2.7	2.1	1.1	2.4	3.0
Austria	0.4	0.3	0.3	0.4	0.7	0.5	0.5	1.5
Finland	0.5	4.3	0.7	0.3	1.0	0.4	0.6	1.8
Sweden	1.1	3.8	1.3	1.1	2.2	1.4	0.9	3.1
UK	4.6	5.7	5.0	2.0	7.3	7.4	7.0	4.4
US	29.0	35.7	49.3	36.2	33.7	43.5	51.3	19.0
Japan	33.1	18.2	16.6	29.4	11.8	10.1	9.8	12.6
World	100	100	100	100	100	100	100	100

Source: OST
Data: EPO; data processed by OST

Third European Report on S&T Indicators, 2003

The EU's performance in high-tech patenting can be summarised as follows:

- in Information technology, Pharmaceuticals and Biotechnology, the US is well ahead of the EU;
- in Materials, the EU, with 55% of European patents, is far ahead of the US and Japan, which are under 20%; Germany's share alone (24%) surpasses these two countries;
- in Telecommunications and Analysis-Control, the EU and the US are at similar, fairly high levels (over 35%) and well above Japan, which is at a more modest level (below 20%);
- in Audio-visual and Semi-conductors, the three poles of the Triad are at a similar level (around 30%).

Among the EU countries, Belgium, Denmark and the UK have strong positions in Biotechnology and Pharmaceuticals. This profile contrasts with that of the Netherlands and Finland, which are strong in Telecommunications and, in the case of the Netherlands, also in Audio-visual.

France, Sweden and Germany are strong in Analysis-Control and Materials, and France and Sweden also in Pharmaceuticals and Telecommunications.

Between 1992 and 1999, the sharpest changes in the EU's share of European high-tech patents occurred for IT and Semi-conductors where the share increased by 33% and 29% respectively, and Biotechnology and Materials where the share declined by 10% (table 6.1.8).

The US improved its world share in all the selected high-tech areas, and in some cases significantly: Audio-visual, Telecommunications and Biotechnology. Conversely, Japan's positions have declined, except in Materials. The sharpest decline (45%) occurred in IT and Biotechnology.

Among the EU Member States, Denmark and Spain have recorded remarkable growth in all the high-tech sub-areas. Finland, Belgium and Sweden also have a very positive overall performance, except in Biotechnology and Materials.

Germany, Austria and Italy have excellent performances in Information technology and Semi-conductors, but show a decline in the other sub-areas, notably Telecommunications. Italy and Austria have seen declining shares in Biotechnology and Pharmaceuticals.

Table 6.1.8 Change in shares of European patents for advanced technological sub-fields (1999, base 100 for 1992)

Country groups	Audio visual	Telecom-munications	IT	Semi-conductors	Analysis-Control	Pharma-ceuticals	Biotech-nology	Materials
European Union	104	102	133	129	97	94	90	90
Belgium	128	96	132	250	119	115	91	96
Denmark	169	136	302	455	138	126	109	156
Germany	94	78	154	167	106	99	81	87
Spain	231	111	178	187	164	106	136	175
France	85	63	85	77	67	93	82	70
Italy	73	65	143	133	78	59	66	134
Netherlands	112	117	142	95	109	79	93	101
Austria	99	65	179	277	75	78	51	108
Finland	119	485	564	332	133	175	69	104
Sweden	167	362	357	341	142	104	84	72
UK	116	89	105	67	89	90	106	71
US	128	120	106	112	114	113	117	106
Japan	71	63	54	68	68	65	55	123
World	100	100	100	100	100	100	100	100

Source: DG Research
Data: EPO; data processed by OST

Third European Report on S&T Indicators, 2003

The Netherlands is progressing well in Audio-visual, Telecommunications and Information technology and maintaining its positions elsewhere. The UK is progressing in Audio-visual, Telecommunications, Information technology and Biotechnology.

France is the only country whose patent share is falling in all the sub-areas reviewed, particularly Telecommunications, Analysis-Control and Materials.

3. Patenting by multinational firms

The invention and ownership of technology by foreign groups

The analysis of a country's patenting performance is complicated by the fact that some of the R&D of its large companies may be carried out abroad. Conversely, affiliates of foreign multinationals in the host country may be performing R&D on its territory. This has been a growing phenomenon over recent years, and has implications for the interpretation of data on patented inventions.

Many patents – in most countries the majority of them – have been applied for by firms which developed the technology in their own country. However, for a significant number of patents, the technology has been invented by an affiliate of a multinational group in one country, but is actually owned by the company at the head of the group which is located in another country. For a given country this means that some of the patents produced by inventors located on its territory in reality relate to foreign-owned patents. Furthermore, a country's multinational firms may also own patents that are produced from R&D carried out abroad by their affiliate companies.

For certain countries the international production and ownership of technology is a very significant phenomenon, which has an important impact on the size and dynamics of their patenting activity. Moreover, the presence of foreign affiliates performing R&D can bring benefits to the host country as well as to the home country of the affiliates. Patents directly reward the owner companies/countries by allowing them to capture the economic returns to the inventive activities of their foreign subsidiaries. The host country may also benefit from various spillover and interaction effects between foreign R&D affiliates and the local economy.

The following analyses identify the important sub-set of patents registered by multinational firms (cf. box concerning "The analysis of multinationals' patenting activities" for more details), and examine both the country where the inventor is located (i.e. where the technology has been produced), and the country in which the headquarters of the multinational group are based (i.e. the country which owns the patented technology).

The analysis of multinationals' patenting activities

This section looks at the sub-set of patents belonging to organisations which registered more than seven European patents during the period 1997-1999 ("major patenters"). The world shares for the various countries differ from those presented before, which were based on the total number of patents.

Between 1997 and 1999, these major patenters comprised 2 700 organisations which together registered about 50% of the total number of European patents. In "Who owns whom?" (Dun & Bradstreet) about 15% of the major patenters are identified as separate bodies and 85% as belonging to an enterprise group.

It is therefore possible to identify two national indicators for each of the patents obtained by the major patenters:

- the country in which the inventor lives, being the country in which the research has been carried out or the technology has been produced (the 'source country');
- the country in which the group (or the patenting company itself if it is not part of a group) is based (the 'owning country').

Each country will be characterised by two patent indicators: the number of patents invented in the country as the source country, and the number of patents controlled by the country as the owning country. Furthermore, it is possible to identify the countries which control (own) all the patents invented by a single country and the inventing (source) countries for all patents controlled by any one country.

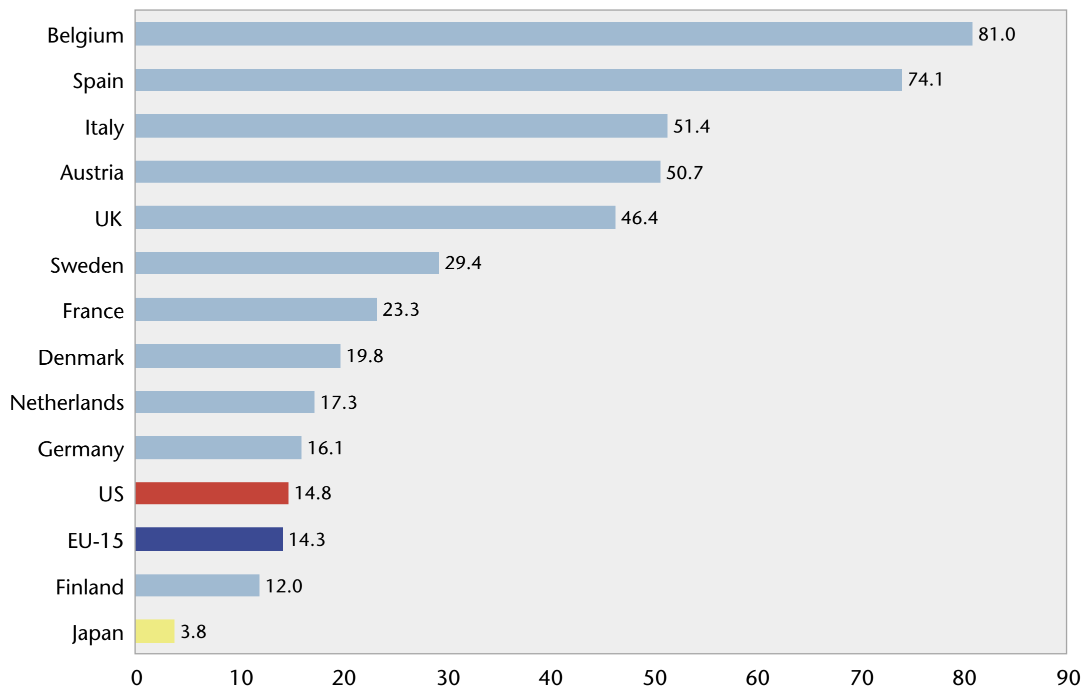
Greece, Portugal, Ireland and Luxembourg are excluded from the analysis due to the low numbers of patents involved.

Technology produced in Europe by foreign multinationals

Roughly one patent in seven invented in the European Union is produced by a non-EU multinational company located in Europe[4]. Nearly three quarters of these are affiliates of US-owned groups.

The situation is more or less identical in the US, where foreign-owned companies with affiliates in the US are responsi-

Figure 6.1.14 Patents produced locally by foreign-owned affiliates (%), 1999



Source: DG Research
Data: EPO; data processed by OST
Note: The graph shows the percentage of European patents produced (invented) in a country by affiliates of foreign-owned multinational groups. The EU figure relates to affiliates of non-EU countries.

Third European Report on S&T Indicators, 2003

[4] *All figures in this section relate to European patents, i.e. those patents applied for at the European Patent Office.*

ble for around 15% of patents invented on US soil, of which 75% relate to EU-owned companies (compare figures 6.1.16 and 6.1.14). However, the bulk of patents produced in Japan (96%) belong to domestic firms.

The proportion of foreign-owned patents produced in the EU is a measure of the degree to which Member States' technological activities involve foreign multinationals. It can also be regarded as a tentative indicator of the openness and attractiveness of EU countries as a place for companies to do research.

Among the Member States, Germany appears to attract the most foreign inventive activity in absolute terms. It is not surprising, since it accounts for the largest number of patent applications in the EU. Germany has by far the greatest number of patents controlled by foreign multinationals, as well as the largest number controlled by other EU countries.

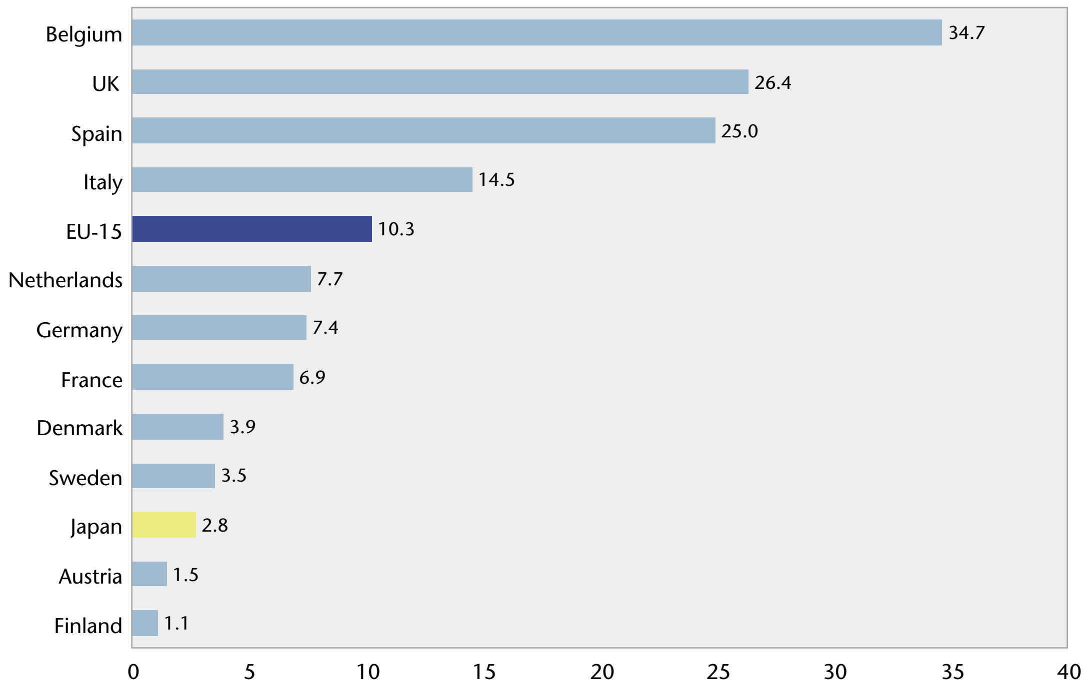
In relative terms, when one looks at the percentage of European patents invented in a country by affiliates of foreign multinationals (figure 6.1.14), Belgium and Spain stand out with the highest presence of technological activity by foreign companies. Four out of five European patents invented in Belgium are controlled by foreign-owned firms. Approximately half of them are multinationals from other EU countries, and the other half are US-owned affiliates. Three quarters of patents invented in Spain belong to foreign multinationals, two thirds of which are from other EU Member States.

In Germany, Finland, Denmark and the Netherlands, less than 20% of locally invented patents are owned by another country, while in the UK, Austria and Italy about half of all this technology is owned by companies from abroad. France and Sweden are in an intermediate position, at 23% and 29% respectively.

After Belgium and Spain, Austria and Italy have the highest proportion of patents owned by foreign multinationals (figure 6.1.14), and also the highest owned by multinationals of other EU countries (figure 6.1.16).

The patenting activities of US companies are most prominent in Belgium, followed by UK and Spain, where approximately one in four patents invented on national territory is owned by a US multinational (figure 6.1.15). There is a marked presence of technologically active Japanese companies in the UK, with 3% of patents invented in the UK attributable to UK-based Japanese subsidiaries, a much higher figure than in any other Member State.

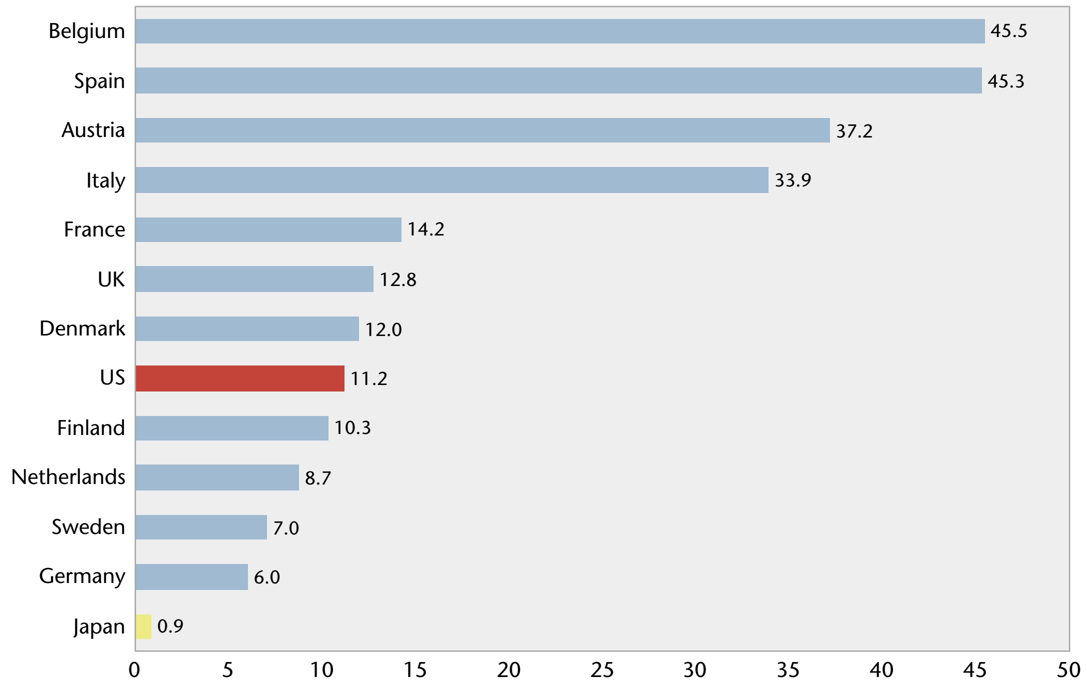
Figure 6.1.15 Patents produced locally by affiliates of US multinationals (%), 1999



Source: DG Research
Data: EPO; data processed by OST
Note: The graph shows the percentage of European patents produced (invented) in a country by affiliates of US-owned multinational groups.

Third European Report on S&T Indicators, 2003

Figure 6.1.16 Patents produced locally by affiliates of EU multinationals, (%), 1999



Source: DG Research
Data: EPO; data processed by OST
Note: The graph shows the percentage of European patents produced (invented) in a country by affiliates of EU-owned multinational groups. For an EU country the data relate to affiliates of other EU countries.

Third European Report on S&T Indicators, 2003

The foreign control of technology produced in France is mainly in the hands of other EU countries. In the case of Sweden, the controlling countries are mainly EU countries and non-EU European countries (Switzerland, Norway, etc.).

Technology produced abroad by European multinationals

Approximately one in nine European patents owned by EU firms have been invented by EU subsidiaries located outside the EU. More than three quarters of these relate to subsidiaries based in the US. This compares with one in six patents controlled by US groups but invented in a foreign country. In contrast, Japanese firms produce the bulk of their technology in Japan (only one in 23 patents controlled by Japan is invented by a subsidiary abroad), indicating a rather weak globalisation of technology[5].

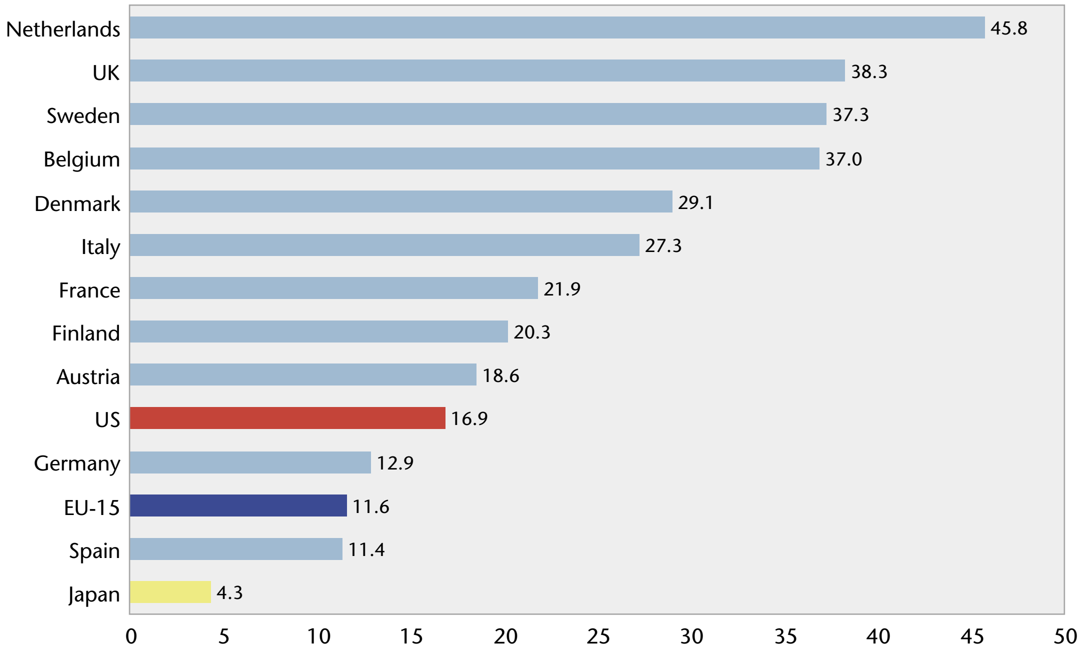
Within the EU, there are major differences in the proportion of inventive activity undertaken by affiliates of EU multinationals abroad. Germany and Spain have the lowest percentage of patents produced by their overseas affiliates (13% and 11% respectively)[6]. In contrast, the Netherlands, UK, Sweden and Belgium have more than a third of their patents invented by their multinationals' affiliates abroad. For the Netherlands this figure is almost 50% .

Comparing figure 6.1.19 with figure 6.1.17, one sees first that the foreign patent-producing affiliates of Belgian and Dutch multinationals are mainly located in other EU countries. However, those of the UK and Sweden are mostly found in the US (a comparison of figures 6.1.18 and 6.1.17 reveals that 66% of UK foreign affiliates producing patents are based in the US, compared with 53% for Sweden).

[5] *The globalisation of technology is a complex issue, and depends also on the type of technology and the strategy of the enterprise. Pavitt and Patel found evidence that multinationals tended to concentrate the development of their core technologies at home (Patel, P. and Pavitt, K. (1990) Large Firms in the Production of the Worlds Technology: An Important Case of Non Globalisation, Journal of International Business Studies).*

[6] *Although in absolute terms, Germany is the leading Member State in the number of patents produced by its affiliate companies abroad, in relative terms it is only a small percentage of all German owned patents.*

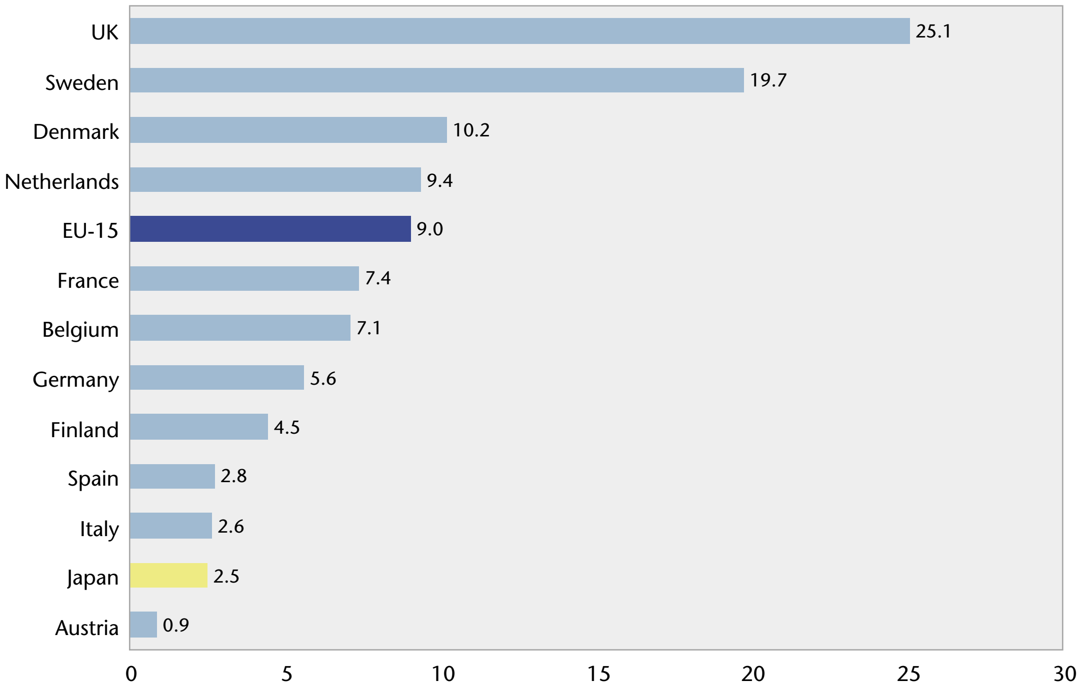
Figure 6.1.17 Patents produced by a country's foreign-based affiliates, % (1999)



Source: DG Research
Data: EPO; data processed by OST
Note: The graph shows the percentage of the European patents owned by a country (i.e. by its companies or other major patenting institutions) that are produced (invented) abroad by affiliates of its own multinationals. The EU-15 figure relates to affiliates based outside the EU. The Member States' figures include affiliates based in other EU countries.

Third European Report on S&T Indicators, 2003

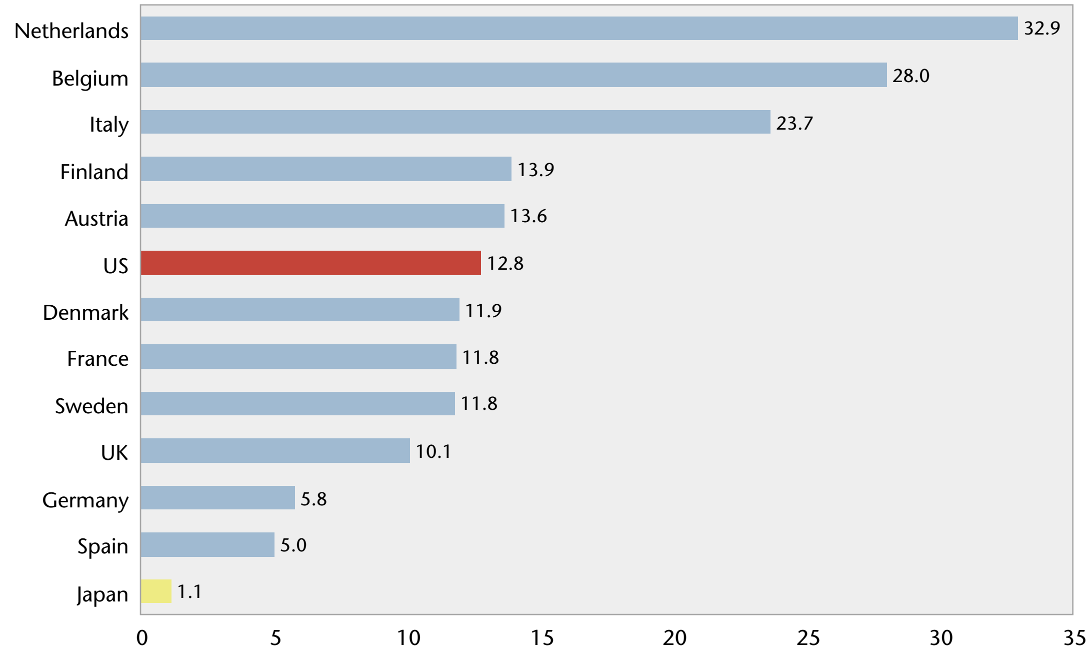
Figure 6.1.18 Patents produced by a country's affiliates based in the US, % (1999)



Source: DG Research
Data: EPO; data processed by OST
Note: The graph shows the percentage of European patents owned by a country (i.e. by its companies or other major patenting institutions) that are produced (invented) in the US by affiliates of its own multinationals.

Third European Report on S&T Indicators, 2003

Figure 6.1.19 Patents produced by a country's affiliates based in the EU, % (1999)



Source: DG Research
Data: EPO; data processed by OST
Note: The graph shows the percentage of the European patents owned by a country (i.e. by its companies or other major patenting institutions) that are produced (invented) in the EU by foreign affiliates of its own multinationals. For an EU country the figures relate to its affiliates in other EU countries.

Third European Report on S&T Indicators, 2003

4. A final look at EU patenting performance: the link with research effort and challenges for the future

The data presented in this section indicate that since 1992 the EU has lost share of patents to the US at the EPO and at the USPTO. Nevertheless, there have been some encouraging signs of EU growth and consolidation since the second half of the 1990s. In terms of its share of higher value Triad patents, the EU is doing reasonably well, following just behind the US.

Despite leading in some technologies (notably Materials), the EU is performing less well in certain key fields such as IT, Pharmaceuticals and Biotechnology. The situation varies significantly between Member States, and the stronger dynamism of the smaller EU countries is particularly evident.

Since the mid-1990s, there has been a significant increase in the absolute volume of patenting worldwide, with patenting by EU inventors very much part of this general rise. Some of this expansion in patenting activity can be attributed to various non-technological factors[7], and some to the surge in fields which have a high propensity to patent (such as ICT and Biotechnology). There is also evidence that it is linked to a real innovation dynamic, and a growing strategic use of patenting, both as a protection tool and as a factor in inciting inter-firm co-operation[8].

It is all the more interesting to examine this rise in numbers of patents in relation to recent trends in business R&D spending. It would be over-simplistic to relate patenting output directly to overall R&D obtaining a measure of technological productivity. However, research effort and patented inventions are linked, and a comparison of their respective trends raises some interesting questions.

When set against its business R&D effort, the EU's performance in patenting has been relatively healthy since the late 1990s (figure 6.1.20). The surge in patenting activity around the end of the millenium has led to an increase in the numbers of European and US patents per unit of research expenditure for the EU, the US and Japan. Of particular interest is that, in spite of a much more modest increase in R&D spending by EU businesses compared with their US counterparts (cf. chapter 3), Europe has managed to generate significant growth in patenting, both in the European patent system and

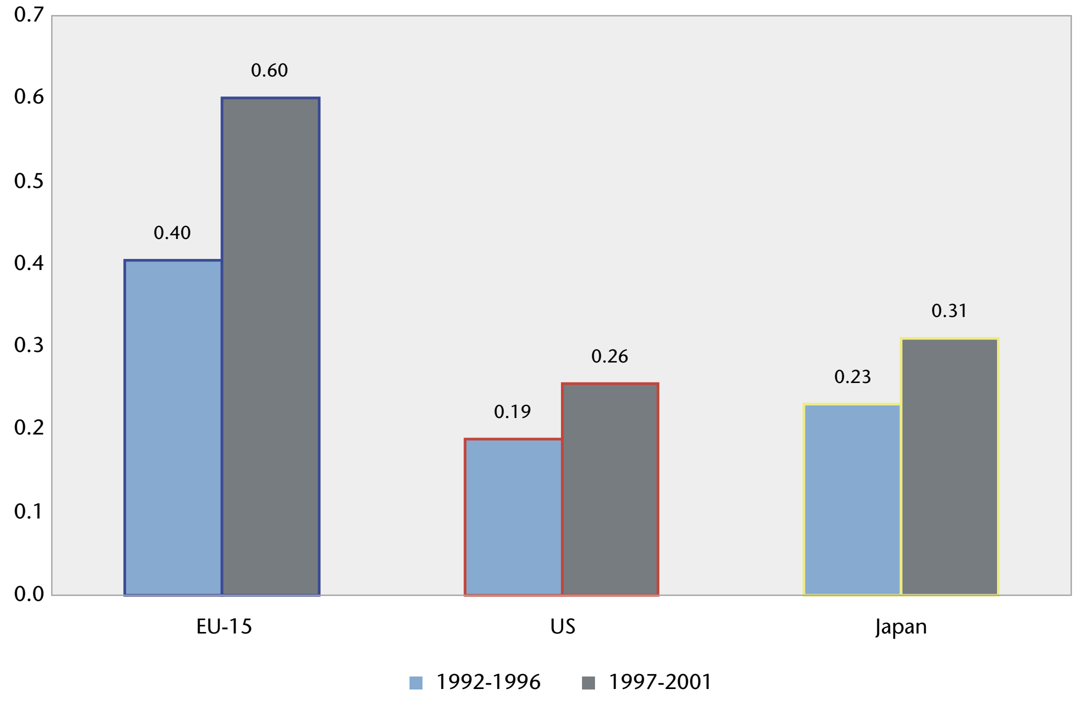
[7] *An example is that patenting in Europe has been boosted by the extensive use of the Patent Co-operation Treaty procedure, which has the advantage of delaying the decision on cost-intensive foreign patenting , allowing more time to assess whether an invention will be successful in a foreign market.*
[8] *OECD (2001) "Science, technology and industry outlook: The drivers of growth; information technology, innovation and entrepreneurship".*

in terms of US patents. This would suggest that EU patenting activity has been boosted by more than just an expansion of business research spending. A logical question would be whether there has been a real surge in the inventiveness of EU firms, which has been achieved without significant extra financing. It would also be interesting to know to what extent various government measures may have played a part in stimulating patenting in Europe, such as promoting IPR in public research institutes, establishing commercialisation units for public science, and simplifying patent procedures. Such effects might be characterised on the one hand as a rationalisation of innovation systems in Europe, but also as the impact of indirect non-financial actions aimed at improving framework conditions for innovation.

Looking to the future, there are a number of policy challenges. In general, there is a need to reinforce the various measures already undertaken to facilitate and stimulate the use of patenting as a strategic instrument by EU inventors, and to encourage innovation in enterprises. However, there are limits to the additional inventions and patenting that can be generated through government policy initiatives, without firms injecting substantially higher R&D funds. If the EU manages to raise business R&D spending in line with the targets set by European governments at the Barcelona summit, this would be an important stimulus to the creation of new technologies.

Complementary to this is the initiative to create a Community Patent, which is now high on the EU agenda (cf. box). Such an instrument would be more attractive and affordable than the existing ones. It should also help to encourage innovative activity and in particular to stimulate business R&D spending.

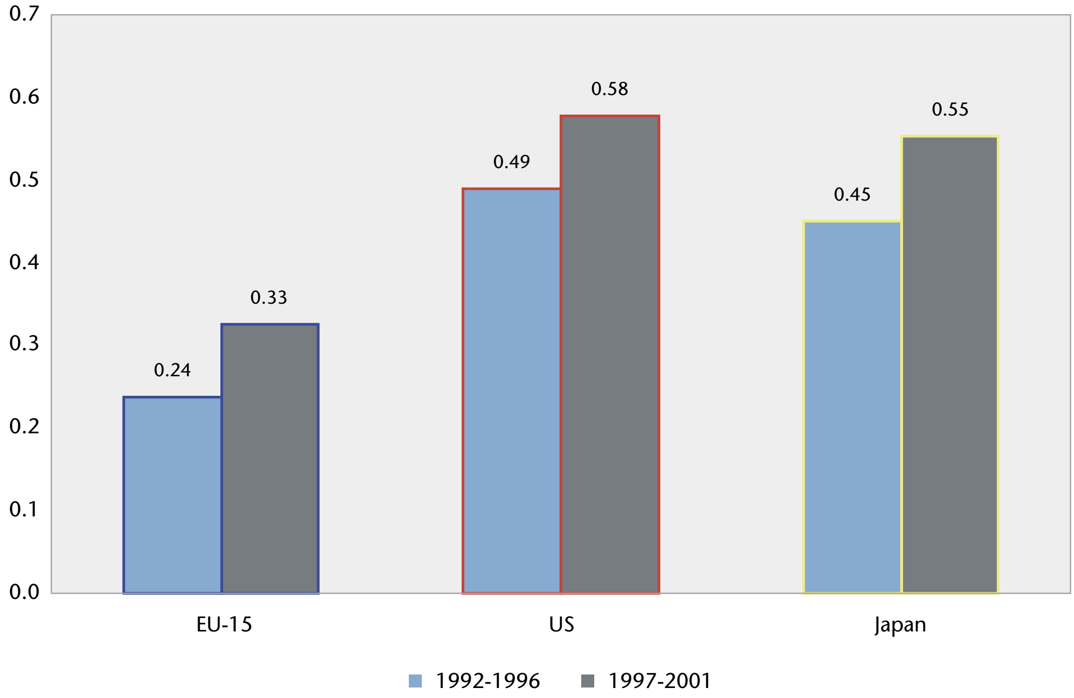
Figure 6.1.20 European patents per unit of business R&D expenditure



Source: DG Research
Data: EPO, data processed by OST; OECD, Eurostat
Note: Business R&D (BERD) measured in million purchasing power standards (PPS) at 1995 prices. Calculated using a two-year time lag between year of R&D expenditure and year of patenting.

Third European Report on S&T Indicators, 2003

Figure 6.1.21 US patents per unit of business R&D expenditure



Source:	DG Research
Data:	USPTO, data processed by Fraunhofer-ISI; OECD, Eurostat
Note:	Business R&D (BERD) measured in million PPS at 1995 prices. Calculated using a two-year time lag between year of R&D expenditure and year of patenting.

Third European Report on S&T Indicators, 2003

Proposal for a Community Patent

The current cost of patenting

At present, patents are awarded either on a national basis or through the EPO in Munich, which grants European Patents. These are essentially a bundle of national patents. The EPO, established by the intergovernmental European Patent Convention of 1973, offers an application and granting procedure and so saves the applicant the trouble of having to file with a series of national patent offices. Nevertheless, Member States may still require the European Patent, in order to be legally valid in their territories, to be translated into their official languages. Because of the cost of translation it is currently significantly more expensive to patent an invention in Europe than it is in the US or Japan. Moreover, in the case of disputes, the national courts have competence. In principle, therefore, there can be 15 different legal proceedings, with different procedural rules in every Member State and with the risk of different outcomes.

The aim of the Community Patent

The European Commission has proposed the creation of a Community Patent to make it possible for inventors to obtain a single patent which is legally valid throughout the European Union[9]. By reducing the cost of obtaining a patent, and providing a clear legal framework in case of dispute, this proposal would help to lighten the burden on business and to encourage innovative activity. The Lisbon and Feira European Councils in 2000 cited the creation of a Community Patent as an essential part of Europe's efforts to harness the results of research to new scientific and technological developments and so contribute to ensuring a competitive, knowledge-based economy in Europe.

The Community Patent would create a new unitary industrial property right which would help to remove distortions of competition due to the territorial nature of national protection rights. At the same time, it should encourage the free movement of goods protected by patents, and make it easier for firms to expand their activities to the European level. It could also prove to be a critical tool for stimulating business R&D in Europe, and improving Europe's ability to translate its strong performance in research and knowledge into commercially successful products.

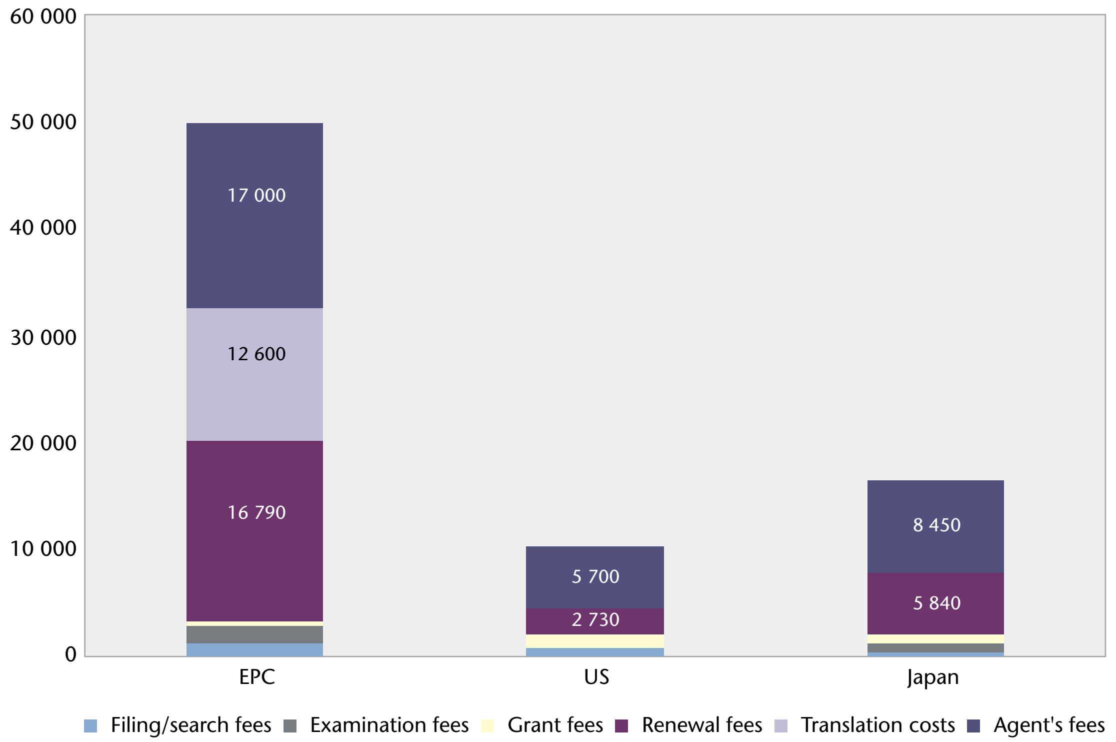
---

[9] *"Proposal for a Council regulation on the Community patent", COM (2000) 412 final, August 2000.*

One of the key aims of the Community Patent is to provide a more affordable and more attractive instrument than the present European Patent. Moreover, it is essential for the overall cost of a Community Patent to be in the same order of magnitude, or even cheaper, than that of patents granted by the Community's main trading partners. Figure 6.1.22 provides a comparison of the current situation in the United States, Japan and the EPO as regards the various costs and fees due.

The cost of the current European Patent is three to five times higher than that of Japanese and US patents. There is evidently an urgent need to improve the incentives for inventors to apply for a patent in Europe.

Figure 6.1.22 Cost of obtaining a patent (€)



Source: DG Research
Data: "Proposal for a Council regulation on the Community patent", COM (2000) 412 final, August 2000

Third European Report on S&T Indicators, 2003

Section II Trade in high-tech products: Europe's performance

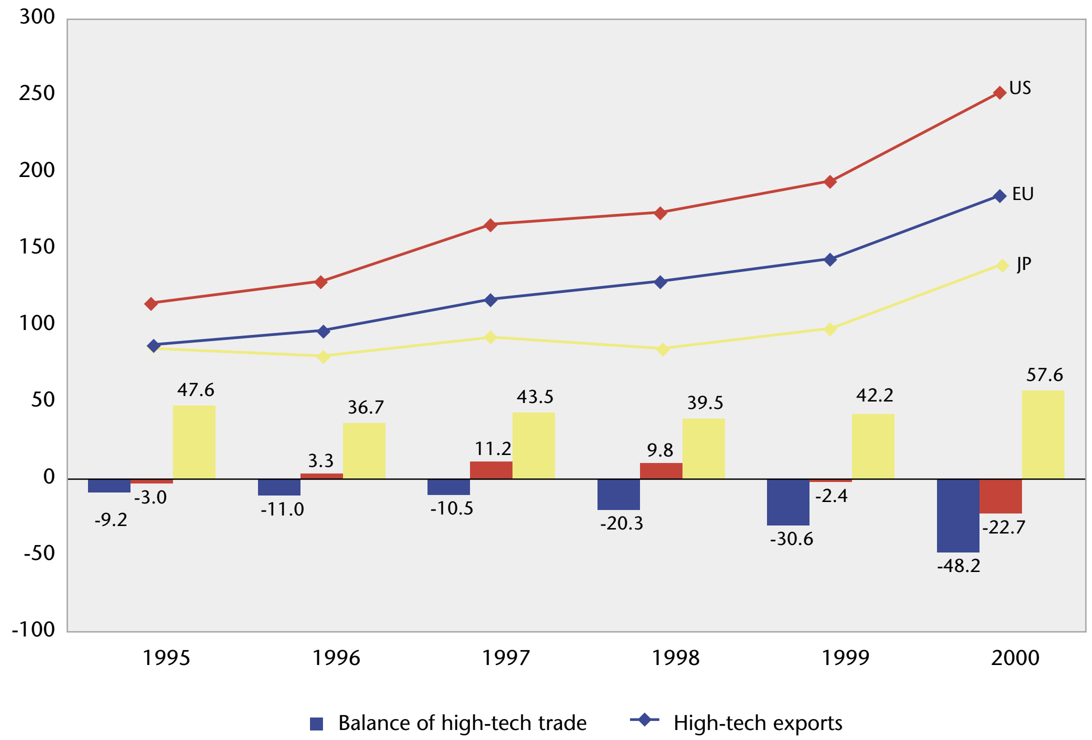
High-tech products represent the technological leading edge of traded goods. In many advanced economies, high-tech trade accounts for around 20-25% of total imports and exports (cf. figure 6.2.9). High-tech products reflect a country's ability to carry out research and development, and to exploit the results in global markets. Moreover the industries producing these goods are generally a source of high value added and well-paid employment. Exports of such products therefore represent an important indicator of competitiveness in the knowledge-based economy, and also embody and diffuse many new technologies which have an impact on both the economy and society.

1. Main global trends in high-tech trade

The European and US trade deficits widened in 2000, while Japan increased its strong surplus. The EU's trade deficit in high-tech products has grown from 9 billion euro in 1995 to 48 billion euro in 2000. Japan's high-tech trade surplus was more or less stable from 1995 to 1999, but registered a further increase of 15 billion euro in 2000. In contrast, since 1999 the US balance has moved from a surplus to a deficit position.

In 2000 the EU's trade in high-tech products amounted to 185.4 billion euro in exports (19.7% of total exports) and 233.6 billion euro in imports (22.7% of total imports). The corresponding figures for 1995 were 87.7 billion euro (15.3%) and 96.9 billion euro (17.8%) respectively.

Figure 6.2.1 Trade in high-tech products (€ billion), 2000



Source: DG Research
Data: Eurostat (Comext), UN (Comtrade)

Third European Report on S&T Indicators, 2003

The interpretation of high-tech trade statistics

What is high-tech trade?

Essentially, high-tech trade covers exports and imports of those products with a high intensity of R&D. Such products represent the technological leading edge of traded goods. High-tech products come from the following main product groups : Aerospace, Computers, Electronics and Telecommunications, Pharmaceuticals, Electrical and Non-electrical machinery, Chemistry and Armaments. A detailed definition and list of high-tech products is given in the table at the end of this section.

However, it should be borne in mind that exports and imports of high-tech products are not the same as the exports and imports made by high-tech industrial sectors. Not all the goods produced by high-tech sectors are actually high-tech products. For example, less than 10% of products in the chemical industry are high-tech, the remainder being either medium or even low tech. The data given in this section for exports of chemicals relate only to high-tech chemical products and not to the total exports of the chemical industry.

What is the importance of trade in high-tech products?

High-tech products are generally among those products at the leading edge of technological innovation. High-tech products are amongst the most dynamic traded internationally, and the growth in their trade has been significantly stronger than that of other traded goods. Producing and selling high-tech products is important for several reasons. It reflects a country's ability to carry out R&D and develop new knowledge, and to turn this into advanced goods and services sold in global markets. These activities lead to strong gains of dynamic efficiency, increase overall productivity and favour a virtuous circle of learning, productivity and competitiveness.

Is a high-tech trade deficit necessarily a bad thing?

Trade in high-tech products reflects the specialisation of countries. In recent decades established specialisation patterns have generally consolidated, as countries produce and sell more efficiently the types of products they are more familiar with. For high-tech products in particular, strong entry barriers exist for countries wishing to develop their production, notably the need for advanced knowledge, large investment requirements and high minimum efficient scales of production.

In the last decades Europe has lost its advantage in high-tech trade and has been running increasing trade deficits for these products, largely due to the computer and Electronics sectors. While the loss of domestic production capacity in these fields is problematic, a strong import of such goods can be beneficial for the economy as they incorporate new knowledge which may increase productivity of the user sectors. Moreover, a country's imports of high-tech may be complementary to its exports.

Global market shares in high-tech trade

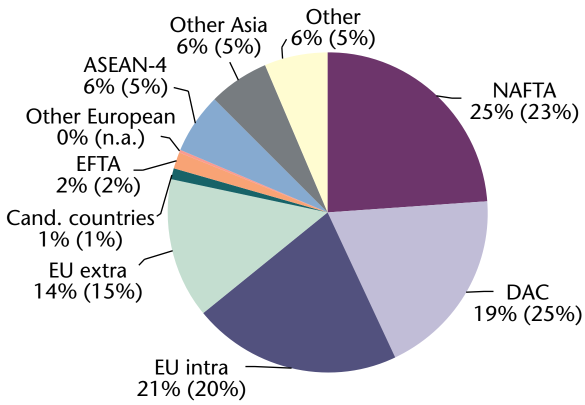
Figure 6.2.2 shows regions' shares in world trade of high-tech products. In 1999, EU exports to third countries amounted to 14% of the global high-tech market[10]. This is one percentage point below its 1995 level. Exports between EU countries account for a further 20% of all global high-tech trade, making the EU by far the largest intra-regional market in the world.

However, one should exclude intra-EU trade when comparing EU exports with those of the US and Japan. Thus the EU's 14% market share for exports to non-EU countries in 1999 was somewhat below the 19% share of the US, but ahead of Japan (10%).

NAFTA accounts for 25% of global exports, the bulk of which is attributable to the US .

Next come the Developed Asian countries[11] (DAC) with a world market share of 19%, of which Japan remains the leading player (10% world share). The DAC share has fallen sharply from its level of 25% in 1995, due largely to the decline over this period in the export market share held by Japan and Singapore. However, the Association of South East Asian Nations (ASEAN) and other Asian countries' market shares have increased over the same period. China and Hong Kong have been especially dynamic with market shares of 3% each, just below South Korea and Malaysia.

Figure 6.2.2 Share of the world market in exports of high-tech products, 1999 (1995 figure in brackets)



Source: DG Research
Data: Eurostat (Comext), UN (Comtrade)
Note: Candidate countries = BG, CY, CZ, EE, HU, LV, LT, MT, PL, RO, SI, SK, TR
NAFTA = US, CA, MX
EFTA = CH, IS, NO
Developed Asian countries (DAC) = JP, KR, SG, TW
ASEAN-4 (Assoc. of South East Asian Nations) = ID, MY, PH, TH.
Other Asia = IN, PK.
Third European Report on S&T Indicators, 2003

Table 6.2.1 Top 10 exporters of high-tech products

	World market share % (1999)	Av. annual growth in exports % (1995-1999)
1 US	19	14
2 EU-15	14	13
3 Japan	10	4
4 France	7	13
5 Germany	7	12
6 UK	6	13
7 Singapore	6	8
8 Netherlands	4	21
9 South Korea	4	14
10 Malaysia	4	18

Source: DG Research
Data: Eurostat (Comext), UN (Comtrade)
Note: "EU-15" = exports from EU to non-EU countries (i.e. excludes intra-EU trade).
The World total used to calculate market shares includes intra-EU trade.
Third European Report on S&T Indicators, 2003

[10] *These data are calculated by defining the world market as the sum of exports of all countries (which includes intra-EU export flows). Sometimes market shares are calculated excluding intra-EU trade from the world total. In this latter case, the high-tech export market shares for 1999 would become: EU 18% (exports to non-EU countries), US 25% and Japan 12%.*

[11] *The Developed Asian countries are Japan, South Korea, Singapore and Taiwan*

What is high-tech trade?

High-tech trade is defined as exports and imports of the products listed below. This list, drawn up by the OECD, contains technical products of which the manufacturing involved a high intensity of R&D (product codes are SITC Rev.3).

1. Aerospace

792 = Aircraft and associated equipment, excluding 7928, 79295, 79297
714 = Aeroplane motors, excluding 71489, 71499
87411 = Other navigational instruments

2. Computers - Office Machines

75113 = Word-processing machines
7513 = Photo-copying apparatus excluding 75133, 75135
752 = Computers:excluding 7529
75997 = Parts and accessories of group 752

3. Electronics - Telecommunications

76381 = Video apparatus
76383 = Other sound reproducing equipment
764 = Telecommunications equipment excluding 76493, 76499
7722 = Printed circuits
77261 = Electrical boards and consoles 1000V
77318 =Optical fibre cables
77625 =Microwave tubes
77627 =Other valves and tubes
7763 = Semi-conductor devices
7764 = Electronic integrated circuits and micro-assemblies
7768 =Piezo-electric crystals
89879 =Numeric recording stays

4. Pharmacy

5413 = Antibiotics
5415 = Hormones and their derivatives
5416 = Glycosides, glands, antisera, vaccines
5421 = Medicaments containing antibiotics or derivatives thereof
5422 = Medicaments containing hormones or other products of heading 5415

5. Scientific Instruments

774 = Electro-diagnostic apparatuses for medicine or surgery and radiological apparatuses
871 = Optical instruments and apparatuses
87211 = Dental drill engines
874 = Measuring instruments and apparatuses excluding 87411, 8742
88111 = Photographic cameras
88121 = Cinematographic cameras
88411 = Contact lenses
88419 = Optical fibres other than those of heading 7731
8996 = Orthopaedic appliances excluding 89965, 89969

6. Electrical machinery

7786 = Electrical capacitors, fixed, variable or adjustable excluding 77861, 77866,77869
7787 = Electrical machines having individual functions
77884 = Electric sound or visual signalling apparatus

7. Non-electrical machinery

71489 = Other gas turbines
71499 = Part of gas turbines
7187 = Nuclear reactors and parts thereof, fuel elements etc..
72847 = Machinery and apparatus for isotopic separation
7311 = Machine-tools working by laser or other light or photon beam, ultrasonic electro-discharge or electro-chemical processes
7313 = Lathes for removing metal excluding 73137, 73139
73153 = Other milling machines, numerically controlled
7316 = Machine-tools for deburring, sharpening, grinding, lapping etc; excluding 73162, 73166, 73167, 73169
73312 = Bending, folding, straightening or flattening machines, numerically controlled
73314 = Shearing machines, numerically controlled
73316 = Punching machines, numerically controlled
7359 = Parts and accessories of 731- and 733-
73733 = Machines and apparatuses for resistance welding of metal fully or partly automatic
73735 = Machines and apparatuses for arc, including plasma arc welding of metal; fully or partly automatic

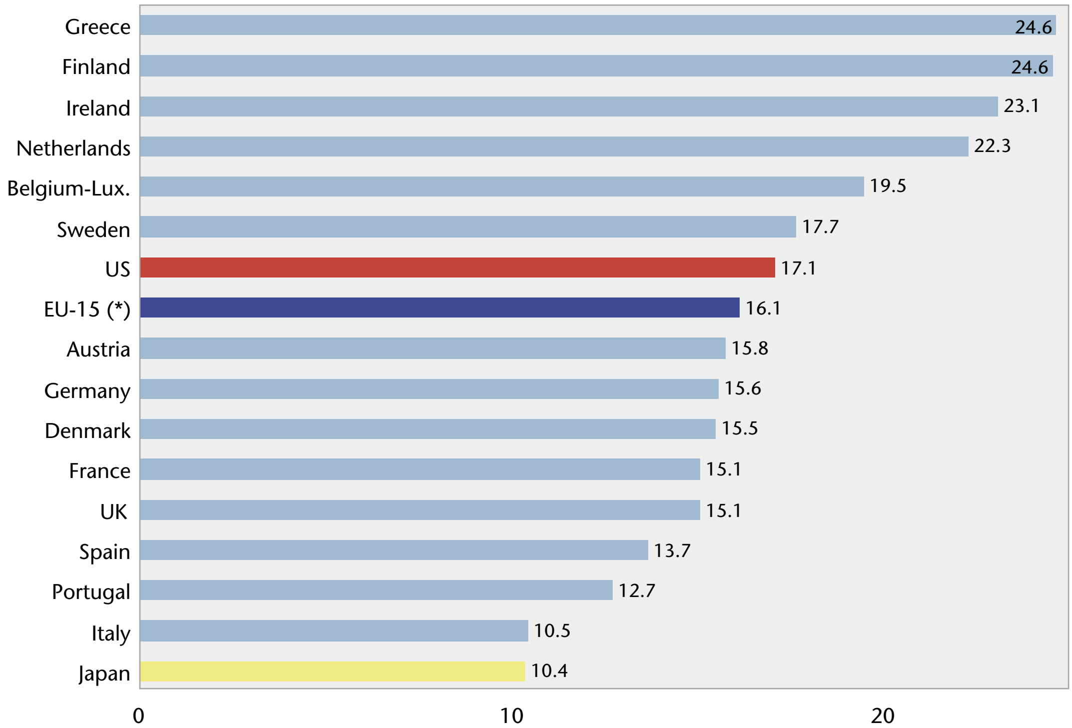
8. Chemistry

52222 = Selenium, tellurium, phosphorus, arsenic and boron
52223 = Silicon
52229 = Calcium, strontium and barium
52269 = Other inorganic bases
525 = Radio active materials
531 = Synthetic organic colouring matter and colour lakes
57433 = Polyethylene terephthalase
591 = Insecticides, disinfectants

9. Armament

891 = Arms and ammunition

Figure 6.2.3 Average annual growth in high-tech exports, % (1995-2000)



Source: DG Research
Data: Eurostat (Comext), UN (Comtrade)

Third European Report on S&T Indicators, 2003

Growth in high-tech exports: the main world regions compared

High-tech exports have risen substantially in value terms since 1995 in all three of the main relevant economies – the EU, the US and Japan[12]. Figure 6.2.3 shows that the EU's exports of high-tech products rose almost as fast as those of the US between 1995 and 2000. The EU posted an average yearly increase of 16.1% in its high-tech exports between 1995 and 2000, compared with 17.1% in the US and 10.4% in Japan. At the same time the even faster growth of the EU's imports of high-tech products (19.2% per year on average) contributed to widening the trade deficit.

In Europe and America, growth in high-tech trade considerably outstripped growth in total goods exports which increased by an average of 10.4% and 13.7% respectively over the same 5 year period. Japan's growth in high-tech exports (10.4%) was only slightly higher than the growth in total Japanese exports (8.9%).

2. Europe's main partners in high-tech trade

The previous sections have outlined the main global trends in high-tech trade. This section considers the European scale, by seeking to answer the question 'What are the patterns of the EU's trade in high-tech products?' Broadly seen, this section looks at the EU's main high-tech trading partners, in terms of both exports and imports, and areas of growth. This sets the scene for a more detailed analysis of trends in EU exports and imports. The section closes by bringing all this data together to consider the EU balance of trade in high-tech products.

Overview

Table 6.2.2 gives an overview of the EU's top ten trading partners in high-tech products. On the export side, the US and Switzerland are the top two trading partners of the EU, followed by Japan. The importance of the Asian countries in EU high-tech trade can be seen in both exports and imports. EU purchases of high-tech products from China have grown particularly strongly since 1995, making China now the third largest source of EU imports.

[12] *In general, trade here is measured in value terms in ecus/euro. Owing to the strong appreciation of the dollar and the yen against the ecu/euro since 1995 (and especially in 2000), trade growth will be considerably higher when expressed in its euro value than in dollars or yen.*

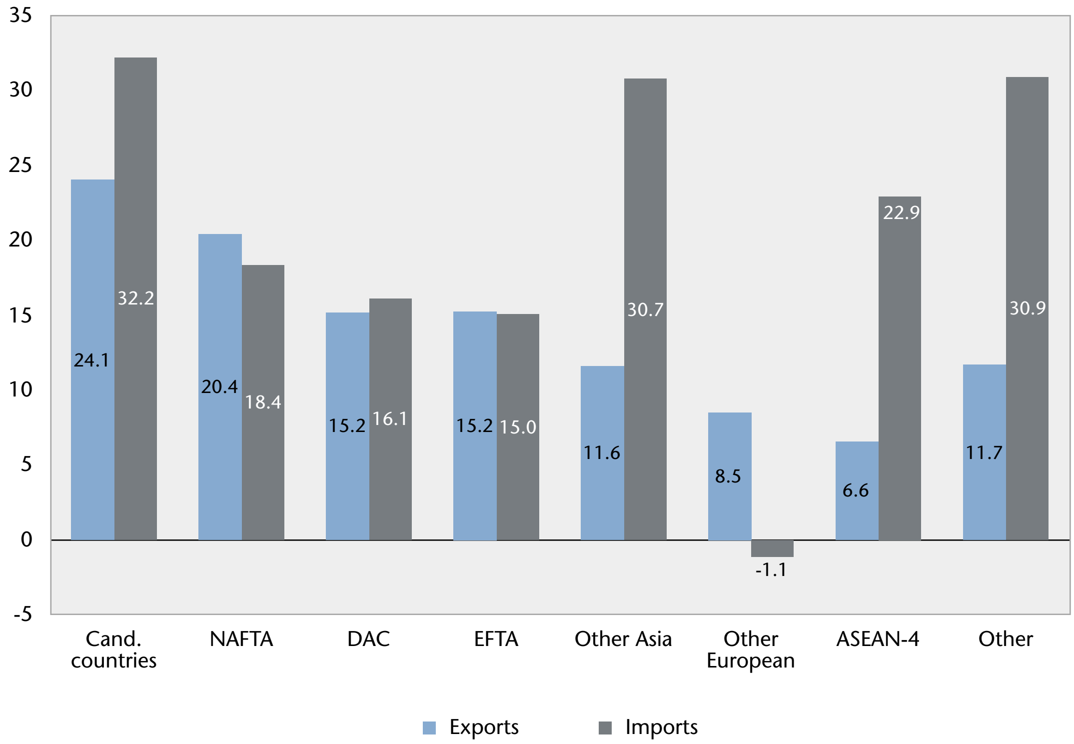
Table 6.2.2 The EU's top ten partners in high-tech trade

	High-tech exports			*High-tech imports*	
	Share of EU-15 exports % (2000)	Average annual growth (%) in EU-15 exports (1995-2000)		Share of EU-15 imports % (2000)	Average annual growth (%) in EU-15 imports (1995-2000)
1 US	27.7	19.6	1 US	35.6	18.1
2 Switzerland	7.3	15.2	2 Japan	11.8	11.4
3 Japan	4.6	10.8	3 China	6.2	36.4
4 China	3.4	15.9	4 Taiwan	6.1	23.0
5 Turkey	2.8	27.0	5 Switzerland	5.0	15.0
6 Singapore	2.8	16.4	6 Singapore	4.6	13.9
7 Hong Kong	2.6	8.1	7 South Korea	4.5	27.6
8 Canada	2.5	24.5	8 Malaysia	3.7	16.5
9 Taiwan	2.3	22.2	9 Canada	2.4	20.5
10 South Korea	2.1	17.9	10 The Philippines	2.0	42.7

Source: DG Research
Data: Eurostat (Comext)

Third European Report on S&T Indicators, 2003

Figure 6.2.4 Growth in EU-15 high-tech trade by partner zone, average annual growth (1995-2000)



Source: DG Research
Data: Eurostat (Comext)

Third European Report on S&T Indicators, 2003

Growth in EU trade by partner region

Another way of expressing the main data can be seen in figure 6.2.4, which shows the growth in EU imports and exports by trade partner region. During the late 1990s, the EU's high-tech trade with the Candidate countries registered the strongest dynamics, both on the export side (average annual growth of 24%) and on the import side (32%). The EU's next most dynamic export market during this period was NAFTA, where export values rose on average by 20% per year.

After the Candidate countries, the highest growth of EU's imports of high-tech have been from the emerging Asian economies. Imports from the ASEAN countries increased by 23% per year, while those from China and Hong Kong increased even more sharply (32%).

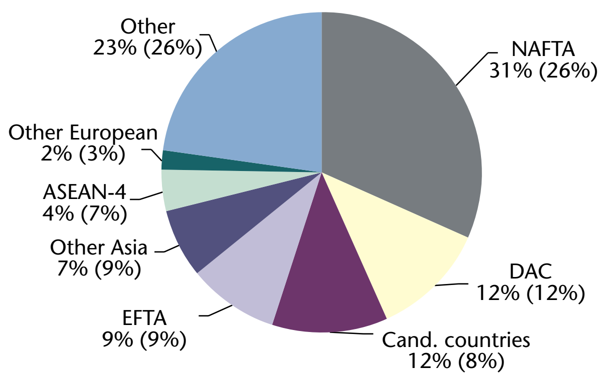
EU exports of high-tech products

North America and Asia remain the most important markets for EU exports, representing 55% of EU high-tech sales abroad. Figure 6.2.5 gives an overview of the EU's high-tech exports in 2000, with 1995 figures in brackets. The share of EU high-tech exports sold to NAFTA countries has risen from 26% in 1995 to 31% in 2000, while the Developed Asian countries accounted for 12% of EU sales in 2000.

The Candidate countries have also emerged as one of the EU's major markets for high-tech goods, accounting for 12% of all EU exports in 2000. This is up from 6% in 1995, and now equals the share for the Developed Asian countries (Japan, Korea, Singapore and Taiwan).

In terms of individual countries, the US is still the number one destination for EU exports, representing 28% of all high-tech sales outside Europe. Next are Switzerland and Japan (7% and 5% respectively), followed by China, which has risen steadily to become an important high-tech market.

Figure 6.2.5 Breakdown of EU-15 high-tech exports by main partner zone, 2000 (1995 figure in brackets)



Source: DG Research
Data: Eurostat (Comext)
Note: For definition of partner zones cf. note to figure 6.2.2.
Third European Report on S&T Indicators, 2003

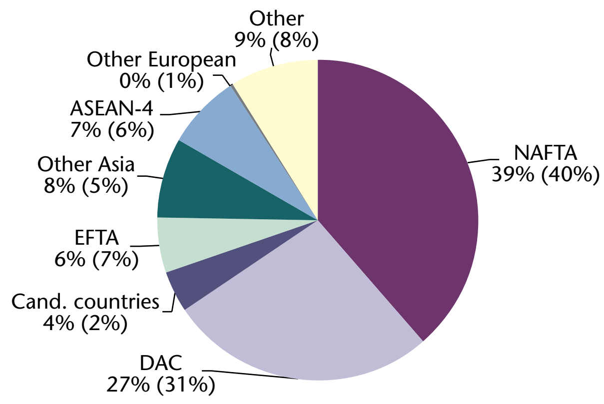
EU imports of high-tech products

While figure 6.2.5 displays EU high-tech exports, figure 6.2.6 below shows the sources of its high-tech imports.

NAFTA and the developed Asian economies supply two thirds of the EU's high-tech imports, 28% of which is due to the US alone. While NAFTA's share of the European market has held steady since 1995, the share of the Developed Asian countries has fallen from 31% to 27%. Much of this change is attributable to the arrival of other Asian economies, notably China and Hong Kong, whose exports to the EU tripled in value from 1995 to 2000. China is now the third most important supplier of high-tech products to the EU, with just over 6% of the imports market.

The new dynamism of the Candidate countries is apparent again, with their share of the EU import market almost doubling since 1995 to 4% in 2000.

Figure 6.2.6 Breakdown of EU-15 high-tech imports by main partner zone, 2000 (1995 figure in brackets)

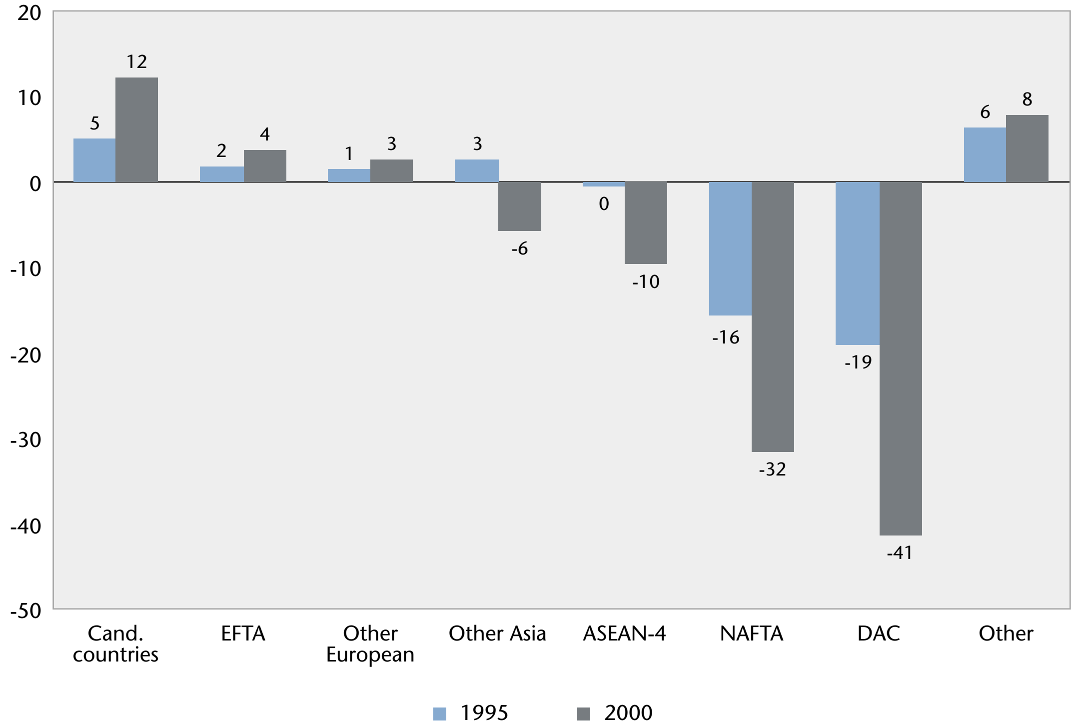


Source: DG Research
Data: Eurostat (Comext),
Note: For definition of partner zones cf. note to figure 6.2.2.
Third European Report on S&T Indicators, 2003

EU's balance of high-tech trade

Whereas figure 6.2.5 and 6.2.6 has provided an overview of the EU's high-tech exports and imports, the focus now shifts to its balance of high-tech trade. As shown in figure 6.2.7, the EU's largest deficit in high-tech trade is with the Developed Asian countries (41 billion euro), closely followed by NAFTA (32 billion euro). While the latter deficit is almost entirely due to trade with the US, trade with Japan now

Figure 6.2.7 Breakdown of EU-15 high-tech trade balance by zone (€ billion 2000)



Source: DG Research
Data: Eurostat (Comext)
Note: For definition of partner zones cf. note to figure 6.2.2.

Third European Report on S&T Indicators, 2003

accounts for less than half of the deficit (19 billion euro) with the DAC countries. The rest is due to the burgeoning of high-tech flows to and from Taiwan, South Korea and Singapore. Imports from other Asian countries have also expanded since 1995.

The European Union's main surpluses in high-tech are with other European countries, most notably the Candidate countries, where the balance of trade rose from 5 billion to 12 billion euro during the second half of the 1990s.

3. High-tech trade – the EU and its Member States

The previous parts of section II have established a global overview, and also an overview of Europe's main trading partners in high-tech products. This section moves to a finer level of analysis to consider high-tech trade in the EU and its Member States in more detail.

Overview

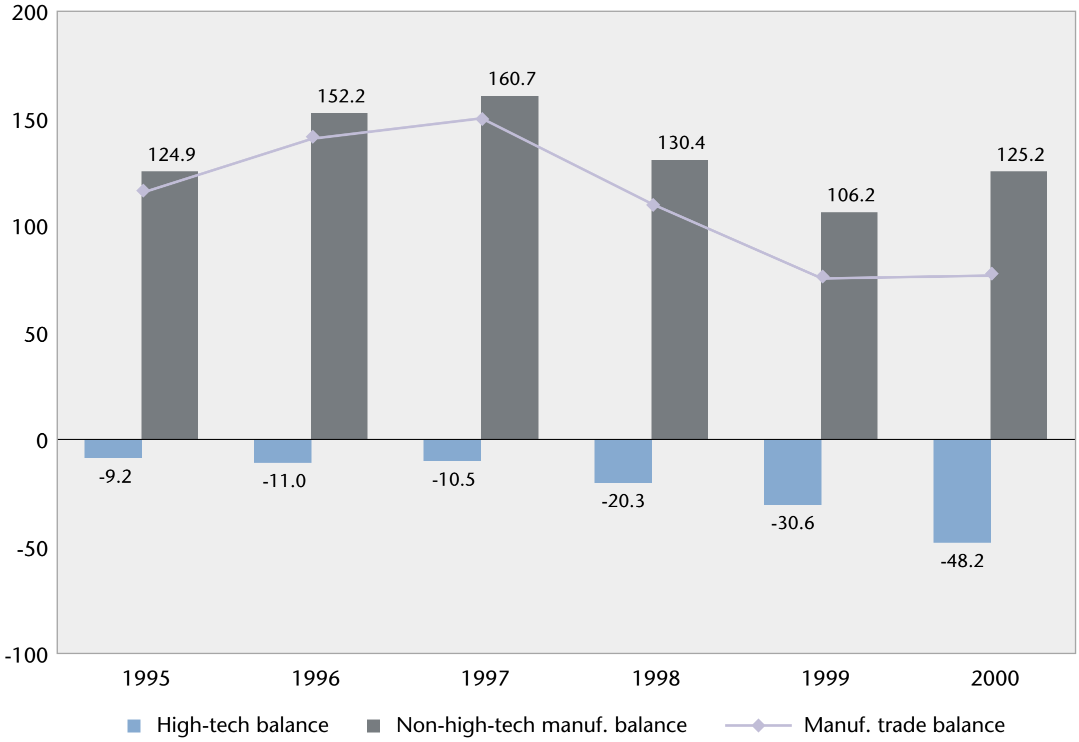
A review of manufacturing trade in general (which includes both high-tech and non-high-tech goods), shows that Europe's surplus shrank during the late 1990s, notwithstanding a significant decline in the euro. The growing deficit in high-tech products was an important contributory factor in this decline, as shown in figure 6.2.8.

As will be shown later, an important part of this declining balance is attributable to growing deficits in Computers and Electronics, which represent 78% of EU high-tech imports, and 48% of its high-tech exports.

However, one needs to be cautious in interpreting these trends, for several reasons. For one thing, levels of specialisation and performance in high-tech trade differ enormously between Member States. Moreover, it should be borne in mind that a high-tech deficit may be a positive indicator if it reflects a country's "catching-up" investment, for example in IT and Telecommunications equipment or in advanced electrical machinery, or it may reflect necessary imports of intermediary goods.

In addition, EU-based foreign multinationals can have an important influence on the high-tech balance. They frequently import high-tech components from their overseas affiliates and turn them into end products, many of which may be exported to other EU countries. Such intra-firm trade will create a net deficit on the extra-EU trade balance.

Figure 6.2.8 Contribution of high-tech trade to the EU's manufacturing trade balance (€ billion)



Source: DG Research
Data: Eurostat (Comext)

Third European Report on S&T Indicators, 2003

High-tech trade as a proportion of exports

High-tech products comprise a significantly smaller proportion of Europe's total exports than those of the US and Japan. High-tech products account for 20% of the EU's total export trade, compared with 30% in the US and 27% in Japan. Conversely, Europe imports a higher proportion of high-tech products than the US and Japan: 23% of total imports in the EU versus 21% in the US and 20% in Japan.

As shown in figure 6.2.9, the importance of high-tech trade varies significantly from one country to another, partly reflecting differences in industrial structure. Within the EU, Ireland has the highest proportion of high-tech products in both its exports (41%) and its imports (37%), due to its expanding high-tech sector and the strong presence of foreign affiliates of high-tech multinationals. In France, UK, Finland and the Netherlands, high-tech products represent 20-25% of exported and imported trade. While Portugal, Greece, Spain and Italy have the lowest share of high-tech products in their exports, these countries have a much higher proportion of high-tech in their imports.

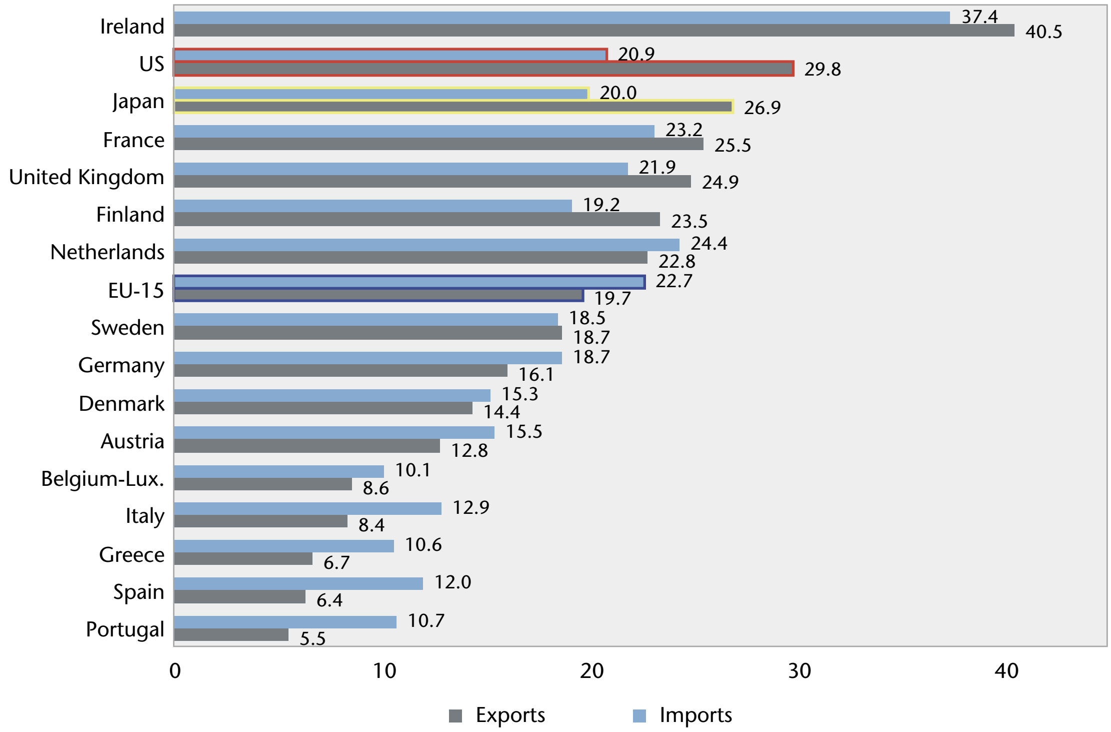
Indeed, figure 6.2.9 highlights the complementarity of import and exports. France, UK and Finland have high shares of both, while Portugal, Greece, Spain, Italy and Belgium have low shares of both. In other words, the relevance of intra-industry trade means that countries with an industrial structure where high-tech is strongly present have to export and import a lot, which usually results in a positive trade balance, while countries without a large high-tech sector import and export much less, and tend to have large deficits.

High-tech exports are growing faster than other exports

Figure 6.2.10 compares growth in exports of high-tech goods with the growth in exports of other goods. As pointed out earlier, high-tech export growth in the US and EU has been significantly higher than the growth in exports of other goods, and slightly higher in Japan. This overall result is reflected within most EU countries.

Most EU Member States have experienced high-tech export growth of between 3% and 10% higher than that for all products combined. Finland, Greece and Belgium-Luxembourg have recorded even larger divergences between high-tech dynamics and that for other products.

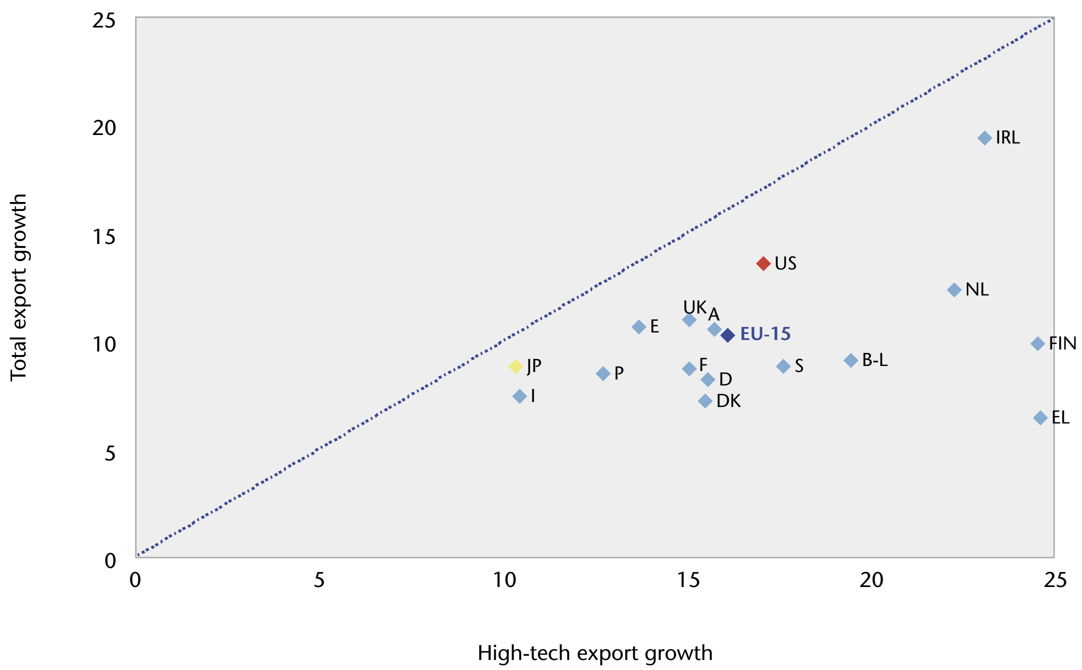
Figure 6.2.9 High tech trade as a % of total trade (2000)



Source: DG Research
Data: Eurostat (Comext), UN (Comtrade)

Third European Report on S&T Indicators, 2003

Figure 6.2.10 Growth in high-tech exports compared with total export growth in % (average 1995-2000)



Source: DG Research
Data: Eurostat (Comext), UN (Comtrade)

Third European Report on S&T Indicators, 2003

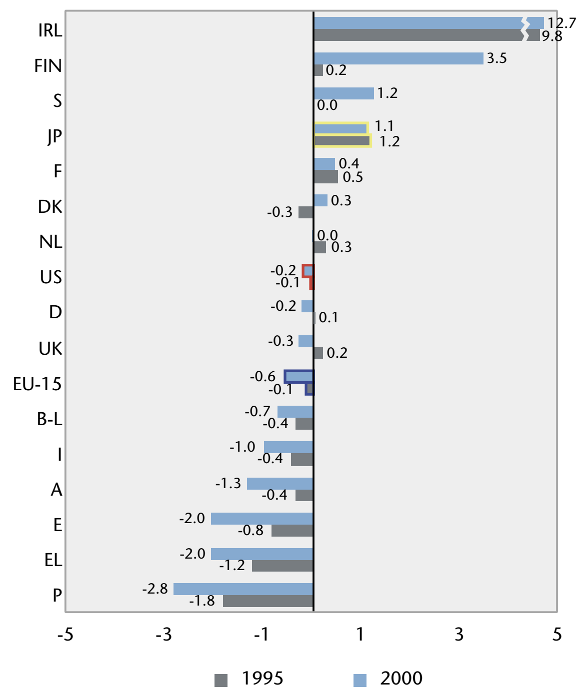
High-tech trade balances of EU Member States

Since 1995, Ireland, Finland and Sweden have experienced significant increases in their high-tech surpluses. France and Denmark have also registered improved balances. Figure 6.2.11 shows the high-tech trade balances of EU Member States and of Japan, the US and the EU as a whole (also refer to figure 6.2.3, which compares the average annual growth in high-tech exports for individual Member States).

The graphics shows that the dynamics of high-tech trade in Ireland have been exceptional, and deserve special note. Ireland's high-tech surplus now represents nearly 13% of GDP, well above that of the other EU countries, due to the burgeoning high-tech sector and the effects of strong inward investment by foreign multinationals. Finland has also experienced an exceptional high-tech surge during the 1990s: it began the decade in deficit, but now boasts one of the strongest surpluses in the EU (3.5% of GDP in 2000) due to an average annual growth in high-tech exports of nearly 25%. Greece shows with a similar strong trend, albeit from a lower base.

Ireland registered an average annual growth in high-tech exports of 23%, followed closely by the Netherlands. Belgium and Luxembourg are also among the most dynamic high-tech exporters of the last five years (nearly 20% annual growth), although their imports too have risen sharply over the same period. Italy, Portugal and Spain have experienced export growth well below the EU average.

Figure 6.2.11 High-tech trade balance as a % of GDP



Source: DG Research
Data: Eurostat (Comext), UN (Comtrade)
Third European Report on S&T Indicators, 2003

As seen in table 6.2.1, the biggest high-tech exporting countries in absolute terms among the EU Member States are France, Germany and the UK, which are also among the top five global exporters after the US and Japan.

All other Member States, however, registered deficits of varying degree. Six of them which started with deficits in 1995 – Portugal, Greece, Spain, Austria, Italy and Belgium-Luxembourg – showed a deficit increase in 2000.

4. Dynamics and structure of high-tech trade by product group

The following section presents an analysis of the global trade in high-tech products by product group. It starts with an overview of the product composition of total world high-tech trade, and considers the surpluses and deficits found in the high-tech product trade undertaken by the main trade regions of the world. This is followed by an analysis of those product sectors in which trade is growing fastest. Lastly, a more detailed investigation of trends in individual product sectors is presented.

Product composition of high-tech trade

Figures 6.2.12 and 6.2.13 give an overview of the product composition of EU, US and Japanese high-tech trade.

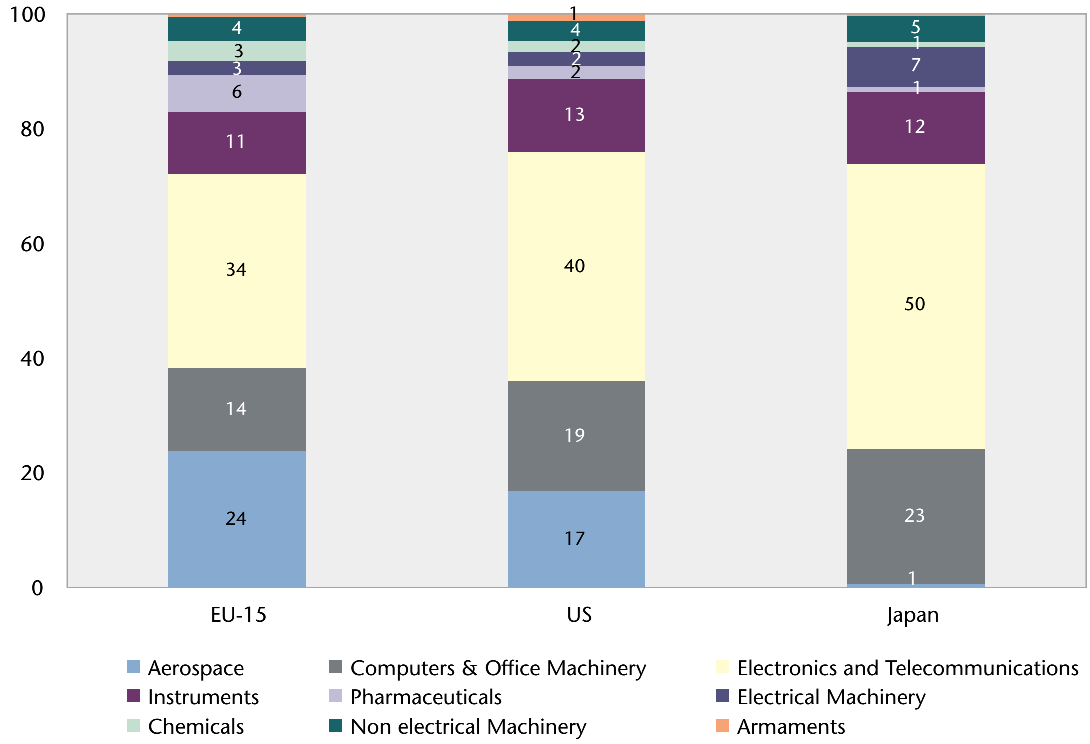
Europe's trade differs in several respects from that of the US and Japan. Firstly, trade in Aerospace is a significantly more important component of EU high-tech: Aerospace products comprise 24% of EU high-tech exports compared to 17% in the US and 1% in Japan, and 17% of EU high-tech imports against 9% in the US and 5% in Japan.

Electronics and Computers feature less in Europe's high-tech trade than that of the US or Japan. Of EU high-tech exports, 34% relate to Electronics and Telecommunications, compared to 40% in the US and 50% in Japan. Computer goods account for 14% of EU high-tech exports, compared to 19% in the US and 23% in Japan.

Pharmaceutical exports are also higher for the EU at 6% of high-tech exports, against 2% for the US and 1% for Japan.

The top three product groups in EU high-tech trade are Electronics and Telecommunications (34% of both exports and imports), Aerospace (24% of exports and 17% of imports), and Computers (14% of exports and 28% of imports).

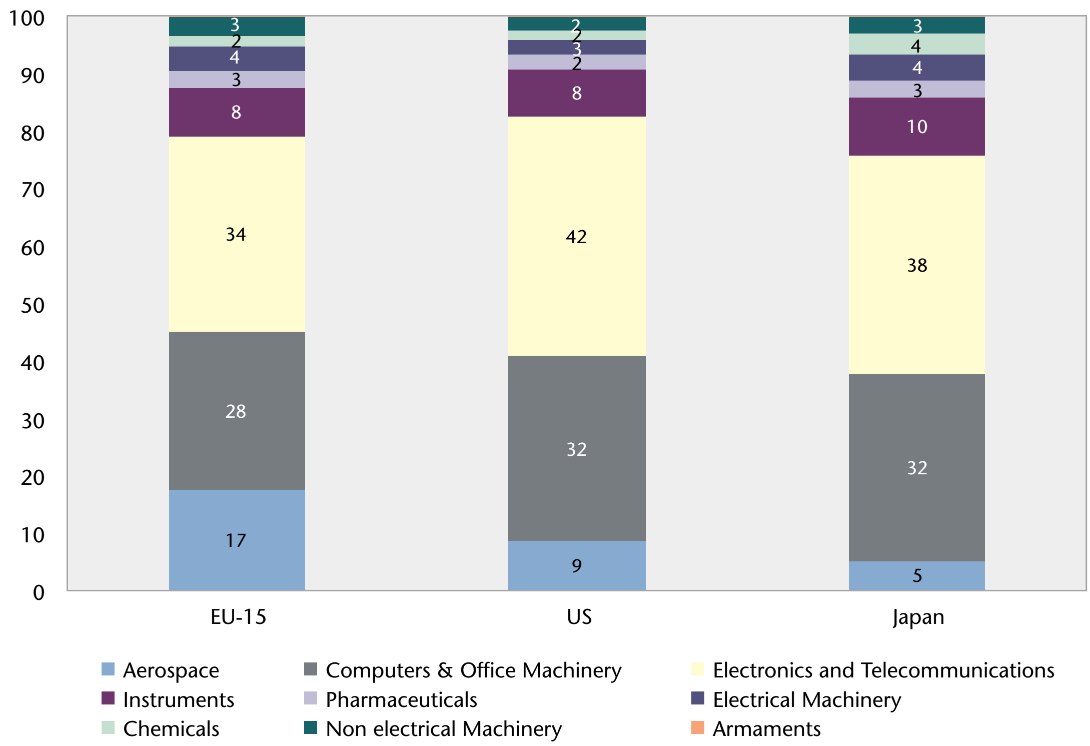
Figure 6.2.12 Composition of high-tech exports by product group (2000) %



Source: DG Research
Data: Eurostat (Comext), UN (Comtrade)

Third European Report on S&T Indicators, 2003

Figure 6.2.13 Composition of high-tech imports by product group (2000) %



Source: DG Research
Data: Eurostat (Comext), UN (Comtrade)

Third European Report on S&T Indicators, 2003

Comparing product deficits and surpluses

In figure 6.2.14 the top row shows that in 2000 the EU was carrying a high-tech trade deficit of 48 billion euro, compared to the US with a deficit of 23 billion euro and Japan with a surplus of 58 billion euro.

Other rows in the figure 6.2.14 graphic give detail by product group. Since, the largest share of high-tech trade is in the field of Computers and Electronics, it is not surprising that these product groups contribute most to the EU's overall deficit position. Since 1995 Europe has carried a gradually increasing trading deficit in Computer and Office Machinery, reaching 38 billion euro in 2000. A similar trend has occurred in the US which now has a deficit of 41 billion euro in Computer equipment. Japan continues to enjoy a surplus in its computer trade, although it is declining (6.1 billion euro in 2000).

Europe and the US also recorded deficits in 2000 for Electronic and Telecommunications products (16 billion euro for the EU and 13 billion for the US), which were substantially larger than in 1999. However, Japan had a sharp increase in its surplus, reaching 39 billion euro in 2000. Europe and the US had deficits in Electrical Machinery too, which is another one of Japan's surplus areas.

Nevertheless, since 1995 the EU has registered surpluses in certain other high-tech product groups, the largest of which relate to Pharmaceuticals, Aerospace and Chemicals (4.2, 3.5 and 2 billion euro respectively in 2000).

Products showing highest rates of trade growth

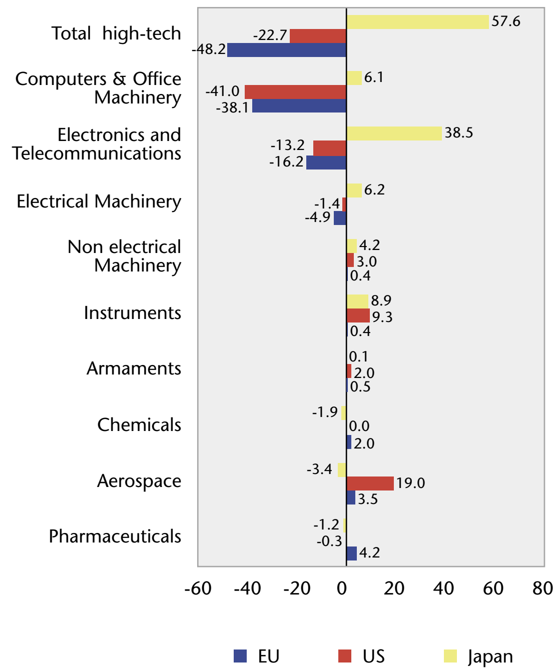
Figure 6.2.15 displays data for exports growth by high-tech product group. The EU's fastest growing exports have been in electrical machinery and Electronics and Telecommunications, which have risen by more than 20% per year in value terms since 1995. These are products in which Europe still had a trade deficit in 2000, since EU imports in these fields were also high and grew at the same rate as exports during the late 1990s. Exports of Aerospace and computer products were the next highest, gaining more than 15% a year during the same period.

The EU's growth in computer products has outstripped that of the US and Japan to a large extent. Even so, the value of its exports, at 27 billion euro in 2000, remains well below that of the US (48 billion euro) and Japan (33 billion euro).

Electrical Machinery, Electronics and Telecommunications and Aerospace have also been strong growth areas for the US. In contrast, Japan's exports of Electronics and Telecommunications and Computers were less dynamic in the second half of the 1990s. More significant growth patterns emerged in Electrical Machinery and to a lesser extent Instruments. Japan's high rate of growth in Aerospace and Armaments should be set against the fact that these products represent a very small proportion (less than one percent) of Japanese high-tech exports.

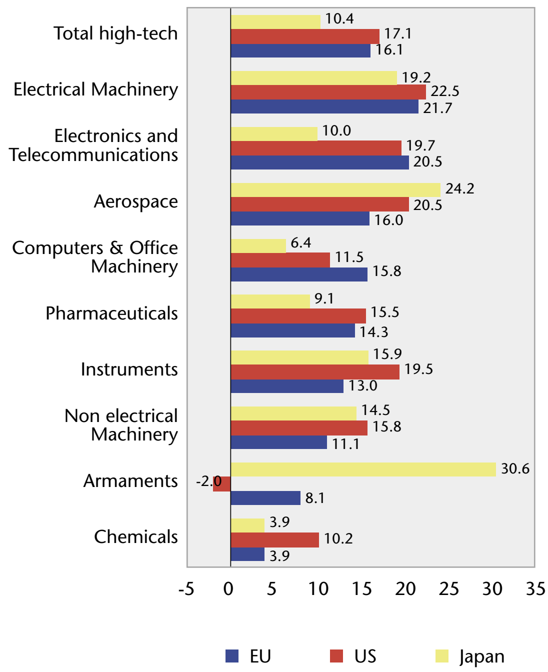
Of all the EU's high-tech exports, chemical products showed the slowest growth. In the US and Japan too, it was one of the least dynamic exports sectors.

Figure 6.2.14 Balance of trade in high-tech products (exports - imports) (€ billion), 2000



Source: DG Research
Data: Eurostat (Comext), UN (Comtrade)
Third European Report on S&T Indicators, 2003

Figure 6.2.15 Growth in high-tech exports by product group (average annual growth, %, 1995-2000)



Source: DG Research
Data: Eurostat (Comext), UN (Comtrade)
Third European Report on S&T Indicators, 2003

The EU's shares of high-tech export markets

The analysis of high-tech trade ends by focusing on the trends in the export market shares of a number of significant product groups.

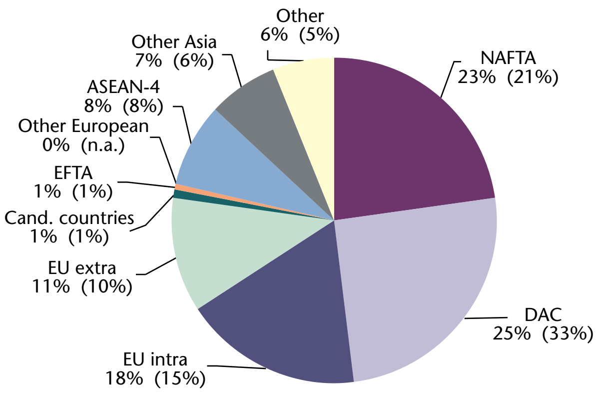
1. High-tech Electronics and Telecommunications exports

As shown in the previous section, the largest market in high-tech products relates to Electronics and Telecommunications (cf. box for definition). In 1999 the EU had 11% of the global export market in high-tech Electronics and Telecommunications goods, compared with 10% in 1995. The market leader is the US with 18%, but collectively the Developed Asian countries account for 25% of exports, and other Asian economies, including ASEAN, for another 15%.

Japan is in second place after the US with 12% of global exports, followed by Singapore and South Korea, which have expanded their market shares significantly during the 1990s. Among the EU countries, Germany is the leading exporter with a 6% share of the world market.

These positions are the result of the dominant trend of the 1990s, namely the rapid geographical diversification of the market for Electronics and Communications equipment, with more and more countries emerging as important global players. Most notable was the rise of the dynamic economies of Asia, some of which reached much higher market shares in ICTs than in other trade sectors.

Figure 6.2.16 High-tech Electronics and Telecommunications exports: world market shares, 1999 (1995 figure in brackets)



Source: DG Research
Data: Eurostat (Comext), UN Comtrade)
Note: For definition of zones cf. note to figure 6.2.2.
Third European Report on S&T Indicators, 2003

Table 6.2.3 Top 10 exporters in high-tech Electronics and Telecommunications products

		World market share % (1999)	Av. annual growth in exports % (1995-1999)
1	US	18	14.3
2	Japan	12	1.9
3	EU-15	11	15.4
4	Singapore	7	9.6
5	South Korea	6	9.6
6	Germany	6	12.6
7	Malaysia	5	13.6
8	UK	5	14.4
9	Hong Kong	4	10.5
10	France	4	18.9

Source: DG Research
Data: Eurostat (Comext), UN (Comtrade)
Note: EU-15 = EU exports to non-EU countries only.
Other countries = total exports.
The World total includes intra-EU trade.
Third European Report on S&T Indicators, 2003

Products included under Electronics – Telecommunications

The following high-tech products are included under the product group "Electronics – Telecommunications":

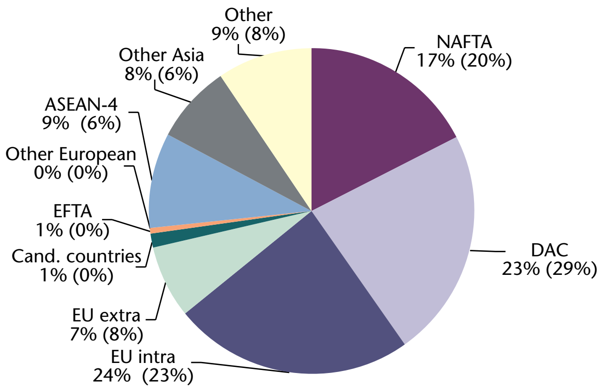
- Video apparatus
- Telecommunications equipment
- Electrical boards and consoles 1000V
- Microwave tubes
- Semi-conductor devices
- Micro-assemblies
- Numeric recording stays
- Other sound reproducing equipment
- Printed circuits
- Optical fibre cables
- Other valves and tubes
- Electronic integrated circuits and Piezo-electric crystals

2. Computers and Office Machinery exports

Collectively, the countries of Asia lead the international market in Computer and Office Machinery, accounting for 40% of world exports, as shown in figure 6.2.17. Japan and Singapore hold the largest shares in Asia (around 10% each). Malaysia and China have recorded remarkable growth in recent years, and are now placed 7th and 10th respectively in the global ranking[13].

The global leader remains NAFTA/US with a 17% share of the export market, which is slightly lower than its 1995 level of 20%. The EU lags behind, as its exports to non-EU countries account for only 7% of the world market (compared with 8% in 1995). The strongest European exporters are the Netherlands (ranked 4th globally), followed by the UK and Ireland. However, Europe's trade in Computers and Office Machinery is strongly oriented to the internal EU market: some 77% of the exports of EU countries are sold to other Member States (84% of the Netherlands' exports are intra-EU).

Figure 6.2.17 Computers and Office Machinery exports: world market shares, 1999 (1995 figure in brackets)



Source: DG Research
Data: Eurostat (Comext), UN (Comtrade)
Note: For definition of zones cf. note to figure 6.2.2.
Third European Report on S&T Indicators, 2003

Table 6.2.4 Top 10 exporters of Computers and Office Machinery products

	World market share % (1999)	Av. annual growth in exports % (1995-1999)
1 US	13	6.5
2 Singapore	10	6.7
3 Japan	10	2.6
4 The Netherlands	9	25.3
5 EU-15	7	12.3
6 UK	7	10.8
7 Malaysia	5	30.7
8 Ireland	5	22.1
9 Germany	4	8.7
10 China	4	38.0

Source: DG Research
Data: Eurostat (Comext), UN (Comtrade)
Note: EU-15 = EU exports to non-EU countries only. Other countries = total exports.
The World total includes intra-EU trade.
Third European Report on S&T Indicators, 2003

Products included under Computers and Office Machinery

The following high-tech products are included under the product group "Computers and Office Machinery":

- Computers
- Computer parts and accessories
- Word-processing machines
- Photo-copying apparatus

Some products which do not have a very high intensity of R&D are not included in this group (e.g. typewriters, calculators)

[13] *South Korea is also one of the rising stars of the Asian region. This is not so evident from the 1999 market shares presented here, but first statistics for 2000 suggest a huge surge in its exports.*

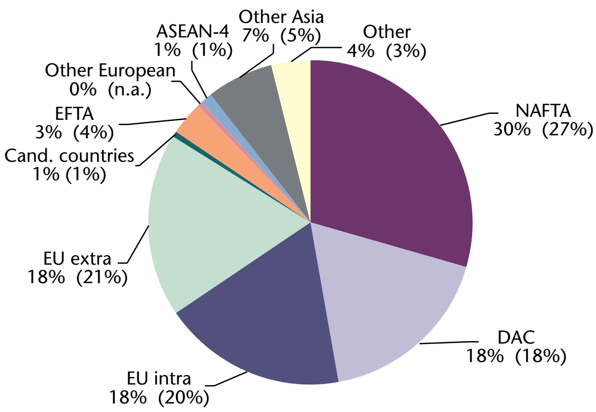
3. Exports of high-tech Instruments

A substantial part – some 50% – of the exports of the instrument engineering industry relate to the high-tech Instruments listed below (cf. box). The rest comprise relatively mature, lower-tech products. Opportunities for growth in this sector frequently arise from technological improvements, many of which are generated around these instruments. Products related to medical applications will be driven increasingly by the needs of the ageing population and the dynamics of health care systems. Developments in industrial instrumentation will remain strongly linked to investment by the downstream industries.

As shown in figure 6.2.18 and table 6.2.5, the largest share of the export market in high-tech Instruments is held by NAFTA, which increased its position from 27% to 30% between 1995 and 1999. The US accounts for almost all of this (26% share in 1999). The EU is in second place, but has lost some of its market share in recent years (18% in 1999 compared with 21% in 1995). Germany is by far the largest exporter of high-tech Instruments in the EU with a 13% market share, equal to that of Japan.

Amongst the Asian countries, the rapid emergence of South Korea and China as important players in this export market is evident.

Figure 6.2.18 High-tech Instruments exports: world market shares, 1999 (1995 figure in brackets)



Source: DG Research
Data: Eurostat (Comext), UN (Comtrade)
Note: For definition of zones cf. note to figure 6.2.2.
Third European Report on S&T Indicators, 2003

Table 6.2.5 Top 10 exporters of high-tech Instruments

	World market share % (1999)	Av. annual growth in exports % (1995-1999)
1 US	26	14.4
2 EU-15	18	10.4
3 Japan	13	8.3
4 Germany	13	8.0
5 France	4	8.3
6 The Netherlands	4	13.2
7 Hong Kong	4	21.8
8 South Korea	3	44.0
9 Switzerland	3	6.9
10 China	3	25.6

Source: DG Research
Data: Eurostat (Comext), UN (Comtrade)
Note: EU-15 = EU exports to non-EU countries only. Other countries = total exports.
The World total includes intra-EU trade.
Third European Report on S&T Indicators, 2003

Products included under high-tech Instruments

The grouping high-tech Instruments contains various medical, optical, photographic and precision instruments associated with high levels of R&D. It covers the following:

- Electro-diagnostic apparatuses for medicine or surgery, and radiological apparatuses
- Optical instruments and apparatuses
- Dental drill engines
- Measuring instruments and apparatuses
- Photographic cameras
- Cinematographic cameras
- Contact lenses
- Optical fibres
- Orthopaedic appliances

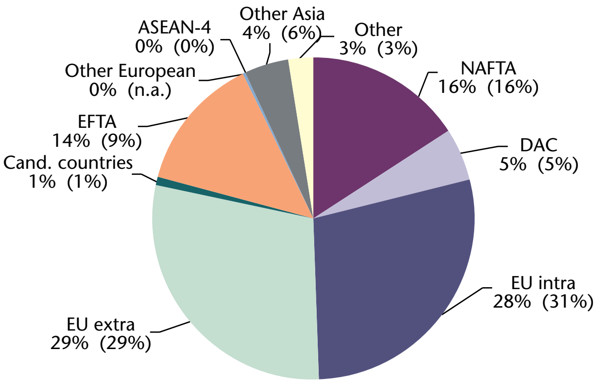
This group excludes many types of instruments which do not involve high levels of R&D (e.g. watches and clocks, conventional meters and counters, household electrical equipment).

4. R&D-intensive Pharmaceuticals exports

The Pharmaceuticals industry is one of Europe's top-performing high-tech export sectors. The EU is by far the leading exporter of R&D-intensive Pharmaceuticals. Its share of the global export market in 1999 was 29% (exports to non-EU countries), compared with 14% for the US. After the US, Switzerland is the next largest exporter with a market share of 13%.

The remainder of the top ten exporters are all EU countries, of which Germany, Belgium, UK and France have the highest shares, as seen in table 6.2.6.

Figure 6.2.19 R&D intensive pharmaceuticals exports: world market shares, 1999 (1995 figure in brackets)



Source: DG Research
Data: Eurostat (Comext), UN (Comtrade)
Note: For definition of zones cf. note to figure 6.2.2.
Third European Report on S&T Indicators, 2003

Table 6.2.6 Top 10 exporters of R&D intensive Pharmaceuticals

	World market share % (1999)	Av. annual growth in exports % (1995-1999)
1 EU-15	29	13.9
2 USA	14	12.8
3 Switzerland	13	27.0
4 Germany	8	10.3
5 Belgium	8	:
6 UK	7	8.7
7 France	7	12.4
8 Italy	6	9.5
9 Denmark	5	12.0
10 Ireland	4	31.0

Source: DG Research
Data: Eurostat (Comext) UN (Comtrade)
Note: EU-15 = EU exports to non-EU countries only. Other countries = total exports.
The World total includes intra-EU trade.
Third European Report on S&T Indicators, 2003

Products included under R&D-intensive Pharmaceuticals

The following high-tech products are included under the product group "R&D-intensive Pharmaceuticals":

- Antibiotics
- Hormones and their derivatives
- Glycosides, glands, antisera, vaccines
- Medicaments containing antibiotics or their derivatives
- Medicaments containing hormones or their derivatives

Certain other pharmaceutical products are excluded from this group because they are not associated with sufficiently high levels of R&D (e.g. vitamins, wadding, gauze, bandages).

Section III European performance in future technologies – The emergence of biotechnology and nanotechnology

New technologies have always been crucial for economic growth and improvement of quality of life. History provides many examples, including the industrialisation in the 19th century with the invention of the steam engine and railways, the surge of the chemical and Electronics industries at the end of the 19th century, the Fordic style of mass production at the beginning of the 20th century, and more recently the breakthrough of information and communication technologies (ICT). Over the past two decades, biotechnology has shown much potential for continuing the line of new technologies that have had widespread impact on social and economic life. A second potentially key technology for the 21st century that has also received a lot of attention, is nanotechnology. With its potential for totally new technical applications, this is set to become the continuation and complement of its predecessors, biotechnology and ICT.

Apart from a general introduction to Biotechnology and Nanotechnology, this section address the following pertinent questions:

– What are the revolutionary characteristics of these two technologies?

– What are their links and similarities?

– What is their economic and social significance and the factors governing their success?

Biotechnology

The manipulation of living things to make products that benefit human beings. Biotechnology contributes to such diverse areas as food production, waste disposal, mining, and medicine. Modern achievements include the transferral of a specific gene from one living thing to another (by means of genetic engineering techniques known as transgenics) and the maintenance and growth of genetically uniform plant-cell and animal-cell cultures, called clones.

Nanotechnology

In nanotechnology dimensions or tolerances in the range of 0.1 to 100 nm (from the size of an atom to the wavelength of light) play a critical role. Aims at the manipulation of individual molecules and atoms.

Latin nānus, Greek nanos: dwarf

Nanotechnology and biotechnology as emerging 'key technologies'

Emerging key technologies are bound to have a profound impact on society, industry, policy, products and processes, as well as on the life of each individual. New technologies can help to make daily life easier, to treat diseases better and to make processes faster, cheaper and more ecological. Technically speaking, a 'key technology' is one that opens up other technologies and may have an effect on many industry sectors, with consequent impacts on the entire economy. It can be the catalyst for a 'technological revolution', leading not only to radical changes in firms' innovation processes, but also to significant impacts on society. Bio- and nanotechnologies seem to possess all the characteristics of key technologies in that they may prove to be strategically influential in terms of new products, processes and employment.

In general, it is hardly ever possible to tell whether a particular line of basic research will lead to a new technology or technologies, and whether it will become a key technology. In its early stages, it is not clear whether a technology will be able to challenge existing production processes and products or to meet the demand of consumers. Consequently, it will also not be clear whether it will reach the stage of widespread application in production activities and uptake in wider markets. Even so, apart from technology and market assessments, there are methods to assess the potential of promising future technologies through monitoring of ongoing developments.

In recent decades, with the decline of the traditional industries such as steel and machinery, the search has intensified for new technologies that can replace them as drivers of growth and change. Information technology has emerged as a driving force, and has proven to be a true key and strategic technology. It has opened up new business opportunities for established businesses, and has created new enterprises. Already, a vast number of new products, processes, and jobs have been created due to the IT revolution.

Are biotechnology and nanotechnology set to become key technologies too? To find the answer, one needs to look more deeply at their nature. Their most important common characteristic is that they are seen as most likely to have a horizontal impact across a whole range of industries – indeed across practically all industries. A second characteristic is that they are generating technologies incorporated in a broad range of products and processes. More likely than not, consumers will be unaware that a product they are buying has been made through biotechnological or nanotechnological processes. So a key technology is not necessarily a prominent technology in the daily use, its contribution to the product's characteristics is not always obvious for the consumer.

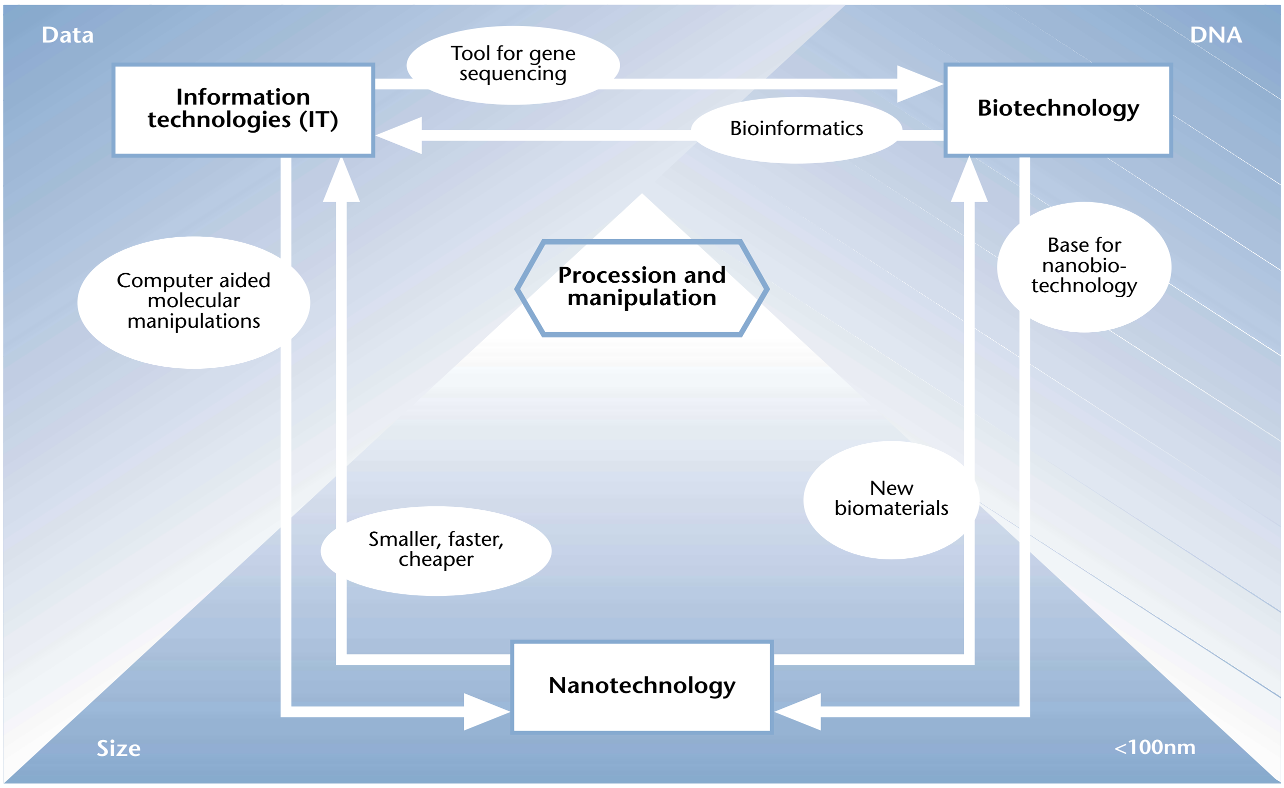
Increasingly, both technologies look set to interact strongly with information technologies, forming new fields such as bioinformatics or nanobiotechnology. This may lead to a blurring of technological boundaries, making it increasingly difficult to distinguish between these technologies. Products and processes are being defined more and more by their underlying principle for example, DNA manipulation in biotechnology, the relevance of the size below 100 nanometer of the manipulated elements in nanotechnology, and the procession, storage or transfer of data in information technologies. Figure. 6.3.1 demonstrates these underlying principles with examples of mutual influences.

The three technologies have a common characteristic of being applicable across the majority of, if not all, industrial sectors and a huge variety of products. Biotechnology is likely to have an impact on human life through manipulation of genetic properties, possibly including the eventual elimination of genetic diseases. It can also influence the agricultural environment by breeding plants or animals to enrich nutritious values. Nanotechnology is expected to create new materials with totally new, problem-solving properties. The development of new nanoscale semiconductors that take advantage of quantum effects will revolutionise the computer industry. Nanotechnology also looks set to utilise the properties of ultra-short waves to develop new and better optical devices. Together, both technologies have the potential to influence all areas of social and economic life.

This is the technological position. However, factors other than technical feasibility must be taken into account, such as acceptance of the technologies, and market potential. This is especially true for biotechnology, where consumers and other affected parties have expressed ethical concerns about certain medical applications, and a reluctance to consume genetically manipulated food. It has become clear that technological feasibility on its own is not a guarantee of economic success.

In the case of strategic technologies, risk assessment and possible controversial issues arise at all stages of technological development. There will always be disapproving and sceptic individuals and organisations alongside those who embrace the new technology. As the technology develops and more and more applications become feasible, the list of potential risks inevitably lengthens. A recent report has identified several issues relating to biotechnology, including eugenics, the cloning of human beings, gene patenting, the safety and ethics of genetically modified organisms, the use of stem cells (currently from human embryos), animal rights, privacy of genetic profiles, the danger for the environment from genetically modified organisms, and the increased risk of biologi-

Figure 6.3.1 Connections between IT, biotechnology and nanotechnology



Source: DG Research

Third European Report on S&T Indicators, 2003

cally engineered weapons (RAND 2001). The issues mentioned imply concerns over morality, errors, induced medical problems, gene ownership, and ethics of human or animal breeding.

In nanotechnologies, the risks are not so obvious, although recently some concerns have been raised about total surveillance by nanocameras and self-reproducing robots (Joy 2001). Because of the relatively immature character of nanotechnology, such concerns are not very concrete and are more appropriate to the visions ascribed to this technology than to realistic, current developments.

Current developments in both technologies point towards success. The technological potential is practically unlimited, and the expected effects on the economy and society, described shortly above, are promising. Nevertheless, it is still a long road from scientific research and technological development to industrial mass application and market uptake. Some applications will be successful on a large scale, and others will not.

In the following two subsections, biotechnology and nanotechnology are analysed in detail with the use of relevant indicators of scientific and technological development.

A. Biotechnology: revolutionary in many respects

Biotechnology is one of only a few new technologies that can be termed revolutionary, in the sense that its impact is felt throughout society – sometimes almost imperceptibly so. An increasing number of industrial sectors and the daily life of people is being influenced by biotechnology. New processes and products incorporating aspects of biotechnology are not only influencing the environment directly (humans, animals, and flora), but also different industries and technologies (Freeman and Perez 1988). As pointed out earlier, biotechnology is a 'key technology' – the basis for other technologies, for example the emergence of the field of bio*informatics*. Biotechnology is a prime example of a science-based technology. Although biotechnological methods are applied in several industrial sectors, the technology has created a whole industry of its own. However, biotechnology is not covered as a separate industry sector in most statistics - this makes an analysis rather difficult at times.

So far, the pace of scientific findings has been breathtaking. However, their implications for growth and employment are not equally shared at the moment by Europe, North America and South-East Asia. Recent surveys conducted by Ernst & Young (BIO 2000, Ernst & Young 2001) provide an overview of global developments:

- in 1999, US public life science companies accounted for some 20 billion euro in revenues, while those in Europe amounted to 4.4 billion euro;
- the US had 300 public life science companies and 114 000 employees, while Europe had 105 public companies and 23 630 employees;
- a US public life science firm on average had 380 employees and earned 66.7 million euro in revenues, while a European firm on average employed 225 people and realised 41.8 million euro in revenues.

Ernst & Young estimated that the biotechnology industry had generated 151 000 direct jobs and 287 000 indirect jobs in the US. The revenues generated indirectly by the US biotechnology sector account for another 27 billion euro in 1999.

All European companies put together barely realise a higher market capitalisation than the US industry leader Amgen (69 billion euro for Amgen against 75 billion euro for the European total).

The rather bleak figures for Europe do not reveal the significant dynamics on both sides of the Atlantic. Whereas the US industry had a major upsurge as early as the 1980s, Europe started later and has been trying to catch up since the early 1990s. Although the research base is strong on both continents and scientific findings did and still do occur in the US as well as in Europe, the US appears to be ahead in the biotechnology race.

1. Biotechnology: a science-driven set of techniques

Biotechnological methods have been used for hundreds of years. The use of yeast for brewing, bacteria cultures for making yoghurt and fermentation for producing soy sauce are methods associated with the first generation of biotechnology. Along with the methods of the so-called second generation – cell culture and cell tissue for growing flowers, plants and vegetables, for example – the first generation biotechnologies are not commonly perceived as biotechnology by the public, policy makers and companies.

Modern biotechnology is largely associated with genetic engineering and cloning. This is not an accurate perception: modern biotechnology is a large set of techniques and methods used in extremely varying applications. Compared to the methods of the first and second generation of biotechnology, third generation biotechnology methods are based on contributions from a range of scientific disciplines, some of which are more applied, such as microbiology, biochemistry and chemical engineering, others are more basic science disciplines, such as genetics and molecular biology.

The initial pioneer findings of modern biotechnology started with the development of the *recombinant DNA*-technique (rDNA) by Cohen and Boyer in 1973. This enabled a change in the scientific paradigm: the previously dominant paradigm of biology gave way to molecular biology, and the scientific discipline of molecular biology became the basis for biotechnology and genetic engineering (Ziman 1994).

Although it appears to be a smooth, evolutionary development, its impact on the science system as well as on industry has been revolutionary. Even if scientists are used to incorporating the new models and findings in their research, it usually takes place within a given paradigm. A paradigm shift takes place when a large part of the common knowledge of a group of scientists becomes outdated for any new work. The education of young scientists who adopt the new paradigm takes time, and their numbers are relatively small in the early stages.

Consequently, there is a period in which the old and the new knowledge co-exist, but in terms of innovation the new knowledge is more important. The situation is even more difficult for industry. During the 20th century, large in-house research divisions have been a distinctive feature, for example of pharmaceutical and chemical companies. In-house researchers have the same problems with paradigm shifts as all researchers, but as their research is the main basis for their firms' innovations, firms have an urgent need to access new knowledge via other means. Co-operation with the science base has been limited to some research projects with universities and contacts to universities in order to attract graduates. However, the new developments in science and technology were challenging in particular to the pharmaceutical industry. Here, the way of discovering and developing new drugs changed significantly, requiring new types of knowledge. Genomics, bioinformatics, combinatorial chemistry, pharmacogenomics are some of the key disciplines. The main change in the innovation process is the necessity to integrate the different disciplines and develop an interdisciplinary research approach. The new types of knowledge required go beyond the experience and traditional R&D capabilities of pharmaceutical firms. There are two main strategies for adjustment: First, building of in-house know-how – e.g. through mergers and acquisitions. Second, utilisation of specific scientific and technological expertise from external sources e.g. high-tech firms, research organisations, or universities.

In biotechnology, this has led to the creation of a whole new industry, dominated by small technology-based start-ups, and a shake-up of the pharmaceutical industry.

Milestones of modern biotechnology

- 1943 Avery demonstrates that DNA is the 'transforming factor' and the material of genes.
- 1951 McClintock discovers transposable elements ("jumping genes") in corn. The Nobel Prize is awarded to her in 1983.
- 1953 Watson and Crick describe the DNA structure (Cambridge, UK); the Nobel Prize follows in 1962.
- 1956 Kornberg discovers the mechanisms in the biological synthesis of RNA and DNA and receives the Nobel Prize in 1959.
- 1960 Hybrid DNA-RNA molecules are created; messenger RNA (mRNA) is discovered.
- 1961-1966 The genetic code is being decoded.
- 1967 The first protein sequencer is perfected.
- 1971 The conceptual description of the polymerase chain reaction (PCR) method is put forward by Kleppe et al. Experimental data by Saiki et al follows in the mid 1980s.
- 1973 Cohen and Boyer invent the rDNA technique, and the University of Stanford and the California Patent System apply for a patent. This patent will lead to tremendous revenues for the university and a major push for improved science-industry links in the US. The patent is awarded in 1980.
- 1975 Köhler and Milstein describe the production of monoclonal antibodies; they receive the Nobel prize in 1984. The so-called Asilomar conference sets up guidelines for rDNA research.
- 1976 Founding of Genentech, the first dedicated biotechnology firm.
- 1977 The British Sanger Centre develops techniques for DNA sequencing.
- 1978 Genentech and Eli Lilly co-operate to produce recombinant human insulin.
- 1980 Genentech obtains a public listing. It scores a historic rise for an initial public offering (IPO) at the US electronic securities exchange system, NASDAQ: in 20 minutes, the share price rises from 35 to 89 US dollars.
  In the landmark case of Chakrabarty vs. Diamond, the US Supreme Court approves the principle of patenting genetically modified micro-organisms.
- 1981 The North Carolina Biotech Centre is created as the first US state-sponsored initiative to develop biotechnology. Biotech centres are established in 35 other US states.
  Some 90 biotech start-ups emerge in the US.
- 1982 Genentech's genetically modified human insulin 'Humulin' is approved by the Food and Drug Administration (FDA).

- 1983 The PCR technique is established; K. Mullis is assigned as inventor; Cetus applies for a patent, which is issued in 1987. Mullis receives the Nobel Prize for the method in 1993.
  The first biotech product 'Humulin' reaches the US and British markets.
  The number of biotech start-ups in the US reaches 200. The inception of the Orphan Drug Act helps to enforce drug development for diseases that affect fewer than 200 000 people in the US.
- 1984 DNA fingerprinting is developed.
  Chiron clones and sequences the whole HIV virus.
  Amgen and Kirin form a joint venture to produce erythropoietin (EPO).
- 1985 The FDA approves Genentech's human growth hormone (HGH) as the second biotech product.
- 1986 First open field trials of a genetically engineered tobacco plant.
  Ortho Biotech receives approval for the first monoclonal antibody treatment, used to fight kidney transplant rejection.
  Chiron's first genetically engineered human vaccine for the prevention of hepatitis B is approved.
  Pharma buys biotech: Eli Lilly buys Hybritech for 500 million US dollars.
- 1987 The first authorised outdoor test of an engineered bacterium (Advanced Genetic Sciences' Frostban), is conducted on strawberry and potato plants in California.
  The crash of the American stock exchange leads to a stagnation of the biotech sector.
- 1988 The US Congress decides on the funding of the Human Genome Project.
- 1988 Harvard University is granted the "Harvard mouse patent", a patent on a modified mouse predisposed to develop cancer ("oncomouse").
- 1989 Amgen's Epogen is approved for the treatment of renal disease anaemia.
- 1990 FDA approves of recombinant renin, a food additive for the production of cheese.
  First gene therapy is performed successfully on a four-year-old girl suffering from an immune disorder.
- 1992 Chiron buys Cetus for a record 660 million US dollars and acquires the patent on the PCR technique. The patent is subsequently sold to Hoffmann-LaRoche.
- 1993 Approval of the first modified plant: Calgene's Flavr Savr® tomato reaches the market in 1994.
- 1994 The first breast cancer gene is discovered.
- 1995 Rockefeller University gains 20 million US dollar from Amgen in exclusive licence fees for its patent on the obesity gene.
- 1996 Scientists at the Roslin Institute, Edinburgh, clone identical lambs from early embryonic sheep; in 1997 they report cloning from an adult sheep – "Dolly" is born.
- 1998 A first rough map of the human genome is presented, showing the locations of more than 30 000 genes.
- 2000 Celera Genomics and the Human Genome Project complete the rough draft of the human genome.
  "Golden Rice" is developed for vitamin A and iron deficiencies.
- 2001 The sequence of the Human Genome is published in Science and Nature.
  Biotech mergers get more expensive: The largest biotech company, Amgen, buys Immunex (Nr 3 in terms of market capitalisation) for 16 billion US dollars.

2. Industries, methods and applications

Different biotechnological techniques and methods are used in various industries and applications. Dedicated biotechnology firms, which form the biotechnology industry, are often essential suppliers to other sectors. These are predominantly the pharmaceutical, chemical and food producing and processing industries, but also the field of environmental engineering.

This section will introduce major applications and challenges for the above mentioned industries. The focus will be on the pharmaceutical industry as most applications happen there. Reasons for the different degrees of success of the industries will be summoned up.

Dramatic changes in the pharmaceutical industry

The most dramatic change brought about by biotechnology occurred in the pharmaceutical sector. Research and production processes have changed dramatically because of the impact of biotechnology. Protein engineering and DNA analysis have been the two most common technological research platforms. As a result of the 'Human Genome Project', the isolation of human genes became more prominent, leading to significant new platforms such as genomics and proteonics.

Figure 6.3.2 depicts the increasing importance of biotechnology within the countries most active in producing Pharmaceuticals. At the beginning of the 1990s, biotechnology had an average influence on 32% of pharmaceutical patents. This increased to more than 40% within a few years. It is clear that the influence is the strongest in the US pharmaceutical sector, followed by the UK, while Japan is lagging behind. The highest growth rates are those in the UK with 22.8% and Germany with 18.4%. The lowest rate is in the US, at 8.2%.

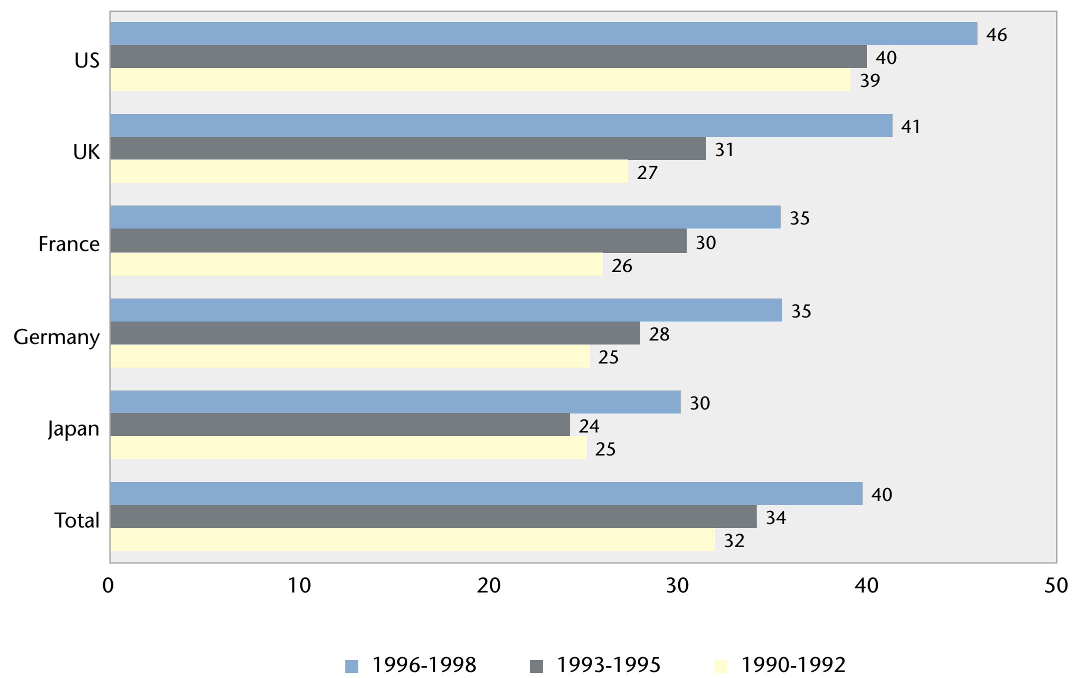
In the early 1990s, the US was well in front in terms of applying biotechnology in its pharmaceutical sector. Its share of patents concerning biotechnology in Pharmaceuticals amounted to 40%, whereas the figures for the UK and Germany were 25% and 27%. During the 1990s, the EU countries were able to catch up partly with their US counterpart, even though the latter had been making progress itself. Nevertheless, the UK made the most significant progress in this regard. Between 1996 and 1998, the US had a share of 46% biotechnology-relevant patents in the pharmaceutical sector, the UK figure increased to 41%, reducing the difference to 5 percentage points. In respect of French and German patent applications, the gap narrowed to 11 percentage points. Japan managed to catch up slightly, which reflect the difficulties faced by the Japanese pharmaceutical sector in making use of the new knowledge base in biotechnology.

The figures reveal a remarkable resemblance to the overall accomplishments and status of biotechnological innovation systems in these countries. The US figures bear witness to the US's early commitment to biotechnology research, mainly on the back of massive public funding, and its downstream commercial applications. The difference in the evolution of the European and Japanese figures are remarkable. Whereas all had a similar share in the early 1990s, the UK was able to take the lead alongside France. In the second period, Germany was able to catch up with France. Due to the UK's strong performance in the middle and late 1990s, it managed to stay well in front. Japan was not able to progress at the same rate as its Western counterparts. These developments have been explained, among others, by differences in the biomedical research base, industry structure, and S&T policies of the countries concerned (see e.g. Sharp 1985, European Commission 1999, Senker et al 2001).

Still lagging behind: applications in the chemical industry

Application-oriented biotechnological methods are predominantly used in the chemical industry for the improvement of

Figure 6.3.2 Relevance of biotechnology for innovativeness in the pharmaceutical industry (1990-1998) %



Source: BMBF 2000
Data: EPAT, PCTPAT, Fraunhofer-ISI (calculations)
Note: The innovativeness is measured by the number of pharmaceutical patents that are linked to biotechnology.

Third European Report on S&T Indicators, 2003

production processes such as by way of fermentation, i.e. amino acids and industrial enzymes. Since a major output of the chemical industry is bulk chemicals, biotechnology is likely to have only an incremental impact on the chemical sector (OTA 1991). However, as the boundaries between companies in the chemical, pharmaceutical and agricultural industries are somewhat blurred, it would be inappropriate to state that biotechnology has no impact on the chemical industry. It certainly has, but this is more evident and significant in the agro-chemical and fine chemicals domains.

The food and agricultural sectors – industry versus consumer interests

Biotechnology applications in the food sector have been one of the most controversial issues in some countries in recent years. Biotechnology promises to deliver various benefits, including increased process security, the reduction of hygienic risks, a simplification of production processes, and profit gains. Genetically modified enzymes are the most commonly used method so far.

Biotechnology potentially offers benefits in animal husbandry and crop cultivation. Biotechnology can offer some benefits in animal husbandry and plant breeding/cultivation. Some of the goals to use modern biotechnology in plant breeding are to establish resistances against pathogens (e.g. insects, bacteria, fungi), tolerance to pesticides or environmental stress (e.g. draught, salinity) as well as to improve quality parameters of plants (e.g. content of specific nutritional ingredients, removal of allergens). In animal husbandry, modern biotechnology contributes to the selection of highly valuable animals for breeding purposes (e.g. DNA diagnostics, marker-assisted breeding), the enhancement of production efficiency (e.g. transgenic animals with transferred growth hormon genes) as well as to the production of substances used in animal feeding or veterinary medicine (e.g. enzymes, amino acids, antibodies, vaccines) with the help of genetically modified micro-organisms.

As mentioned earlier, the various developments in the food and agricultural industries have met with severe public criticism in most European countries. Nevertheless, moral issues such as whether such applications are necessary, if they will be supported by the public, and are morally justifiable, belong in a different debate.

Different industries, different measures of success

The question might be raised why biotechnology has had such an impact on the production of pharmaceuticals, but less so in other industries. There seem to be several reasons:

- The first successful applications had a relatively easy target: hormones (human insulin and the human growth hormone). The human insulin targets a wide population of people suffering from diabetes. This successful commercialisation of effective drug development has proved to be a signal for revenues.
- The production of pharmaceuticals does not require immense upscaling such as in the bulk production of chemicals. Because of the scale of production, the processes involved are easier to control than in chemical production.
- The chemical industries rely on relatively cheap inputs. There are few incentives and opportunities for substituting these inputs by biotechnological means and to control the processes effectively.

The food industry, in theory, offers enormous possibilities for applications. However, apart from basic foodstuffs, food products in general are price sensitive, i.e. if prices rise, demand will fall. Moreover, even it the consumer would readily replace different food products with alternative choices, the production cost of a genetically modified product might not pay off in the market.

Food supply and demand structures are much more varied, and create a larger number of specific markets than, for example, in pharmaceuticals. Nevertheless, biotechnology makes economic sense in respect of food products needed in very large quantities, especially early in the food chain, such as grain products. For grain modification, the genetic code of the grain must be known, as in the case of the rice genome recently. There might be consumer reservations in developed countries about possible choice limitations and corporate profits increases. In underdeveloped and developing countries, consumers often do not have any choice at all. For them it would be a better alternative if their primary food supplies such as rice, wheat and maize were more nutritious or if they obtained better harvests.

An analysis of developments in different industries will show that the scientific knowledge base for certain applied technologies and applications varies considerably. In the pharmaceutical sector, the very latest biotechnological methods and techniques are used for new applications, but those used in the food sector may be less sophisticated, leading not to new products but to different product characteristics.

3. Measuring biotechnology: difficulties prevail

The socio-economic impact of biotechnology has become very important for policy makers, industry, and consumers. Since the mid 1980s, Europe has witnessed the US growth of the biotechnology industry, and public and private efforts have been made ever since on the level of the Member States as well as at the European level. Public and private parties are interested in different issues and try to tackle different problems. Policy makers for example, ask about the numbers of newly established biotechnology firms and newly created employment. They might also want to understand the linkages between the science base and technological applications and observe industry changes, while the pharmaceutical industry might ask how much money was funnelled into the R&D process and how many products realised what profit.

In order to answer questions on intensities, amounts spent and innovations realised, several indicators can be thought of. However, in several countries, biotechnology is an industry in itself although its applications reach into technologies, production processes and products of several other industries. As a result, statistical data on biotechnology, being a horizontal technology, is derived from various sources often difficult to compile and compare.

There are indicators that describe private sector activities, e.g. dedicated biotechnology firms, offering the advantage of a well defined group of firms for observation. Information can be gleaned about the number of new firms, amounts spent on R&D, amounts raised through initial public offerings or cash obtained by inter-industry deals (see for example the annual Ernst & Young reports on biotechnology).

Collecting information on public funding relating to biotechnology or analysing the efforts and performances in other performing sectors such as the food sector, is equally difficult. Funding and performance boundaries are often blurred. The highest share of funding relevant to biotechnology is represented by the life sciences, although other engineering and environmental public funding might be related to biotechnology as well. An inventory of public biotechnology R&D programmes in Europe (European Commission 1999), giving data for the period 1994-1998, provides an overview of the total spending by EU-15 countries, including funding at the European Union level.

Neither more recent data nor data prior to this period is available on the European level. Although some data has been collected on a national basis (Van Beuzekom 2001), it is divers and cannot be compared reliably. The basic problem is the lack of common definitions concerning 'what is biotechnology' and 'what are biotechnology firms'. However, because of the evolving nature of the technology and ongoing industry changes, final definitions seem to be not viable and even the OECD is suggesting a preliminary definition. So far, most studies use ready-made definitions serving a specific purpose and according to the different definitions, unlike data and statistics are produced, leading to a variety of often contradicting information.

Despite the difficulties in comparing countries or different industries using biotechnology, there are various indicators providing important information on the dynamics of this technology, its scientific background and its industrial uptake. They will be outlined in greater detail in the following sections.

4. Europe's efforts to gain ground – financial commitments to foster biotechnology

Figure 6.3.3 lists the contribution of 14 EU Member States. Between 1994 and 1998, they spent a total of 9 670 million euro (ecu at the time). Germany, the UK and France are the countries with the largest contributions. Evidence suggests that public expenditure on biotechnology has been increasing steeply in recent years. For example, France boosted its funding for biotechnology start-ups, aiming to strengthen its biotechnology sector by infusing public money into private biotechnology companies. The French government is providing 60 million euro in 2002 for new biotechnology start-ups, and an additional 90 million euro in loan guarantees for more established companies. The French government hopes that its actions will enable France to follow in Germany's footsteps, which has doubled public investment in biotechnology over the past five years (Nature, 2001).

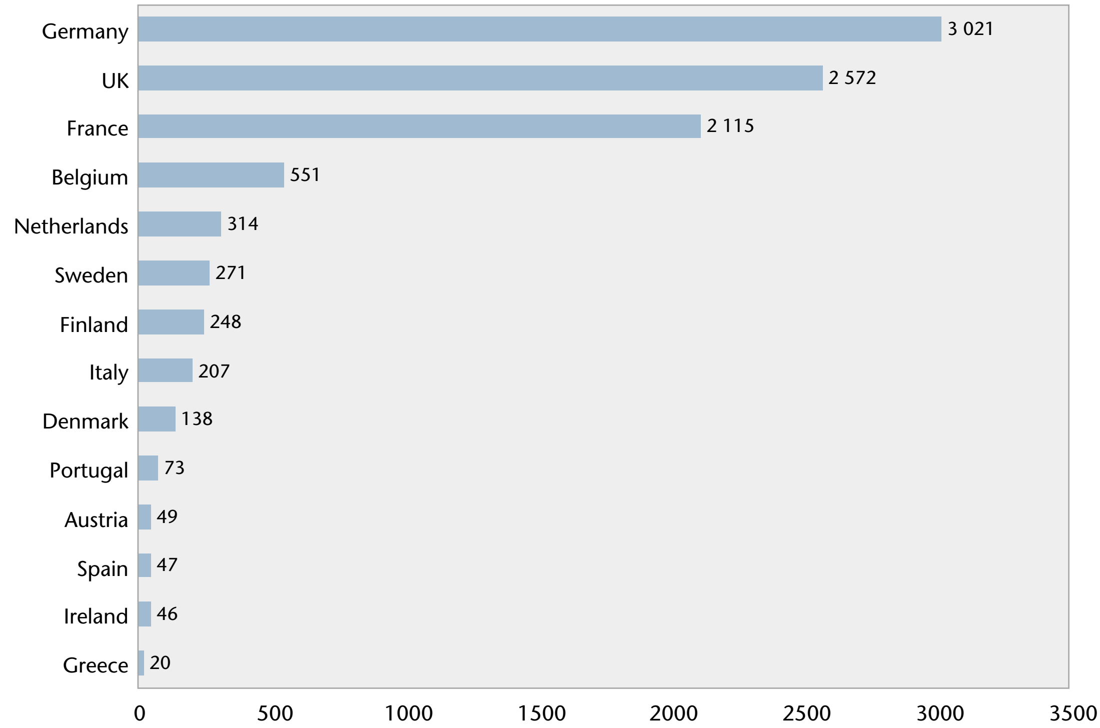
Germany increased its public investment in biotechnology from 246 million euro in 1998 to 330 million euro in 2001 (BMBF, 2002) and has taken over from Britain as European leader in private biotechnology investment. Despite private investment of 400 million euro in Germany, 200 million euro in France, and about 290 million euro in the UK (Nature, 2001), revenue figures vary significantly. In 2000, the UK was leading with 2 066 million euro, far ahead of Germany with 786 million euro and France with 757 million euro (Ernst & Young 2001).

Several European countries have declared the fostering of biotechnology to be a key priority in their science and technology (S&T) policies. Different policies can be observed. Denmark and Sweden, for example, have created Medicon Valley. Core research facilities within this region include the establishment of the Biotechnological Research and Innovation Centre (BRIC) in Copenhagen, which represents a public investment of about 67 million euro, and BMC, the Biomedical Centre in Lund.

Another cross-border initiative is the BioValley in Alsace in northwest Switzerland and southwest Germany. This was more of a private undertaking in 1996, following the merger between Ciba and Sandoz to form Novartis, and the consequent loss of 3 000 jobs in the life sciences sector in this region. In the same year, Germany recorded a major success with the creation of the BioRegio competition, which triggered a large number of regionally based biotechnology networks and supported three winning regions in particular.

The UK announced the launch of a 25 million euro programme in applied genomics in 2000, with a view to supporting platform technologies and collaboration between small firms and university scientists. Ireland dedicated a substantial sum of 635 million euro to promoting excellence in scientific research in strategic areas such as biotechnology and information and communication technologies for the following

Figure 6.3.3 Total public funding of biotechnology by EU countries in million ECU (1994-1998)



Source: DG Research
Data: DG Research

Third European Report on S&T Indicators, 2003

years. In 1998, Greece announced a public programme in agricultural biotechnology to the value of 5.2 million euro.

5. Indicators of the scientific base: the US leads with Europe a close second

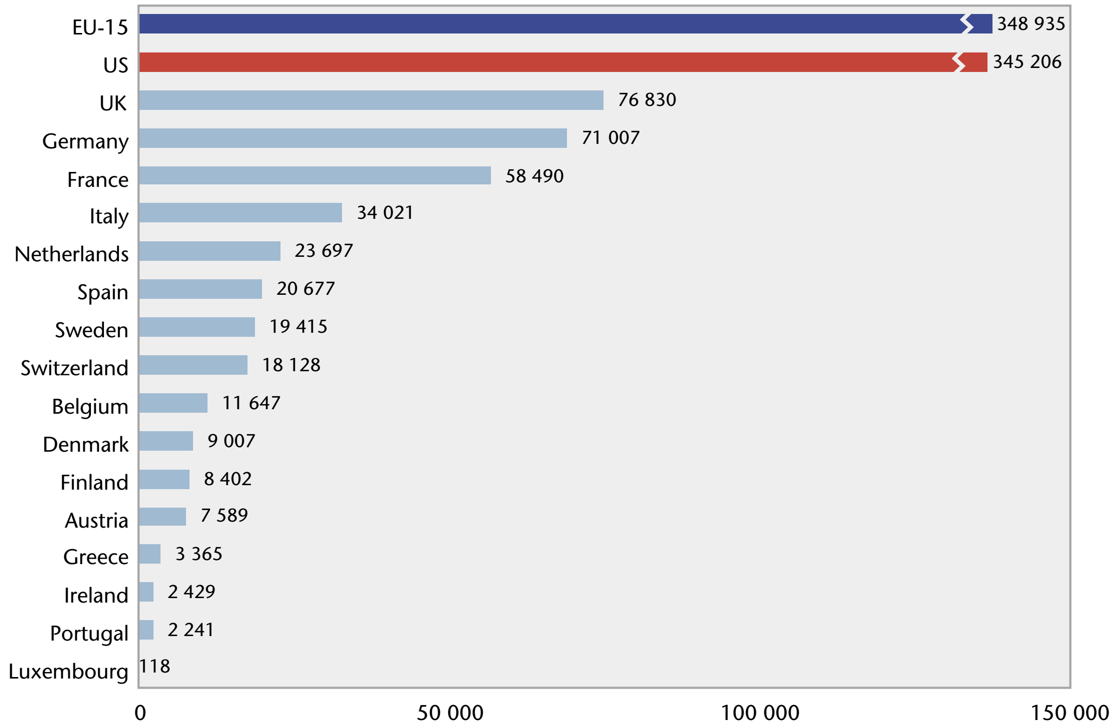
Biotechnology in its science-dominated and early market phase can be motivated through an analysis of scientific literature. The number of biotechnology publications in the past decade has been impressive. Overall, the number of EU-15 publications is slightly higher than that of the US (figure 6.3.4). One can also see that within Europe, Switzerland is an important player.

The most important scientific fields comprising modern biotechnology are the various life sciences, but it also receives injections from the physical, chemical and material sciences. As the disciplines that stimulate biotechnology and its applications change over time, growth rates in biotechnology are difficult to estimate. However, it is assumed that dynamics in the life sciences parallel trends in biotechnology to a large extent. As they are easier to determine – the collection and calculation of data comprise a broader set of well defined disciplines –, they are used to estimate also developments in biotechnology. In the following section, four of the main scientific disciplines bolstering biotechnology are grouped as life sciences: clinical medicine, basic life science, biomedical science and biological sciences.

Figure 6.3.5 depicts the growth rates for the total number of scientific publications and for those in the life sciences. Only a few countries have higher growth rates in the life sciences than overall – Greece, Austria, and Germany in Europe, and Japan and the US. Compared to the EU-15 average in the growth of life science publications, Sweden, Denmark, France, the Netherlands and the UK have lower growth rates. Japan exceeds the EU average by far, while the US has a slightly negative growth rate overall (–0,05%) and a slightly positive one of 0.15% in the life sciences.

In terms of total life science publications (figure 6.3.6), the EU Member States published the largest number. Taken country by country, the US is the dominant provider of scientific knowledge in the life sciences, followed at some distance by the UK and Japan. In terms of relative citation impact (figure 6.3.7), there are huge differences between the US, the EU-15 and Japan. With 1.35, the US is performing well above world average of 0.8 to 1.2, the EU-15 is with 0.9 around world average and Japan is with 0.75

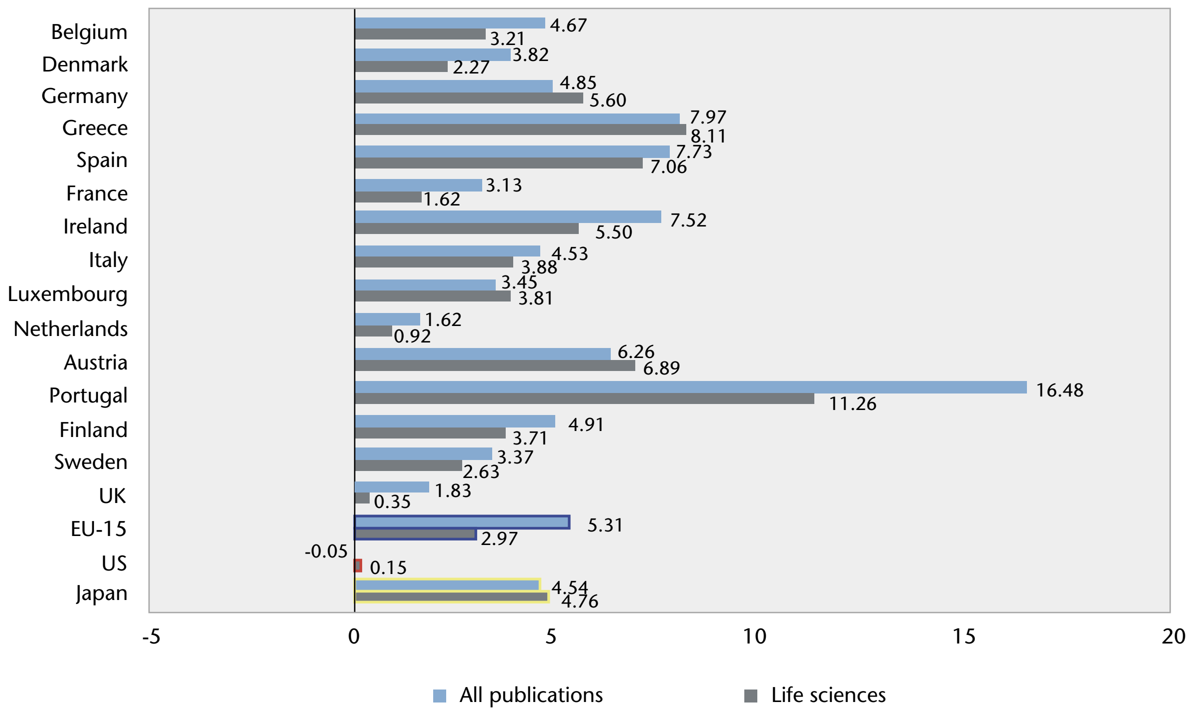
Figure 6.3.4 Number of biotechnology publications, EU-15, Switzerland and the US (1994-1999)



Source: DG Research
Data: ISI; data processed by Fraunhofer-ISI through host STN

Third European Report on S&T Indicators, 2003

Figure 6.3.5 Growth rates of all publications and in the life sciences in % for EU-15, the US and Japan (1995-1999)



Source: DG Research
Data: ISI, CWTS (treatments)

Third European Report on S&T Indicators, 2003

Figure 6.3.6 Number of publications in the life sciences (1995-1999)

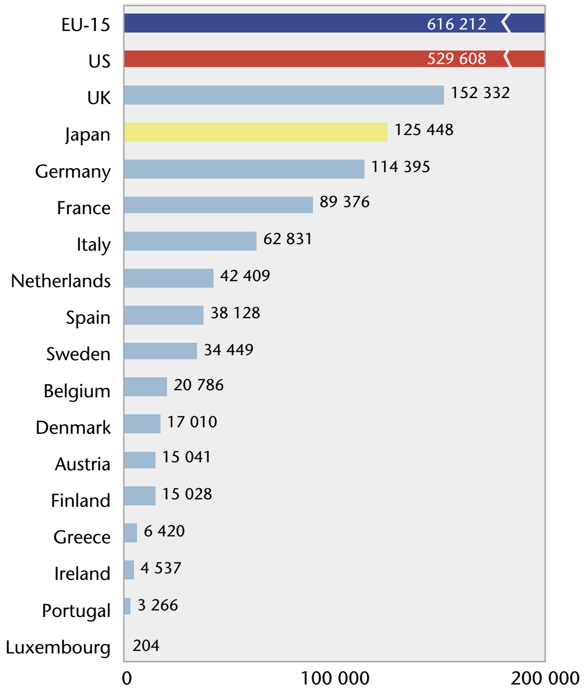
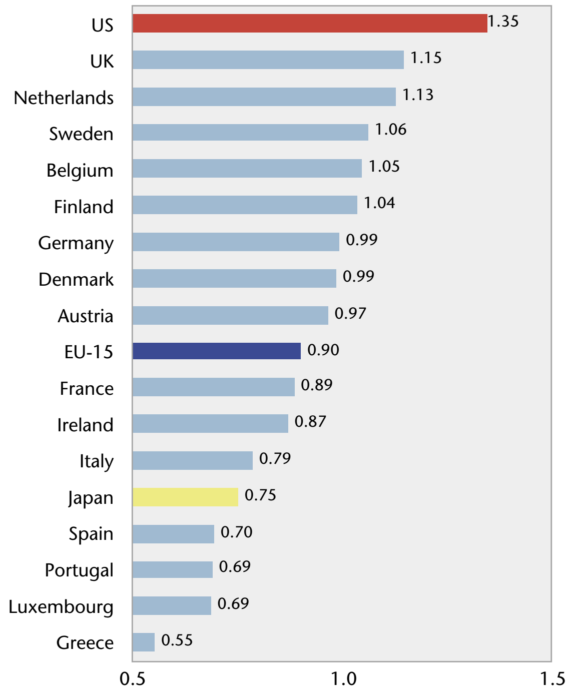


Figure 6.3.7 Citation impact in the life sciences (1993-1999)



Source: DG Research
Data: ISI, CWTS (treatments)

Third European Report on S&T Indicators, 2003

below average. At individual country level, the UK and the Netherlands lie at the upper limit of the world average. Above this mark are Austria, Denmark, Germany, Finland, Sweden, Belgium, the Netherlands and the UK.

The surge of scientific publications pertaining to biotechnology signals that in terms of life cycles in technology, biotechnology is still at an early stage – more important findings are to be expected. From an analysis of scientific literature, some idea can be formed of scientific specialisation per country (cf. chapter 5). By way of a citation analysis, certain implications can be gleaned with regard to the influence of the scientific knowledge base. Lastly, scientific specialisation patterns can also serve as a proxy for future innovation activities. In the case of biotechnology, some European countries have promising research bases.

6. Technological uptake – fewer patent applications in Europe than in the US

Biotechnology is a science-based technology and has found its way into numerous applications. Patent applications add an additional aspect of the innovation process, namely applied research and experimental development. Considering that biotechnology was to a large extent a US development until the late 1990s, it would be interesting to consider the number of patents granted at the US Patent and Trademark Office (USPTO). This will also reveal the order of magnitude of biotechnology patents.

The dominant patenting region is NAFTA, followed at some distance by the EU-15 and the Developed Asian countries, which include Japan, Korea, Singapore and Taiwan (figure 6.3.8). Other regions have had few successful patent applications at USPTO. In terms of growth rates, NAFTA and the EU-15 have been running neck and neck, although the difference in the number of applications has to be taken into account.

Compared to other patent classes at the USPTO, the number of patents in biotechnology (calculated by analysing particular IPC classes as there is no specific 'biotechnology' patent class) is still small. There are few European countries filing larger numbers of patent applications. Figure 6.3.10 suggests that patent applications are proportional to the size of a country. Three clusters emerge: the first comprises the UK, France and Germany, with the highest number of patent applications throughout the period under review. The second group contains the medium sized countries of the Netherlands, Denmark, Belgium, Sweden, Austria, and Finland. Spain, Ireland, Greece, Portugal and Luxembourg are in the third cluster, representing a limited number of patent applications, or none

Figure 6.3.8 Total number of biotechnology related patent as USPTO by world region (1987-1995)

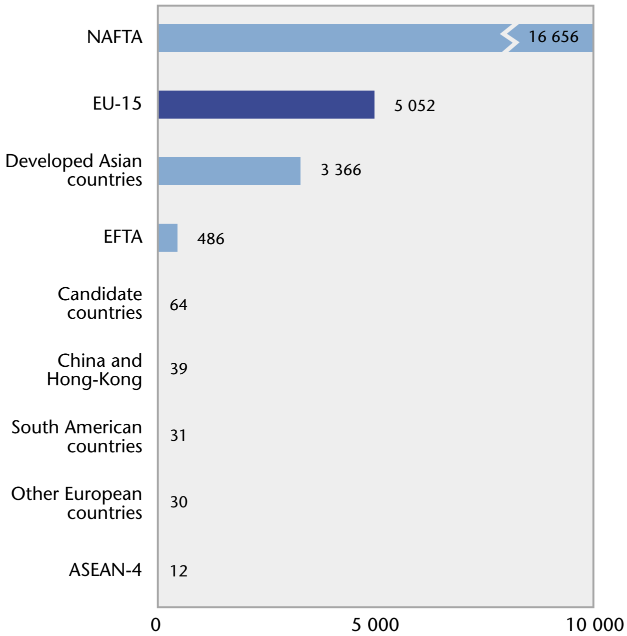
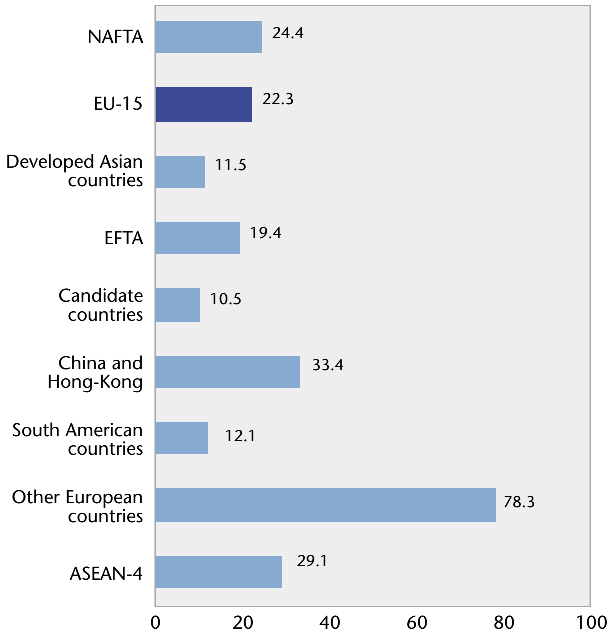


Figure 6.3.9 Growth rates of biotechnology related patent as USPTO in % by world region (1987-1995)



Source: DG Research
Data: USPTO, INCENTIM (treatments)
Note: Number of patents reflect the priority year.

Third European Report on S&T Indicators, 2003

at all. In terms of growth rates, the Netherlands, Denmark, Italy and Belgium are in front, with Belgium and Denmark recording the highest growth rates throughout the period. They are followed by the Netherlands, Italy, Austria and France. Only Greece has a negative growth rate (figure 6.3.1).

The patenting performance of the Triad at USPTO (figure 6.3.12) shows that Europe holds between 17% and 20% of all patents during the period. More than half of all patents in biotechnology are in the US. Japan had a similar share as the EU-15 at the beginning of the 1990s, but has lost ground since 1991.

Patent applications at the European Patent Office (EPO) reveal a similar trend (figure 6.3.13). Despite the EPO not being the home patent office for US based firms, the latter file the most biotechnology patents in Europe, indicating the importance of the European market for US players. The US is followed by the EU-15 and Japan.

An analysis of 1999 data of biotechnology and pharmaceutical patent applications by world region indicates that NAFTA leads the field with 55% of patent applications at the EPO, followed by the EU-15 with 28%. Developed Asia is the third largest bloc with 11% of applications, of which 9.9% are from Japan.

In China too, biotechnology growth trends are impressive. In 1999, China had a 0.5% share of biotechnology patents at EPO. If this is compared with the 1992 figure, China recorded an increase of 950% from 1992 to 1999. Nevertheless, the overall presence of Chinese patents is not yet significant. Given the size of the Chinese market for potential biotechnology applications, it seems a question of time before China becomes a big player. China is also the only new industrialising country participating in the Human Genome Project. Among the major projects are the sequencing of the pig genome and of China's most important rice variety. China has at its disposal several hundreds of scientists returning from the US and Europe. In China, research on almost any conceivable biotechnology topic seems possible. For example, there are no apparent ethical discussions on stem cell research. Chinese gene pools are of major interest for identification of diseases. They are homogeneous within the various pools, with the result that several international pharmaceutical and biotechnology firms are doing research in China. It is likely that Chinese patent applications will not only show significant growth rates, but also increase materially in number.

How do the EU Member States, the US and Japan compare in terms of the data in figure 6.3.14? The 27.8% EU share

Figure 6.3.10 Total number of biotechnology related patent applications at the USPTO, EU-15 countries (1987-1995)

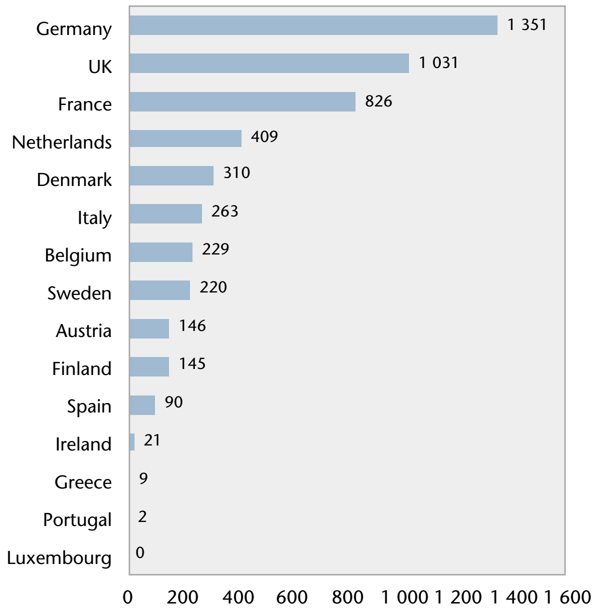
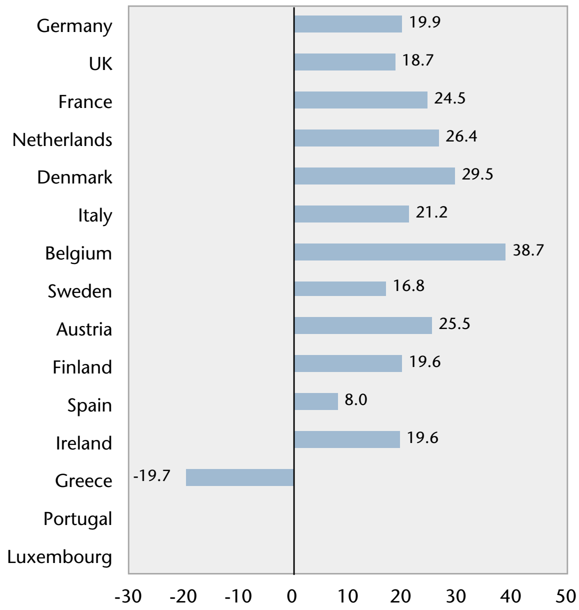


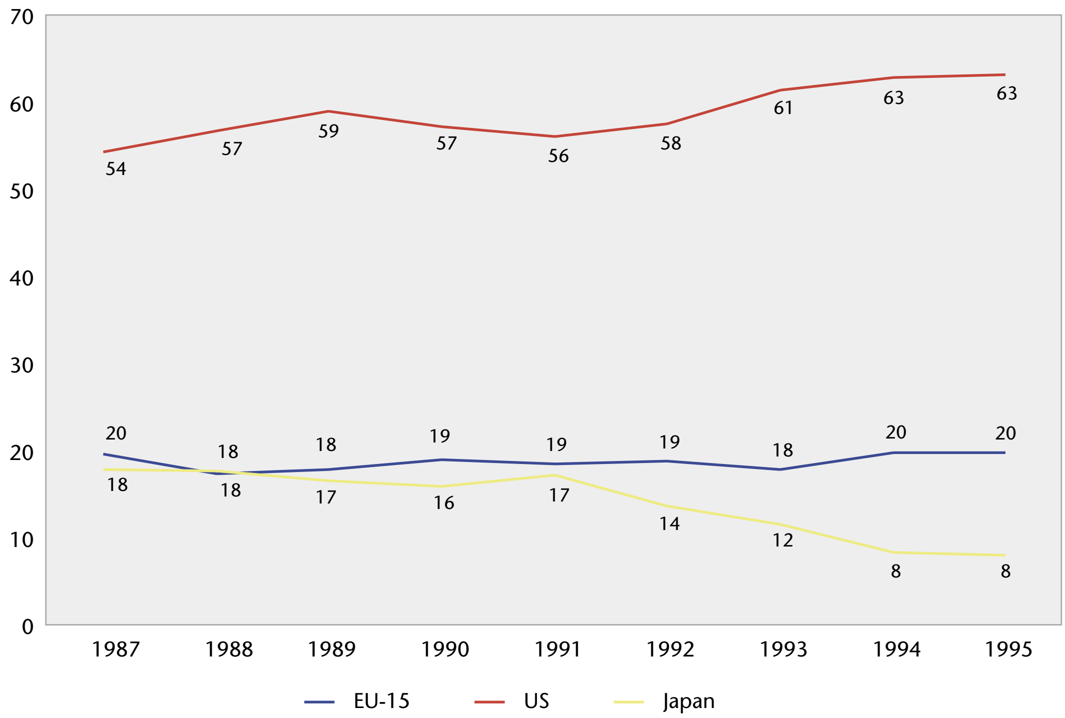
Figure 6.3.11 Growth rates of biotechnology related patent applications at the USPTO, EU-15 countries in % (1987-1995)



Source: DG Research
Data: USPTO, INCENTIM (treatments)
Note: The growth rates for EL are from 1991-1995 and for IRL 1990-1995. P had only two patents in 1995 so that growth rates were not calculated here.

Third European Report on S&T Indicators, 2003

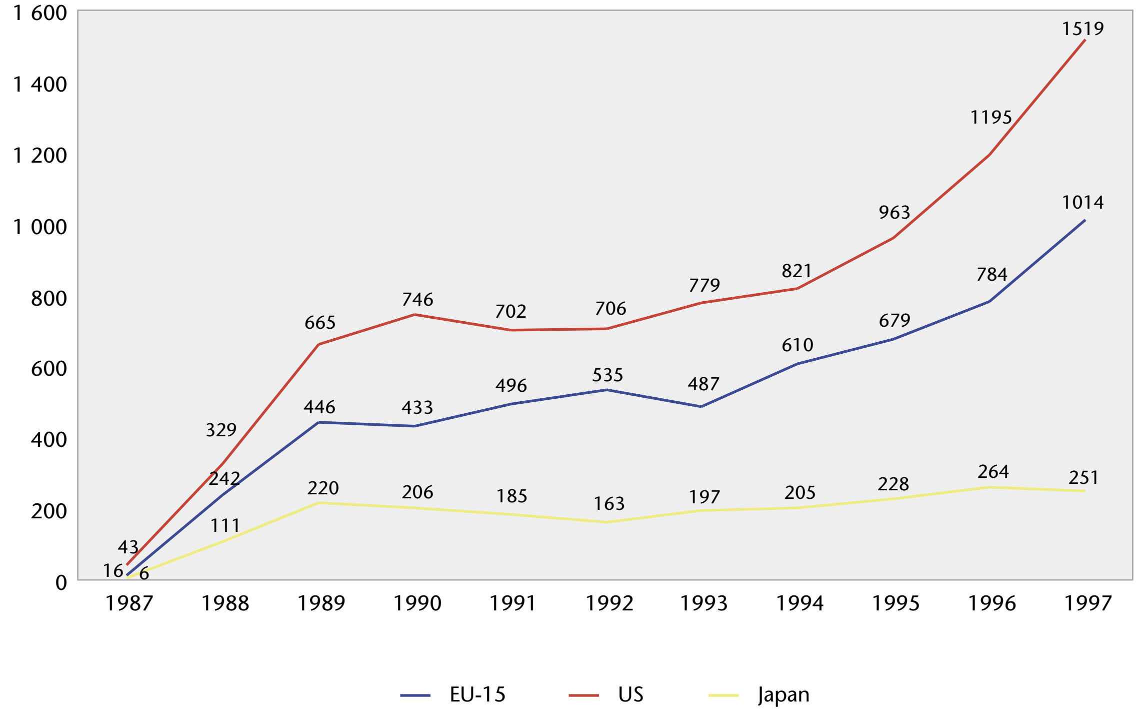
Figure 6.3.12 Development of the shares of biotechnology related patent applications at USPTO by EU-15, US, and Japan in % (1987-1995)



Source: DG Research
Data: USPTO, INCENTIM (treatments)

Third European Report on S&T Indicators, 2003

Figure 6.3.13 Development of biotechnology related patents at EPO by EU-15, U.S., and Japan (1987-1997)



Source: DG Research
Data: EPO, OECD, MSTI database (STI, EAS Division), November 2001

Third European Report on S&T Indicators, 2003

Figure 6.3.14 World shares of pharma and biotechnology patents in % at EPO (1999)

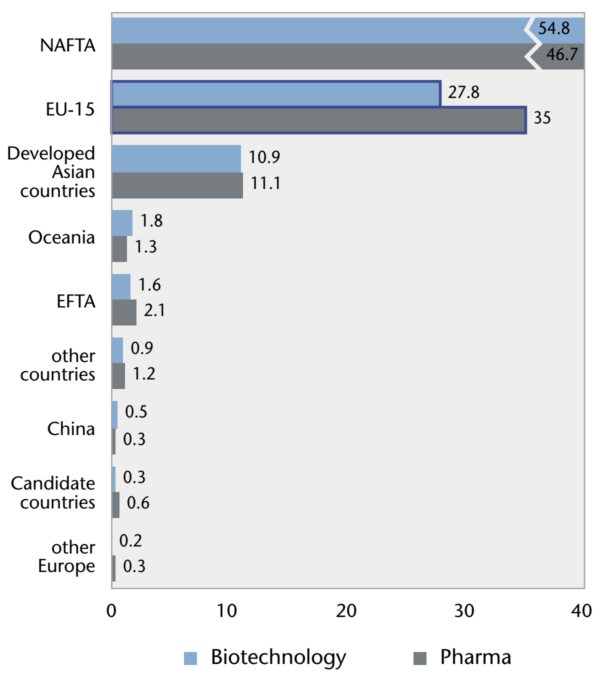
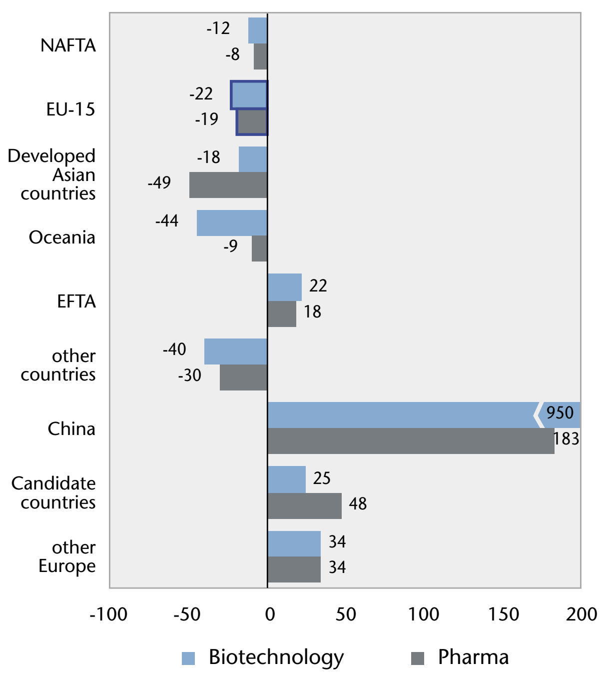


Figure 6.3.15 Changes in world shares of pharma and biotechnology patents in % at EPO (1999 basis 100 for 1992)



Source: DG Research
Data: EPO, OST/Fraunhofer-ISI (treatments)

Third European Report on S&T Indicators, 2003

Figure 6.3.16 World shares of pharma & biotechnology patents in % at EPO (1999) in the EU, the US and Japan

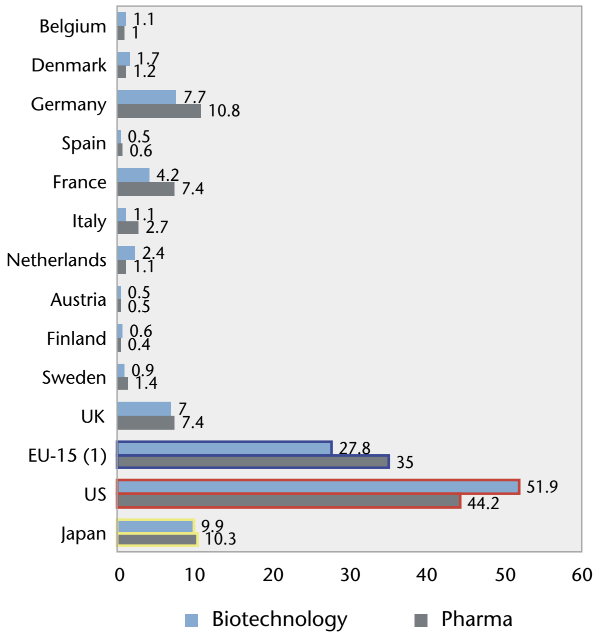
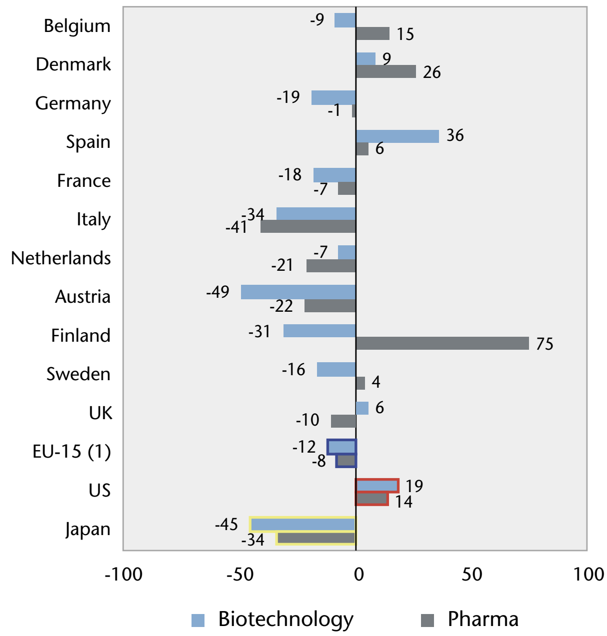


Figure 6.3.17 Changes of world shares of pharma & biotechnology patents in % at EPO (1999 basis 100 for 1992) in the EU, the US and Japan



Source: DG Research
Data: EPO, OST/Fraunhofer-ISI (treatments)
Note: (1) EU-15 does not include IRL, EL, L, P.

Third European Report on S&T Indicators, 2003

of worldwide biotechnology patents in 1999 can be attributed largely to Germany, UK, and France (figure 6.3.16). These three countries each has a large pharmaceutical industry, as reflected in their equally large shares of pharmaceutical patents. The Netherlands and Denmark follow with a significantly smaller share, both for pharmaceutical and biotechnology patents. In the case of both countries, their participation in global biotechnology surpasses their share in pharmaceuticals. It follows that smaller countries which do not have an established pharmaceutical industry sector, still have opportunities in the biotechnology sector.

The dynamics of technical change is also illustrated by the changes in world shares. From 1992 to 1999, several Member States have been able to improve their world share in pharmaceuticals, but only a small number could do so in biotechnology. Nevertheless, changes in share of total are only a relative indicator which does not depict significance and size. As a result of the year-by-year increase in the number of patents and the corresponding changes in world patent shares, the chances of recording a positive change are smaller than of maintaining share or even experiencing a drop in share. Thus, the positive changes do reflect relative as well as absolute net gains.

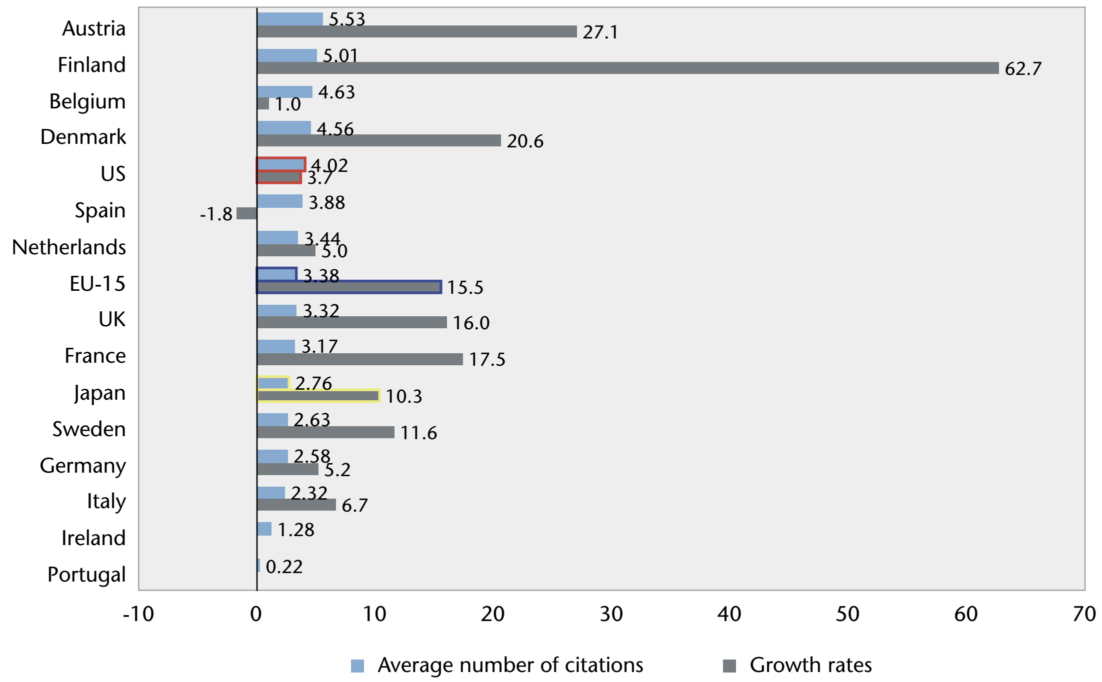
7. Biotechnology – links between basic science and applications

In terms of numbers, the output related to biotechnological scientific outcome is much larger than technological applications. Indicators have been developed to measure and analyse the past knowledge embodied in a patent's specification as stated by the inventor, but also by the patent examiner. The scientific sources mentioned are other patents, but also scientific and other literature, also known as non-patent references (NPRs) (cf. box "Linking science to technology by non-patent references"). As the US Patent Office examiners take the scientific background of an invention or innovation into account, the patent applications at the USPTO tend to cite more NPRs than patents filed at the EPO. Analysing the cited scientific literature in patents from the USPTO will provide an indication of the propensity to citing scientific literature.

Between 1987 and 1995, the number of NPRs in European originating patents at USPTO increased. On a yearly average, a European patent contained 2.7 references to scientific literature, while US originating patents contained 4.0 and Japanese patents 2.8 references. Within the EU-15 there are marked differences. Whereas countries such as Luxembourg, Greece, and Portugal have small numbers of NPRs in patent applications, Austrian patents on average had 5.5 and Finnish 5.0 NPRs per patent (figure 6.3.18)

Within Europe some interesting observations can be made (figure 6.3.18). France, the UK and Germany are the traditional European leaders in biotechnology patenting, and display a high science-technology interaction. However, patents originating from Sweden, Denmark and small countries such as Belgium and the Netherlands, also display a significant science interaction (cf. dossier VI). In terms of growth rates, Finland, Denmark and Austria display particularly large dynamics. This might be a statistical anomaly, since in all three countries the average number of citations in patents in a single year is sometimes up to ten times higher than during the rest of the period. Notwithstanding, even if the statistically odd years are omitted, the three countries show the highest growth rates.

Figure 6.3.18 Average number of scientific literature citations in patents (NPRs) and growth rates (1987-1995)



Source: DG Research
Data: USPTO, INCENTIM (treatments)
Note: Averages and growth rates for B, FIN, I for 1988-1995, IRL 1994-1995. For P, citations are recorded only in 1995 patents.

Third European Report on S&T Indicators, 2003

Linking science to technology by non-patent references

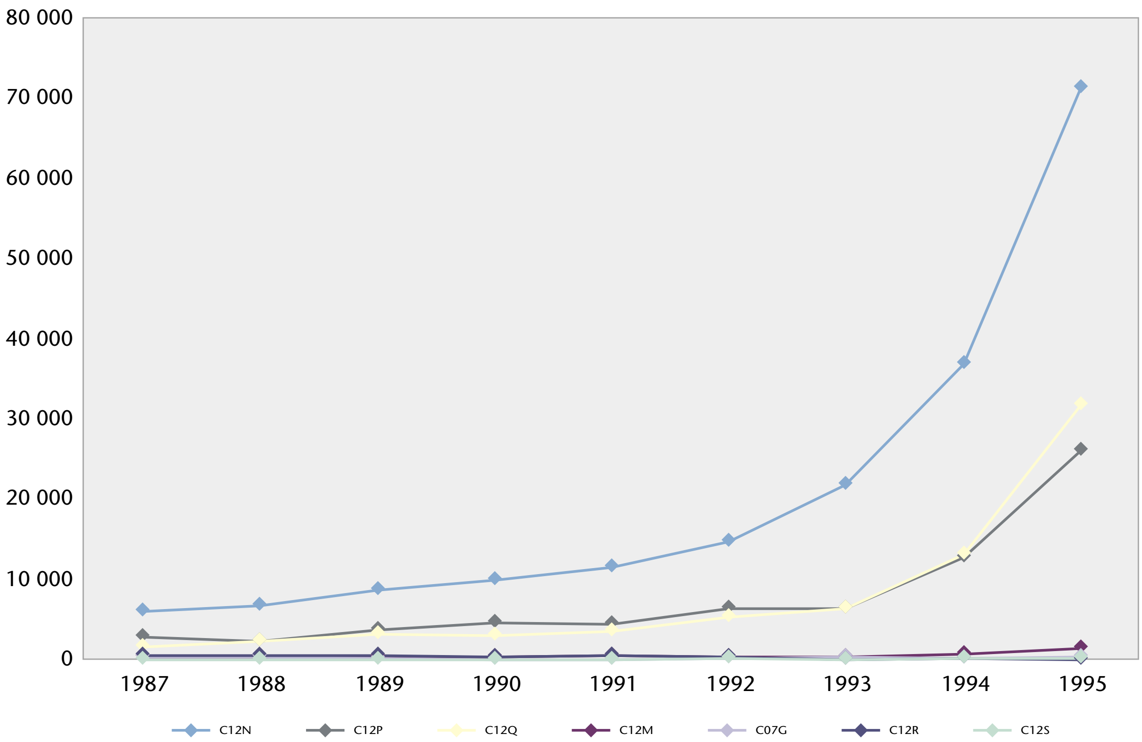
In order to measure and observe the linkage between science and technology, the non-patent references (NPRs) in patents can be used as units of analysis. NPRs are citations of literature such as scientific articles. They can be regarded as an indicator of scientific output entering technological applications. A sophisticated matching algorithm developed in a study by INCENTIM, a research unit at the University of Leuven (KUL) has also resulted in a more profound analysis of biotechnology patents and their scientific citations within the NPR (European Commission 2001). In order to generate valid data, the patents granted within the US patent system must be used, as the number of NPRs in US patents is significantly higher at the EPO.

Biotechnology has been described by a limited number of international patent classification (IPC) classes, namely:

- C07G: Compounds of unknown constitution
- C12M: Apparatus for enzymology or microbiology
- C12N: Micro-organisms or enzymes; compositions thereof

- C12P: Fermentation or enzyme-using processes to synthesise a desired chemical compound or composition or to separate optical isomers from a racemic mixture
- C12Q: Measuring or testing processes involving enzymes or micro-organisms; compositions or test papers therefor; processes of preparing such compositions; condition-responsive control in microbiological or enzymological processes
- C12R: Indexing scheme associated with subclasses C12C to C12Q or C12S, relating to micro-organisms
- C12S: Processes using enzymes or micro-organisms to liberate, separate or purify a pre-existing compound or composition; processes using enzymes or micro-organisms to treat textiles or to clean solid surfaces of materials

Figure 6.3.19 Development of the number of non-patent references (NPRs) in IPC classes



Source: DG Research
Data: USPTO; data processed by Incentim-K.U. Leuven

Third European Report on S&T Indicators, 2003

The number of NPRs per technology component in biotechnology patents can be measured to identify three IPC classes which contain the highest numbers of NPR: C12N, C12Q and C12P. Over the years, class C12N (micro-organisms or enzymes) has comprised between 52% and 61% of NPRs. Between 1987 and 1995, the overall highest growth rate of NPRs occurred in C12Q, at 44.4%.

The three main classes (as well as the others) have been linked to science fields, i.e. citations of scientific literature within patents in the biotechnology related IPC classes have been classified into scientific disciplines. In all three main classes, between 20% and 25% of the scientific literature citations belong to the discipline of biochemistry and molecular biology. This is followed by multidisciplinary research, a field which covers multidisciplinary journals such as Nature and Science. Together, they account for about 40% of citations in the three classes (European Commission 2001, report by INCENTIM 2001).

An analysis of the significance of other scientific research originating in Europe, the US or Japan for a single European country provides some interesting results (table 6.3.1). In the period 1987-1991, EU-15 originated research played a significant role in European biotechnology patents, particularly in Austria, Belgium, Germany, Spain, Italy and Sweden. US originated research played a more important role in Denmark, France, Finland, the Netherlands and the UK. Japanese research is cited to a minor degree in the patents of some EU countries, except in Denmark, where Japanese originating NPR citations amount to almost 25%.

In the second period from 1992 to 1996, only the Netherlands, Spain and Austria used significantly more original European scientific research than in the first period. The UK, Italy, Germany and Denmark used slightly more European sources than US sources, but had similar percentages of European and US science. For the remaining countries of Belgium, France, Finland and Sweden, US research remained the more significant source.

In terms of growth rates, US research gained ground in all countries in the second period, with the exception of the Netherlands and the UK. European research was used less in Austria, Belgium, Germany, Spain, and Sweden. Almost every EU-15 country showed an increase in the number of citations of US papers, which confirms the general importance of US research in the field of biotechnology.

Table 6.3.1 Overview of cross-citation practice of EU-15 countries (1987-1991 and 1992-1996)

	Increase or decrease of NPRs between period 1987-1991 and 1992-1996	EU		JP		US	
		1987-1991	1992-1996	1987-1991	1992-1996	1987-1991	1992-1996
Belgium	⇧	+	-	+	++	+	++
Denmark	⇩	+	++	+	-	+	-
Germany	⇧	+	++	+	-	+	++
Spain	⇩	+	-	+		+	++
France	⇩	+	-	+	-	+	-
Italy	⇧	+	++	+	++	+	++
Netherlands	⇔	+	++	+	++	+	-
Austria	⇧	+	-	+	-	+	++
Finland	⇩	+	++	+	-	+	-
Sweden	⇧	+	-	+	-	+	++
UK	⇩	+	++	+	-	+	-

Source: DG Research
Data: USPTO, INCENTIM (treatments)
Note: + signals cross-citations do exist in this period
++ increase from period one to two
- decrease from period one to two
☐ most significant cross link in this period
EL, P, L and IRL have been omitted due to small number of NPRs or none at all

Third European Report on S&T Indicators, 2003

Another interesting finding is the presence of self-citations per country (table 6.3.2). Inventors from each country often use publications originating from their own country, which is a possible indication of a well functioning network of knowledge transfer and use. One can see from table 6.3.2 that most countries have gotten much more international in citing scientific literature from other European countries than the domestic one. While the first sub-columns per row indicating the linkages 1987-1991 are blank for several possible sources, the second sub-column, indicating links in 1992-1996 are most often filled and have increased relative to the previous period.

Finally, a substantial number of European-based firms have created networks with US-based dedicated biotechnology firms. By using the institutional affiliation method to allocate research publications to a specific country, the research conducted by authors at such US biotechnology firms is regarded as of US origin. Figure 6.3.20 illustrates the overall situation with regard to citation spillovers between Europe, the US and Japan.

Most of EU-15 and US-patentees cite domestic scientific literature but the importance of EU originated research in biotechnology is apparent. European inventors cite EU research in almost 60% of all science citations. US inventors cite US originated research in almost 49% of all science citations, whereas Japanese inventors cite Japan originated research in less then 22% of science citations. Whereas 30% of European patent citations are referring to US research, US patents carry 39% citations of European literature. The EU science base also plays a role in Japan. More than one third of science citations by Japanese inventors refer to EU-produced papers. The reverse is the case in only 4% of all citations. This implies that the EU science base is highly important for US and Japanese technological development. According to this result, Europe depends less on the US science base than the US does on the European science base.

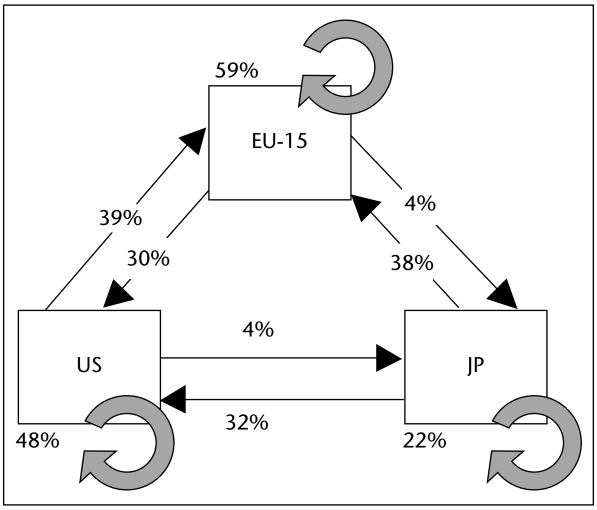
Table 6.3.2 Overview of cross-citation practice between EU-15 countries: 1987-1991 (1) and 1992-1996 (2)

	Belgium		Denmark		Germany		Spain		France		Italy		Netherlands		Austria		Finland		Sweden		UK	
	(1)	(2)	(1)	(2)	(1)	(2)	(1)	(2)	(1)	(2)	(1)	(2)	(1)	(2)	(1)	(2)	(1)	(2)	(1)	(2)	(1)	(2)
Belgium	+	-		+	+	++		+	+	++	+	-	+	++				+	+	++	+	++
Denmark	+	-	+	-	+	++		+	+	++		+		+		+		+	+	-	+	++
Germany	++	-		+	+	-	+	-	+	-	+	-	+	++	+	++	+	++	+	-	+	++
Spain			+		+	+	-		+				+									+
France	+	-		+	+	++	+	++	+	-	+	++		+	+	-		+		+	+	-
Italy	+	-			+	-	+		+	+	+	++		+					+	++	+	-
Netherlands	+	-	+	-	+	++	+	++	+	-		+	+	++			+	-	+	-	+	-
Austria		+		+	+	-		+	+	++		+	+	-	+	-			+	++	+	++
Finland		+	+			+			+	++		+		+		+	+	-		+	+	++
Sweden	+	-	+		+	++			+	-		+	+	-		+			+	-	+	++
UK	+	-		+	+	++	+	++	+	-	+	++	+	++		+	+	-	+	++	+	++

Source: DG Research
Data: USPTO, INCENTIM (treatments)
Notes: + signals cross-citations do exist in this period
++ increase from period one to two
- decrease from period one to two
☐ most significant cross link in this period
EL, P, L and IRL have been omitted due to small number of NPRs or none at all

Third European Report on S&T Indicators, 2003

Figure 6.3.20 Citation spillovers between the Triad regions (1992-1996)



Source: DG Research
Data: USPTO, INCENTIM (treatments)
Note: Arrow points from origin of patent to origin of scientific literature.

Third European Report on S&T Indicators, 2003

Similarly, US inventors use Japanese research in only 4% of their science interactions, whereas Japanese inventors use US research in 32% of their science references. This phenomenon might be explained by the language barrier between Japan and Europe/US – the Japanese are more at home in English than vice versa.

8. Another European paradox?

Despite impressive growth in European production of biotechnology science, the number of innovations in terms of patents does not show the same positive trend. Compared to the US, the number of applications by European inventors is small. Even so, it has to be taken into account that Europe, like almost all other world regions, arrived on the biotechnology scene later than the US.

The US biotechnology innovation system provides a role model for the institutional environment that could facilitate the evolution of the technology. Parallel development of a broad research base and high venture capital investment could form the nucleus of high-tech and science-based technological change. Most European countries have started copying the US model and several policies have been developed at European level (Senker *et al* 2001).

The UK has been highly successful in developing its biomedical research base, as its financial markets were well developed at an early stage. France and Germany have a satisfactory biomedical research base, but lack appropriate financial institutions. Medium sized countries such as Sweden, the

Netherlands and Belgium, with equally satisfactory research bases, often lack an industry with appropriate absorptive capacity.

Catching up in terms of share of scientific publications, patents, numbers of new firms etc. is difficult, given that the frontrunner is all but standing still. Success breeds success. As the scientific and technological bases in the US are favourable and attractive to international researchers and firms, progress follows readily in the US. Europe should make every effort not to lag behind.

As the European biotechnology innovations system develops, scientific discoveries open up more and more potential technological applications and biotechnological techniques. During the 1980s and 1990s, the prime target for industrial development has been the pharmaceutical industry. Other industries might not have been ready, or the necessary biotechnological techniques had not yet been developed.

Various biotechnology experts point to several factors that may be hampering the development of European biotechnology. These include the heterogeneity of European product regulation and small national financial markets. At the same time, they indicate that the situation has changed for the better in recent years. Financial institutions and venture capitalists are exploring different European markets. Product regulation, at least in the pharmaceutical industry, might become more and more co-ordinated owing to establishment of the European Agency for the Evaluation of Medicinal Products (EMEA). So far, the equipment and supplies market is still fragmented by excess differing product standards, and the biopharmaceuticals market by different pricing regimes in each country (Senker *et al.*, 2001).

Europe could embrace the opening up of new biotechnology opportunities. In order to do so, it might be necessary to think bigger than before. The biotechnology sector in the EU is still not a true European sector; biotechnology is more or less concentrated within the different member states. According to Ernst & Young's European Biotech Report 2001, a major stumbling block for the development of a European biotechnology space is the fact that the Member States fund several biotechnology research centres in their respective countries. Instead of a limited number of European centres of excellence, Europe has a large number of institutes that lack critical mass (Ernst & Young 2001).[14]

A recent study commissioned by DG-Research confirmed the existence of a large number of research institutes of varying sizes: whereas about 210 public research institutes have been identified in the US, the number in the EU plus Switzerland amounts to 500 (European Commission, 2002). Nonetheless, in terms of scientific output, several small institutes or research groups of about 25 people performed extremely well and in general much better than larger units with more than 200 people. This paradox might be explained as follows: With regard to biotechnology at least, critical mass is not necessarily achieved through large concentrations of researchers and technicians in one location, but through virtual networks as well.

The study supports the notion that smaller groups and institutions with flat hierarchies and strong external contacts are most innovative in their research. While a lot of day-to-day development work requires professional technical support on the spot, scientists make much more use of their personal and professional networks in order to perform sophisticated research. Biotechnology research in the member states might need more transparency in terms of who is doing what, rather than dramatic structural change. Better co-ordination would lead to improved networks of researchers and scientists.

From the Stockholm European Council to the Barcelona Council: Commission to shape strategic vision for life sciences and biotechnology

The European Commission has been paving the way for a strategic Communication on biotechnology during the Swedish presidency in 2001. The biotechnology strategy that has been submitted to the Council at the Barcelona Council in April 2002 aimed at implementing Europe's commitment to sustainable development, by ensuring that it reaps the full benefits of biotechnology's potentially huge contributions to social development, environmental protection and economic growth. The strategy includes close scruting of ethical and societal issues relating to biotechnology.

Europe will have to build on its strengths, such as its science base and highly skilled labour force. Although the EU has approximately as many biotechnology companies as the US, its biotechnology sector is still comparatively young. Many new biotechnology companies are not yet fully operational. The number of truly world-class biotechnology companies is still too small.

The European Commission has recognised the need for a comprehensive EU-wide approach to biotechnology. All responsible Commissioners and services were working

[14] *The number and nature of institutes addressed by Ernst & Young has not been stated in the report. Comparisons to other data sources might be problematic due to differing definitions and a differing sample.*

together to elaborate a consistent overall biotechnology strategy.

In the context of the so-called Lisbon process, the biotechnology strategy Communication was based on forecasts of the potential economic and social impact of life sciences and biotechnology up to 2010. The Communication includes strategic policy recommendations and suggests integrated action plans. Issues that are addressed within this broad view include:

- the regulatory framework and its implementation, to protect health and the environment;
- biotechnology research in support of European policies and industries; education; supply of skilled staff; intellectual property rights;
- innovation and industrial competitiveness; entrepreneurship; access to loans and equity finance;
- public perceptions and good governance (addressing issues such as societal benefits, ethics, the food sector);
- EU policy in a global context (international governance, development policy and food safety, relations with trading partners, multilateral co-operation).

The Barcelona Council in April 2002 concluded that frontier technologies were a key factor in future growth. The European Council has requested to examine before June 2002 the Commission's communication "Life Sciences and Biotechnology – a strategy for Europe". It has asked the Council and the Commission to develop measures and a timetable which will enable European businesses to exploit the potential of biotechnology, while taking due cognisance of the precautionary principle and the need to meet ethical and social concerns. The Commission has been invited to report on progress in advance of the Spring European Council in 2003.

A recent European study (Senker *et al* 2001) reveals material differences in innovation patterns between the eight European countries covered in its investigation. The national innovation systems, the role of the public sector, including public policy, the private sector, the financial system and the education and training systems are important elements of any biotechnology innovation system. The relationships between these elements help to explain national differences and economic performance. The study reveals that the major impact on innovation comprises demand, the nature of the market and public attitudes to applications of biotechnology. It differs greatly between industries and has a major influence on industry innovation activity.

The substantial difference between countries suggests that each country has its own pattern of innovation in biotechnology. Countries with large home markets appear to have better opportunities to exploit the development of new market niches. Evidence of synergy between sectors at a national level have been found, but only little evidence of integration with European markets for these sectors.

The case of biotechnology in Europe demonstrates the European dilemma: most national industries and biotechnology research systems lack critical mass. It takes time to build research co-operation and establish links between academia and industry within a country, but even more so on the European level. Multinational firms seem to have less difficulty in detecting the knowledge at its origin – wherever it may be. However, they face stiff competition in accessing such knowledge on an exclusive basis.

It is unlikely that the US comparative advantage will be overhauled in the next few years. Existing data on the number of companies and their profits points to a David versus Goliath situation. However, the smaller European countries are most likely to grow too in terms of science base and technological innovation. It is a trend that could be triggered positively by a concerted European effort.

B. Nanotechnology: An emerging technology set for economic breakthrough

Nanotechnology is set to become a key technology of the 21st century. With its origins in the academic nanoscience community, nanotechnology has shifted from universities and research institutes to several industries and has attracted a lot of interest in economic and political debate. Industry is beginning to adopt the first outcomes of nanotechnological research as R&D decision-makers in many parts of the (industrialised) world are establishing large nanotechnology research programmes[15] with a view to achieving competitive advantages at the outset.

This section analyses the current state of nanotechnology by using some sophisticated indicators of scientific and technological development.[16] At country level, it identifies the main players in nanoscience and nanotechnology, their specialisation, patterns of collaboration and support through government policy.

[15] *Cf. e.g. the National Nanotechnological Initiative (NNI) in the United States or the role of nanotechnology in the Sixth Framework Programme of the European Commission.*

[16] *All data for the bibliometric and patent analyses in this section has been provided by A. Hullmann and the Fraunhofer-ISI in Karlsruhe, Germany. For methodological notes on the search strategies, cf. Hullmann (2001).*

1. Development of nanoscience and nanotechnology

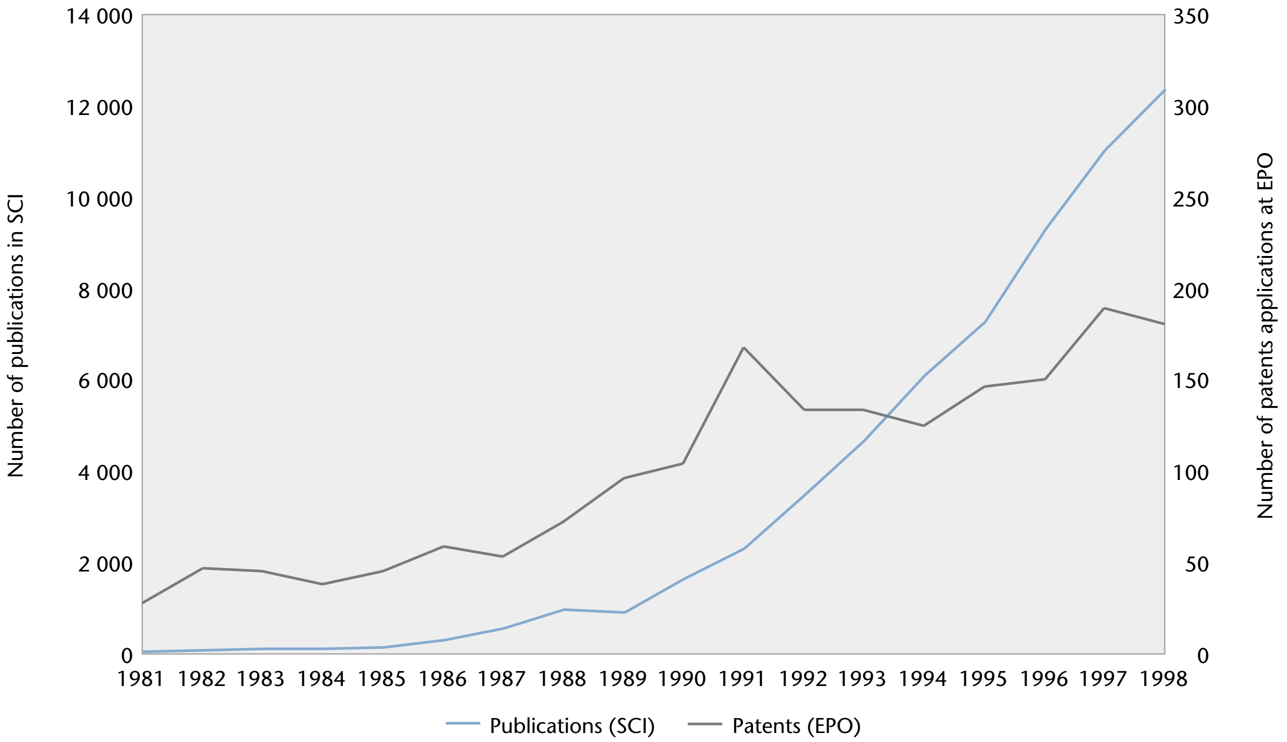
To better understand the concept of nanotechnology, it is helpful to distinguish between nano*science*, which refers to the scientific building blocks in physical, chemical and biological sciences and in engineering sciences, and nano*technology*, which comprises nanotechnological applications in different technologies and industries. Nanotechnology is a classical cross-sectoral technology with applications in nearly all sectors and products. Examples are the materials, optics, precision instruments, mechanics, automobile, chemicals, pharmaceutical/medical, telecommunication and micro-electronic industries. Nanotechnological products have distinctive characteristics, formed by using unique nano-dimensional physical properties and by manipulating molecules to create, for example, ultra-thin layers, ultra-smooth surfaces, and ultra-short waves.

The advantage of this technology is that it creates materials and artefacts with special characteristics, developed for very specific purposes. Such features are developed at molecular level. They are termed nanotechnology because of their minuscule size of less than 100 nanometer (a nanometer is 10^{-9} meter). Some applications are even smaller, at the atomic level of about 0.1 nanometer.[17] At these dimensions, instruments for the manipulation of molecules and atoms play a crucial role, but the scientific foundations of our knowledge of physical, chemical or biological characteristics of structures and interactions are just as vital.

Due to the variety of knowledge bases, technological sub-areas and applications upon which nanotechnology draws, a common definition of what nanotechnology entails is hard to find, even amongst experts. It is also difficult to draw boundaries between the different sub-areas. Because of data constraints, and in order not to complicate the analyses, nanotechnology in this section is treated as a whole.[18]

As mentioned in the introduction, new technologies undergo typical patterns of scientific, technological and economic development. 'Science push' frequently precedes 'technology

Figure 6.3.21 Publications in SCI and patents at EPO in nanotechnology 1981-1998 worldwide



Source: Hullmann (2001)
Data: ISI, EPO

Third European Report on S&T Indicators, 2003

[17] *The expression "nano-technology" was introduced by Taniguchi in 1974, picking up the ideas of Richard Feynman, who as early as 1960 discovered the great potential of "plenty of room at the bottom". Feynman can be seen as the father of nanotechnology. The most important technological foundation was laid by Gerd Binnig and Heinrich Rorer, who developed the Scanning Tunnel Microscope (STM) in 1979 for which they were awarded the Nobel Prize in 1986.*

[18] *In the awareness that the developments and overall performances of countries in nanotechnology are combined by strengths (or weaknesses) in different nano-relevant scientific fields or economic branches.*

pull' and 'market pull'. Figure 6.3.21 shows the development of publications and patents in nanotechnology world-wide from the beginning of the 1980s up to 1998. The time slope of publications as indicator of nanoscientific development shows small numbers in the 1980s, and a surge in the early 1990s. The number of relevant publications – about 1 000 in 1989 – increased to more than 12 000 in 1998. This period saw growth rates of between 10% and 80% per year; the average being 27%. The data for 1999 and 2000, not available for figure 6.3.21, shows this trend is continuing.

The grey line in figure 6.3.21 depicts the evolution of the patents related to nanotechnology registered at the European Patent Office (EPO) for the same period as relevant scientific publications. Over the entire period from 1981 to 1998, the curve shows a clear increase in the number of patents, with an average growth of around 7% for the last ten years. The patent curve fluctuates, not only because of the statistics of handling smaller amounts of data, but also because industrially relevant technological breakthroughs in a specific year have a more significant weight.

Plotting the publications and patent indicators for nanoscience and nanotechnology evolution reveals patterns similar to other emerging technologies, such as biotechnology as analysed in the previous section. After significant progress in basic research in the late 1990s, it is likely that technological development will follow with a time lag of several years. Scientific and technological development is an essential prerequisite for economic success of nanotechnology in the future. Owing to its manifold applications and vast potential for providing new solutions and product improvements, nanotechnology presents tremendous prospects of becoming a key technology.

Various commentators agree that it is only a matter of *when* nanotechnology's economic breakthrough will come, rather than *if*, although an accurate prediction of when it will occur, is not easy. Estimations by the German Association of Engineers (VDI, 2001), put the world market volume of sales in 2001 at some 55 billion euro; Roco (2001) estimates an increase to about 800 billion euro in 2015. Not all areas in nanotechnology will mature at the same time. An analysis of the technology by the Sal. Oppenheim Bank (2001) for Germany expects some areas, such as ultra-thin layers and surface treatment, to be ready for marketing in 2002. Other more science based technological sub-areas such as structuring technology will only be marketable by 2006.

Apart from the time needed for marketing that will influence the economic impact of nanotechnology, different applications demand different kinds of development in various industries and in organisational and market structures. For example, the development of electronic microscopes and other ultra-precise instruments for nanotechnology, called nanoanalytics, is a typical area for SMEs. The application of ultra-thin layers or surfaces or other new kinds of material are more relevant to product improvements by large, often multinational companies in the electronic, pharmaceutical or automobile industries. Both developments will have a significant impact on economic features such as employment, market structures (start-ups and other technology-intensive firms) or international competitiveness.

2. Country performance in nanoscience

Figure 6.3.22 provides some perspective on the global distribution of nanoscientific research and, consequently, the regions best prepared for shaping the nanotechnological progress. It shows the share of publications in five regions: the EU-15 and EFTA, the US and Canada, Asia, the Candidate countries and Russia, and other countries from around the world.

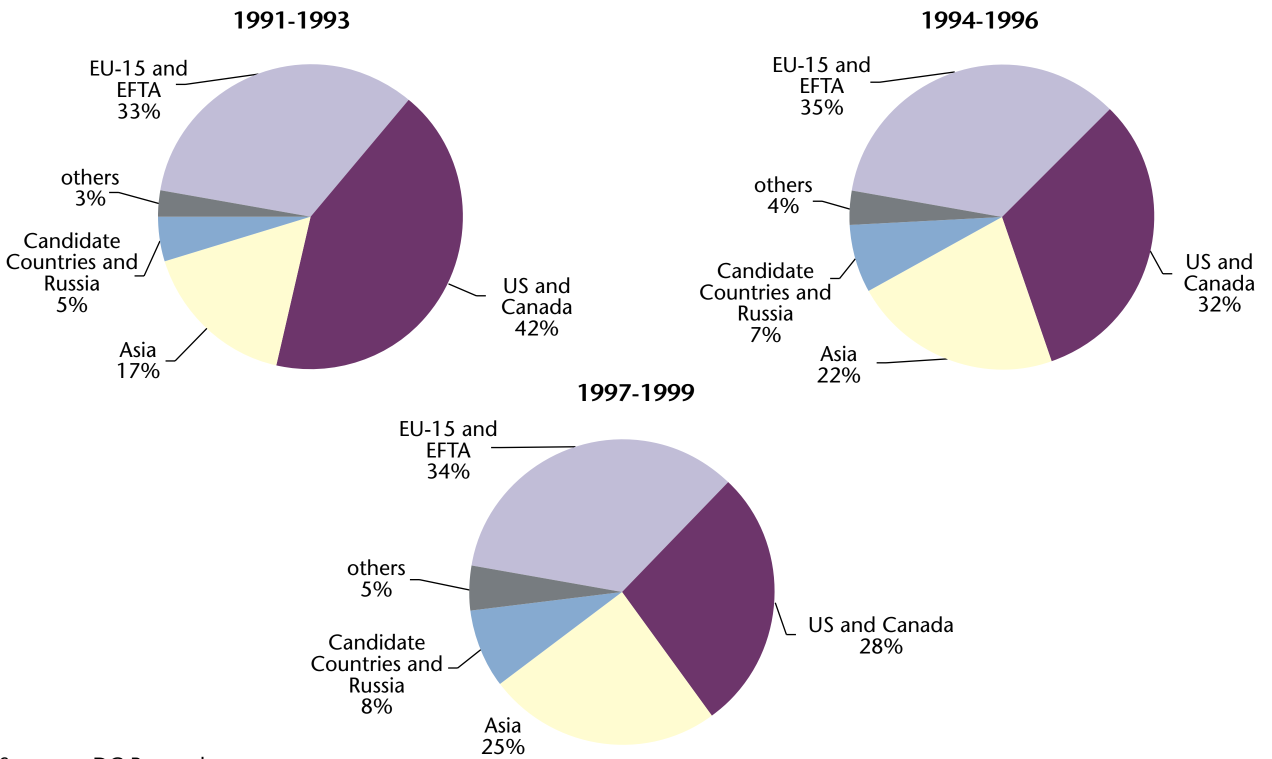
Compared to the large increase in the overall number of scientific publications illustrated in figure 6.3.21, the absolute number of publications shows an increase in all five groups of countries. In terms of the evolution of scientific activity amongst the five groups, the northern American countries' share shows a decrease, mainly in favour of Asian and eastern European countries. At the beginning of the 1990s, the US and Canada had the majority of all publications, followed by the western European countries. In the mid 1990s, the order changed. Towards the end of the decade, the Asian countries had almost closed the gap between themselves and the US and Canada. The Candidate countries and Russia made significant progress, almost doubling their share.

Which countries undertake nanoscientific research? Table 6.3.3 indicates the distribution of nanotechnology related publications between 1997 and 1999 in the SCI database by the authors' country affiliations.

The most active country in terms of nanoscientific research is the US, with about 25% of all publications. Japan and Germany are next, followed by China, France, the UK and Russia. The first seven countries account for nearly 70% of the world's nanoscience papers. The other EU-15 Member States (except Luxembourg) are among the top 40, but they are not more productive than Asian countries such as South Korea, India and Taiwan, or others such as Canada, Israel and Australia. Most of the Candidate countries are in the top 50 list. Poland's position is sound and China and Russia's are outstanding, demonstrating the significance of nanoscience in their research systems.

Figure 6.3.23 eliminates distortions resulting from country size, by normalising the number of publications per million population. This provides some perspective on scientific productivity in nanoscientific research in the different countries.

Figure 6.3.22 Share of publications in nanotechnology by region



Source: DG Research
Data: ISI; data processed by Fraunhofer-ISI

Third European Report on S&T Indicators, 2003

Table 6.3.3 Publications in nanotechnology 1997-1999: 50 most active countries (shares of world in %)

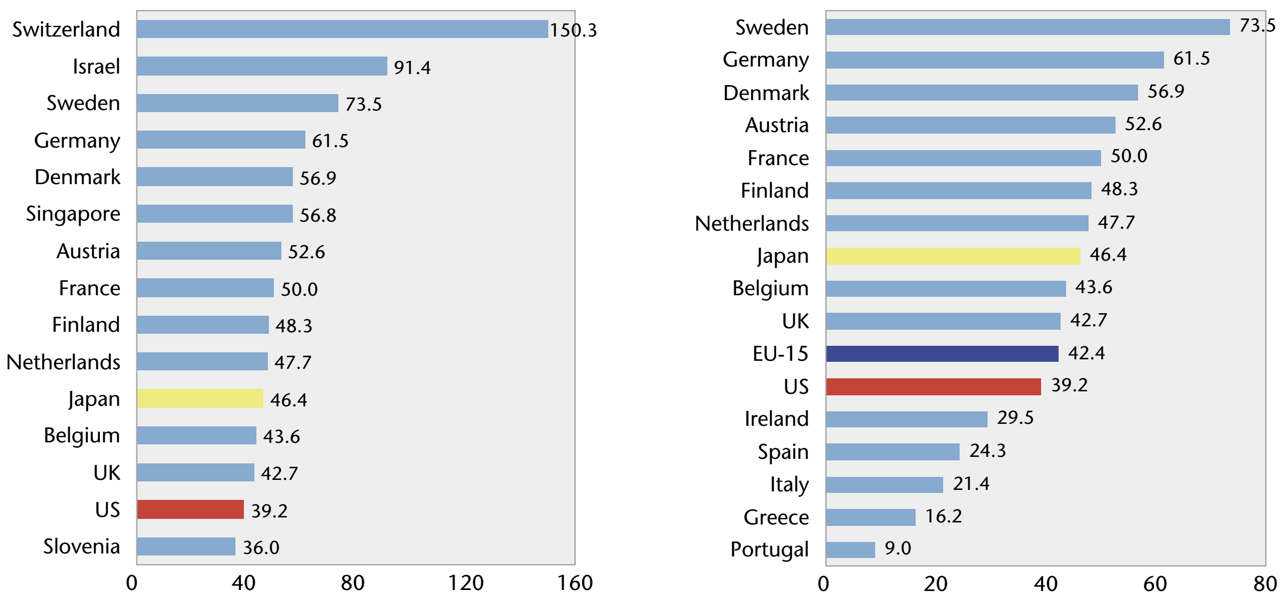
Ranks 1 to 17			Ranks 18 to 34			Ranks 35 to 50		
Rank	Country	Publications	Rank	Country	Publications	Rank	Country	Publications
1	US	23.7	18	Poland	1.2	35	Ireland	0.2
2	Japan	12.5	19	Taiwan	1	36	Slovakia	0.2
3	Germany	10.7	20	Belgium	1	37	Portugal	0.2
4	China	6.3	21	Austria	0.9	38	Bulgaria	0.2
5	France	6.3	22	Brazil	0.8	39	Turkey	0.2
6	UK	5.4	23	Denmark	0.7	40	Slovenia	0.2
7	Russia	4.6	24	Hungary	0.6	41	New Zealand	0.1
8	Italy	2.6	25	Ukraine	0.5	42	Yugoslavia	0.1
9	Switzerland	2.3	26	Finland	0.5	43	Norway	0.1
10	Spain	2.1	27	Mexico	0.5	44	Lithuania	0.1
11	Canada	1.8	28	Hong Kong	0.5	45	Croatia	0.1
12	South Korea	1.8	29	Singapore	0.5	46	Cuba	0.1
13	Netherlands	1.6	30	Czech Rep.	0.4	47	South Africa	0.1
14	India	1.4	31	Greece	0.4	48	Latvia	0.1
15	Sweden	1.4	32	Argentina	0.3	49	Egypt	0.1
16	Israel	1.2	33	Romania	0.3	50	Estonia	0.1
17	Australia	1.2	34	Belarus	0.2		others	0.6

Source: DG Research
Data: ISI; data processed by Fraunhofer-ISI

Third European Report on S&T Indicators, 2003

Figure 6.3.23 Publications per million population (1997-1999)

a) 15 most productive countries worldwide **b) EU-15 Member States, the US and Japan**



Source: DG Research
Data: ISI, UNESCO
Note: To avoid distortions in these calculations, only countries with more than 20 publications in nanotechnology in the period 1997-1999 are considered. The population data is that of UNESCO for mid 2001. No publication data for Luxembourg – it is not included in the EU average.

Third European Report on S&T Indicators, 2003

The positions of the EU-15 Member States, the US and Japan as a separate group are indicated in the right-hand column. The values in the left-hand column for the 15 most productive countries around the world show Switzerland coming out on top,[19] followed by Israel and seven EU-15 Member States led by Sweden, Germany and Denmark. Singapore and Japan are also among the top 10, followed closely by the US. The populous countries that are productive in terms of absolute numbers of publications, such as Russia, Poland and China, are not among the first 15, but among the lower ranks of the top 50. The positions of the European big three, Germany, France and UK, and of Japan and the US reflect not only their performance, but also a relatively high productivity of nanoscientific research in these countries.

Further analysis deals with absolute numbers of publications. Statistical constraints arising from a lack of data, preclude an in-depth analysis of all top 50 countries. Even so, it would be useful to do so for some of them, especially the smaller EU-15 Member States and the Candidate countries. The following section analyses the nine most active EU Member States (Germany, UK, France, Italy, Spain, the Netherlands, Sweden, Belgium and Austria) and the most active non-EU countries (the US, Japan, China, Russia, Switzerland, Canada, South Korea, India, Israel, Australia, Poland and Taiwan).

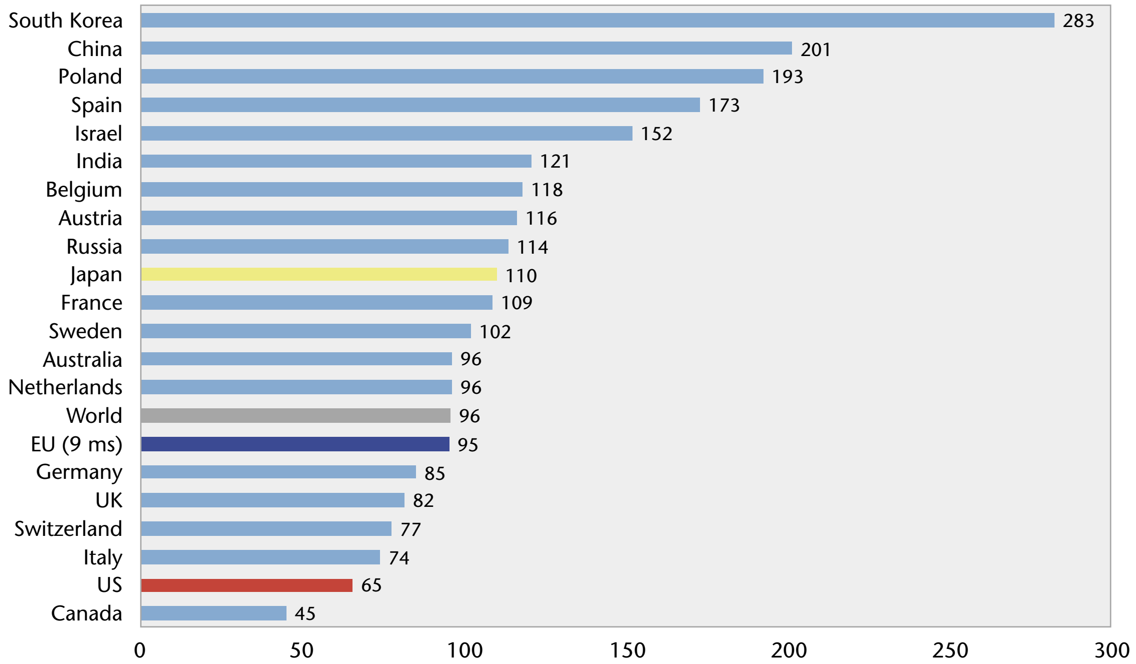
Figure 6.3.24 indicates the growth rates for 20 of the most active countries worldwide, the world average and the EU average for the period 1995-1999.

South Korea, China and Poland have the highest growth rates. China performed very well in the late 1990s. With a growth rate of 200%, it overtook France in terms of annual scientific output in nanotechnology in 1999. Developments in Poland are also promising. The most significant advances have been made in South Korea. Between 1995 and 1999, it almost tripled its nanotechnological publications and is now catching up with the top most active countries. Most of the other countries, from India with 120% to Switzerland with 80%, on average equalled the world growth rate of 100% between 1995 and 1999. Israel and Spain are progressing slightly faster; the US and Canada are stagnating compared to the world average.

Amongst the EU members, the Netherlands, Sweden, Belgium and Austria have achieved moderately sound and better growth than the higher-ranking countries such as Germany, the UK and Italy. Of the larger countries, only France shows

[19] *Switzerland has a long nanotechnological tradition and is still performing very well.*

Figure 6.3.24 Development of nanoscientific output - Growth rates in % (1995-1999)



Source: DG Research
Data: ISI, data processed by Fraunhofer-ISI
Note: No publication growth data for DK, EL, IRL, L, P and FIN is available. They are not included in the EU average for nine EU Member States (EU 9 ms).

Third European Report on S&T Indicators, 2003

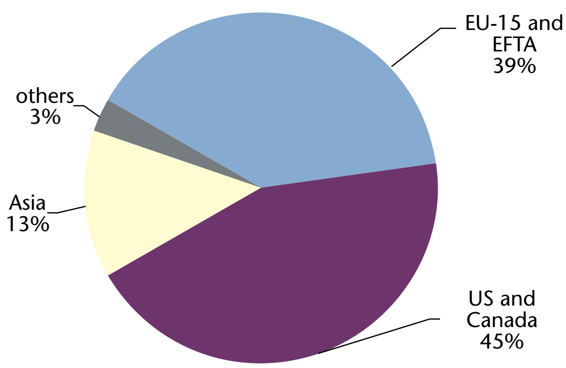
slightly above average progress, equal to that of the smaller countries. Italy, with the lowest growth rate of the EU countries, is a special case. At the beginning of the 1990s it was still maintaining excellent growth rates, but it is now lagging behind the other EU Member States. In contrast with Italy, Spain started moderately in the early 1990s, realised higher growth rates in the late 1990s and is now leading the EU group in terms of growth.

It can be concluded from this data that the best performing countries have followed slightly different routes to arrive at their current positions, and that different developments are to be anticipated in future. The large and generally scientifically active countries such as the US, Japan, Germany, France and the UK display average development in nanoscience. In Europe, Poland and Spain that have advanced most significantly in nanoscience in recent times. In the world at large, Asian countries such as China and South Korea are making the fastest progress. The latter will become increasingly important contributors to progress in nanoscience.

3. Country performance in nanotechnology

The previous section has analysed country performance in nanoscience. In this section, the same analysis is undertaken for countries' performance in nanotechnology, as measured in terms of patent applications. Figure 6.3.25 shows patents in nanotechnology at the EPO and the Patent Co-operation Treaty (PCT) for the 1990s.

Figure 6.3.25 Patents in nanotechnology at EPO and PCT 1991-1999: share of country groups by country of inventor



Source: DG Research
Data: EPO, WIPO
Note: A combination of EPO and PCT patents avoid home biases and facilitate comparison of patent data of European countries with non-European countries. Here, the transferred patent applications from PCT to EPO are counted only once.

Third European Report on S&T Indicators, 2003

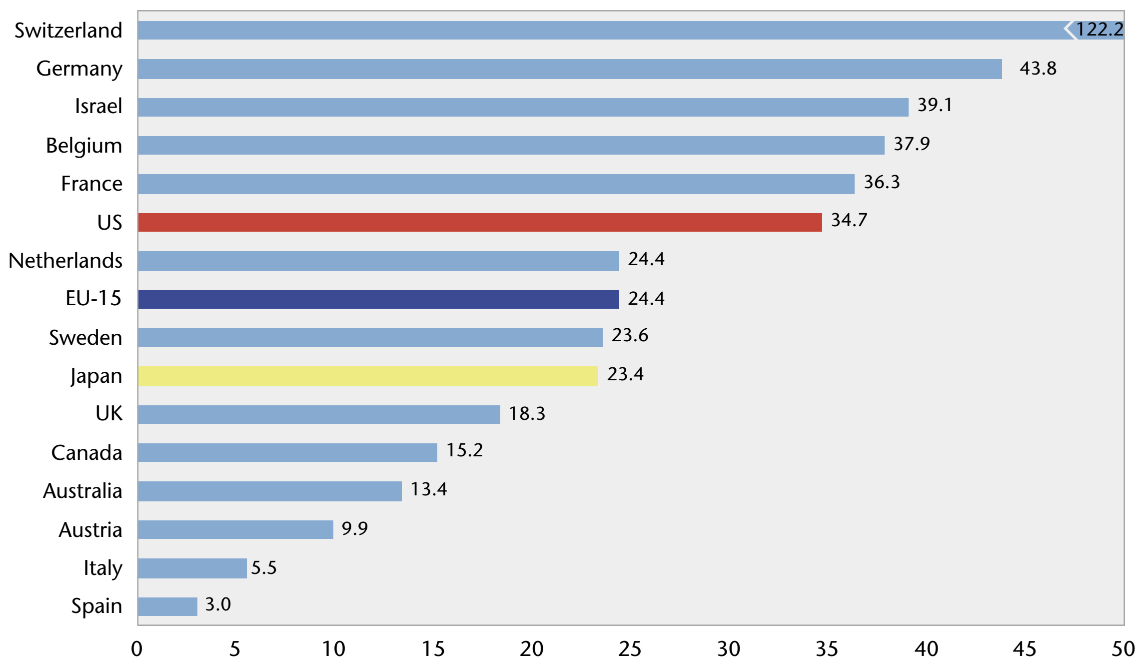
Table 6.3.4 Patents in nanotechnology at EPO and PCT 1991-1999: Share of patents by the 20 most active countries, in%.

Ranks 1 to 7			Ranks 8 to 14			Ranks 15 to 20		
Rank	Country	Patents	Rank	Country	Patents	Rank	Country	Patents
1	US	42	8	Belgium	1.7	15	Spain	0.5
2	Germany	15.3	9	Netherlands	1.7	16	South Korea	0.4
3	Japan	12.6	10	Italy	1.4	17	Austria	0.3
4	France	9.1	11	Australia	1.1	18	China	0.2
5	UK	4.7	12	Israel	1.1	19	Taiwan	0.2
6	Switzerland	3.7	13	Russia	1.0	20	India	0.1
7	Canada	2.0	14	Sweden	0.9			

Source: DG Research
Data: EPO, WIPO

Third European Report on S&T Indicators, 2003

Figure 6.3.26 Patents in nanotechnology at EPO and PCT (1991-1999) per 10 million population: 15 most productive countries world-wide and EU average



Source: DG Research
Data: EPO, WIPO, UNESCO
Note: No patent data for DK, EL, IRL, L, P and FIN. They are not included in the EU-15 average.

Third European Report on S&T Indicators, 2003

The three regional blocs are responsible for almost all nanotechnology patent applications at the EPO and within the PCT. Europe, with almost 40% of all patent applications, is not the most active group; the US and Canada, with 45%, are ahead of Europe. The Asian countries are lagging far behind with 13%. The distribution of nanotechnological research as expressed by nanotechnological patents is much more exclusive than in nanoscientific research (table 6.3.1). Table 6.3.4 shows the list of top 20 patenting countries between 1991 and 1999.

The US leads in patents granted with more than 40%, followed by Germany, Japan and France. Other active inventor countries in Europe are the UK, Switzerland, Belgium, the Netherlands, Italy, Russia and Sweden. Those outside Europe are Canada, Australia and Israel. The Asian Countries rank at the lower end.

The data indicates that in contrast to nano*scientific* research, nano*technological* research with a patent outcome is taking place mainly in more advanced countries. The reason for this is the necessity of costly research infrastructure, including instruments and other expensive equipment, for high quality nanotechnological research. In view of the setbacks endured in Russian research infrastructure, Russia's sound achievement of being in 13th place is remarkable. Nevertheless, the Russian position arises mainly from the mobility of its researchers: many Russian nanotechnologists undertake their research and inventions during visits to research facilities elsewhere, especially in the US and Germany.

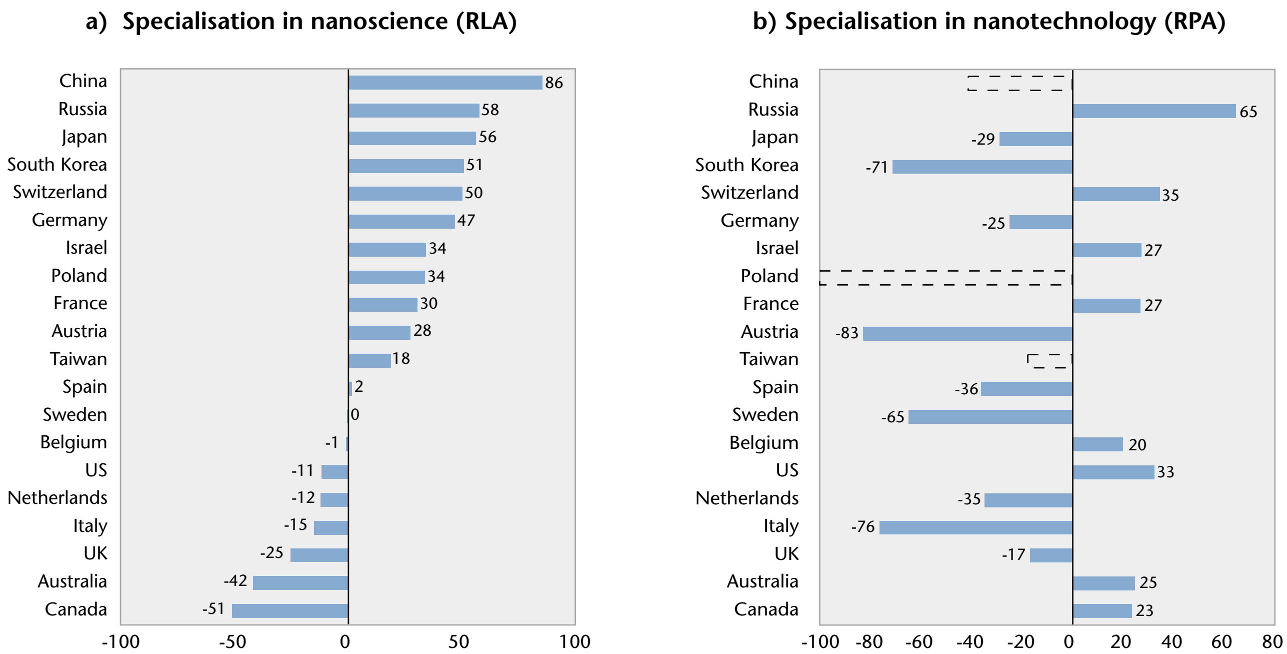
The productivity of the various countries' research systems can be measured by normalising the number of patents for the country's population. Figure 6.3.26 indicates the number of nanotechnology patents per 10 million population.

Switzerland is once more in the leading position. Among the top ten are six EU-15 Member States, led by Germany, with Belgium and France maintaining sound positions. The EU average is similar to that of Japan. However, the US is ahead the EU average, although behind the most productive European countries.

4. Country specialisation in nanoscience and nanotechnology

In previous sections, the scientific and technological performances of the countries have been analysed separately, although they influence each other. As pointed out in the introduction to section 6.3, a good performance in science is the basis for technological development and eventual economic success. Is there any correlation between nanoscientific and the nanotechnological performances of the 20 most active countries? By calculating specialisation indexes, the two indicators of 'revealed literature advantage' (RLA) and 'revealed patent advantage' (RPA) for publications and patent data, respectively, can be compared. These indexes express the importance of nanoscientific and nanotechnological research in relation to the research portfolio of the country concerned.[20] Figure 6.3.27 depicts the results for the 20 most active countries.

Figure 6.3.27 Specialisation in nanoscience and nanotechnology



Source: DG Research
Data: SCI, EPO, PCT
Note: Countries are ordered by their comparative nanoscientific specialisation (measured by their "revealed literature advantage" (RLA)). On the right hand graph, the "revealed patent advantage" (RPA) for CN, PL and TW are the result of numbers of patents that are too small to be reliable; hence the dotted lines.

Third European Report on S&T Indicators, 2003

[20] *The formula of RLA for nanotechnology (nt) for a country (c) is as follows:*
$RLA = 100 * \tanh yp \ln ((Pub_{c,nt}/Pub_{nt})/(Pub_c/Pub))$
RPA is calculated analogously. RLAs and RPAs below 0 show underspecialisation, while those above 0 indicate specialisation.

As mentioned, China and Russia specialise in *nanoscience*. Japan, South Korea, Switzerland and Germany are also on average more active in nanoscience than in other sciences. Below average specialisation is found in the Netherlands, Italy and the English-speaking countries. Regarding specialisation in *nanotechnology*, Russia, Switzerland, the US, Israel and France feature high on the list. A comparison of these two indexes reveals wide divergences, indicating that specialisation in nanoscientific and nanotechnological specialisation does not necessarily go hand in hand.

Only France is specialised in both areas. The other countries show negative specialisation in nanotechnological research, starting from different degrees of specialisation in nanoscience. Compared to this, the US (and to a lesser extent Belgium) show the opposite pattern of specialisation. This leads to the conclusion that scientific excellence of most EU-countries may be wasted by a lack of technological application competencies. In order to make the most of their sound starting position with nanoscience, the EU Member States might have to increase their efforts in the technological and economic arenas to ensure that they benefit from nanotechnology breakthroughs in the future.

5. Collaboration between countries

The results outlined make it possible to analyse the patterns of collaboration in nanoscience. An analysis of the absolute numbers of co-publications will show that co-operation takes place mainly among the large, active countries. Most of the co-publications are undertaken between the US and Germany, followed by the US and Japan, and the US and the UK. The strongest links between EU-15 countries are between the UK and Germany, and between France and Germany, which are to be expected: if a country is very active, the probability increases of some of its authors co-operating with colleagues abroad.

In order to stress real focal points of co-operation, which are not due to activity but to preference, the co-publications are analysed in the sense of deviation from expected rates of co-publication. In table 6.3.5, the blue squares show the values that are above expectation. The grey squares indicate those values below expectation, and the yellow squares show expected rates of co-publication.

The table reveals the close ties among the EU-15 countries, but also the EU-15's ties with Switzerland, Poland, Israel and Russia. The Candidate countries have a much closer relationship with the EU-15 and Russia than with the other active countries. It is striking that the two most active countries, the US and Japan, are not preferred partners in co-publication for most of the countries analysed – only South Korea emphasises co-operation with Japan.

By analysing the respective countries, it is possible to identify patterns of co-operation based on geographical or linguistic proximity and activity in the field.[21] The distances can be visualised on a map created by multidimensional scaling[22]. Figure 6.3.28 portrays the nanotechnology map for the period 1997 to 1999.

Four clusters of countries can be identified. The first comprises the Asian countries and Australia, the second Canada and the small but active European countries of Sweden, Belgium and the Netherlands. The third cluster consists of the UK and the main players – the US, Japan and Germany. The fourth cluster is a varied group comprising the Romance-language countries in Europe, the east European countries, Israel and Austria. The co-operation patterns suggest that co-operation in nanoscience is still influenced by geographical and linguistic proximity, by the size of the countries and by the extent of their activity in this field.

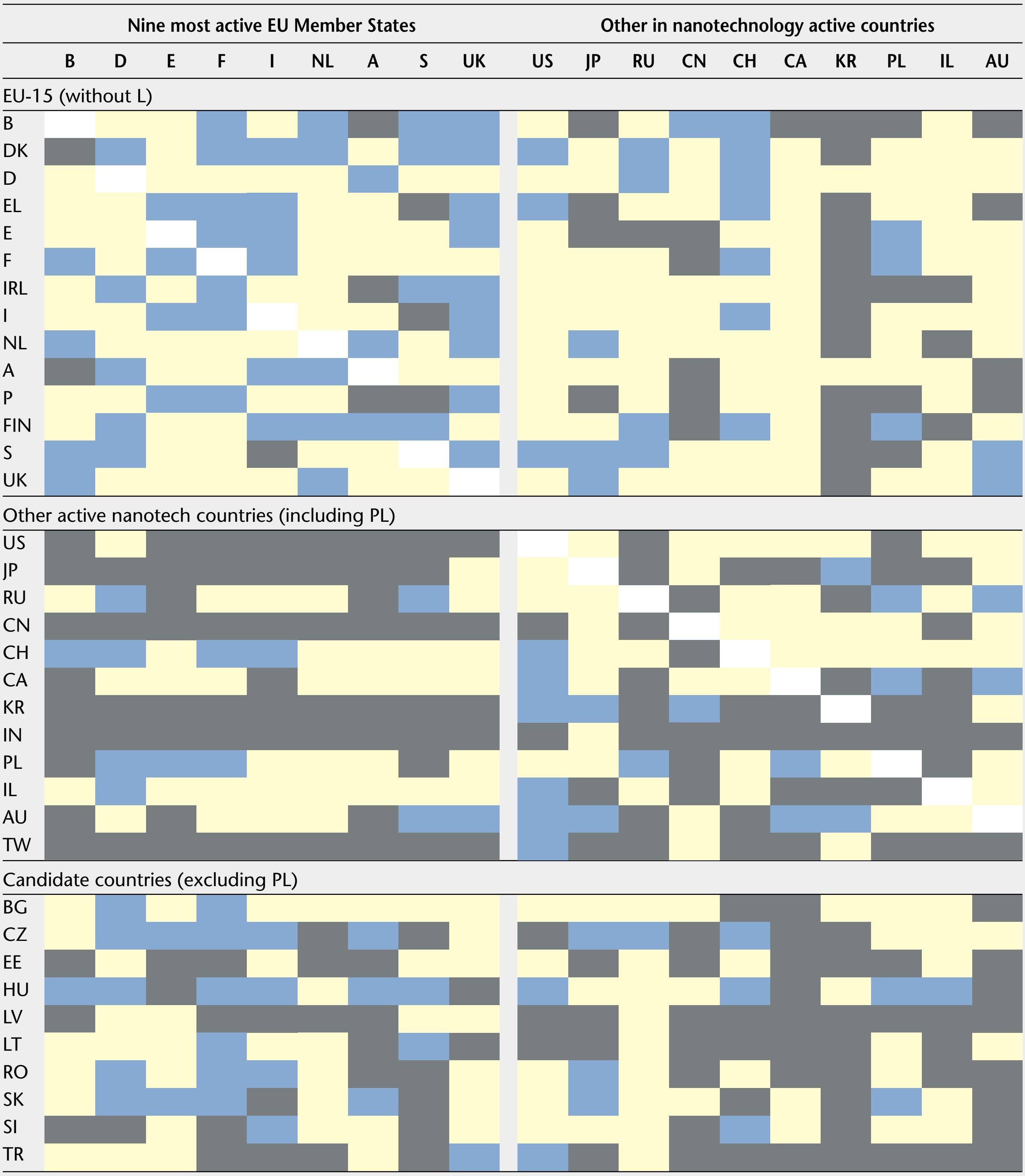
In 2000, nanotechnology collaboration in Europe was also examined the European Commission, by collecting information from nanotechnology experts about existing networks in their respective countries (European Commission 2001). Figure 6.3.29 looks at the results derived from 153 analysed responses. This figure indicates the size of the networks by partner numbers.

Most of the nanotechnology networks analysed involve fewer than 11 partners. Of the 49 networks, 20 are quite large, with more than 10 partners. Amongst them, three have more than 50 partners. The number of members in a network depends on the network's activities and resources. For example, networks with the sole objective of informing their partners, are usually large and cost little to run. In contrast, networks aimed at forging progress in research require significant financial resources. Usually the more advanced and economically relevant a network's research is, the smaller the network will be, mainly because of higher levels of competition in related applied research and industrial development. The divergence in the number of members in nanotechnology networks indicates that there is no dominant style of network. The variation suggests that nanotechnology is eddying between basic research and industrial application.

[21] *For more detailed analyses in this regard see: Hullmann (2001).*

[22] *Multidimensional scaling provides a map, where the distances between the items are defined by the sum of bilateral distances between all items. In such a picture, the distance between two items are therefore also influenced by their distances to other items.*

Table 6.3.5 Patterns of co-operation in nanoscience 1997 - 1999

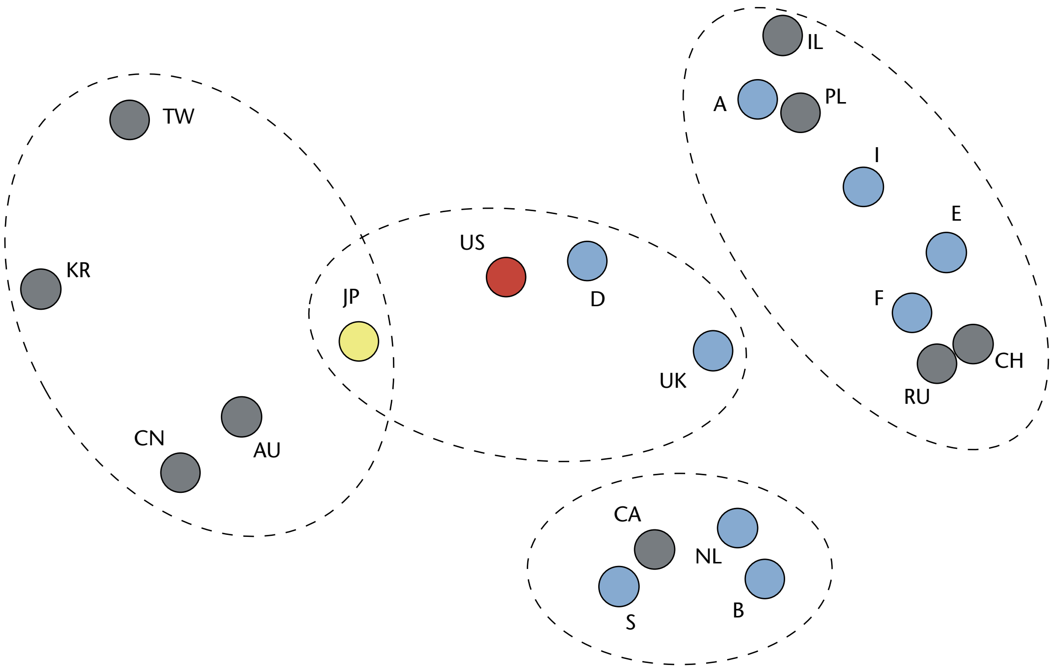


Source: DG Research
Data: SCI
Note: For DK, EL, IRL, P, FIN, IN, TW and the Candidate countries (excluding PL) only co-publication data as partners is available. The expected co-publications are derived from the share of each partner country in overall nanotechnology publications. The deviation is calculated by the difference between real and expected co-publications, indexed by the sum of both; therefore it is between –1 and + 1. The over-average is +0.25 or more, the under-average is –0.25 or less. The marks differ in vertical and horizontal direction. This is because of different perspectives. A less co-operating country can have preferred partners. For the preferred partners the particular country could be average or less. In the table, therefore, the marks should be read vertically to see the preferred partners of a country; they should be read horizontally to see the countries of which the country concerned is the preferred partner.

- above expectation
- below expectation
- expected rates

Third European Report on S&T Indicators, 2003

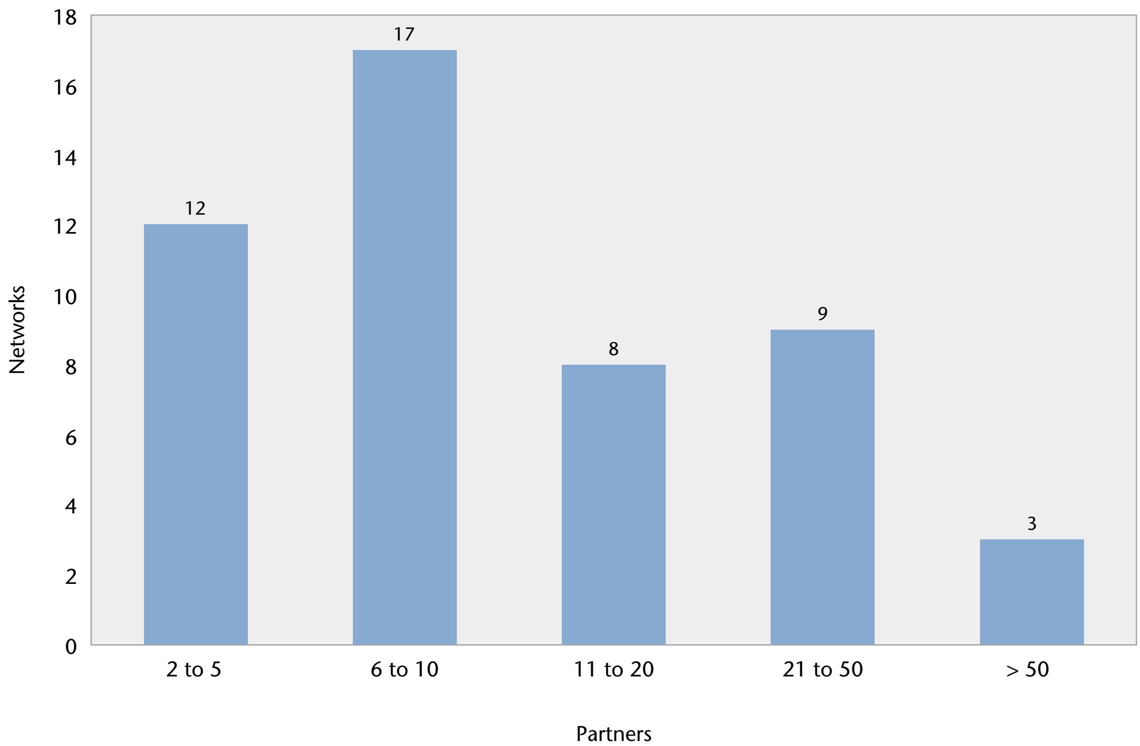
Figure 6.3.28 Distances between countries in nanoscientific research 1997-1999



Source: Hullmann (2001)
Data: ISI

Third European Report on S&T Indicators, 2003

Figure 6.3.29 Nanotechnological networks in Europe (2000)



Source: DG Research
Data: www.cordis.lu/nanotechnology

Third European Report on S&T Indicators, 2003

6. Financial support for nanotechnology

Figure 6.3.30 presents an analysis of the sources of funding for the above-mentioned nanotechnology networks. It indicates the proportion of networks supported by each funding source. The sources are divided into EU funding, national public funding, national private funding and mixtures of these.

Most of the networks – 31, or 57% – are funded by national public funds. EU funding is also significant, involving 17 networks or 31%, which is a measure of the influence of EU funding in bringing about networking in the nanotechnology field. The private sector plays only a small part and funds three networks only. Nevertheless, a simple numerical analysis does not reveal the value of the networks to the companies involved.

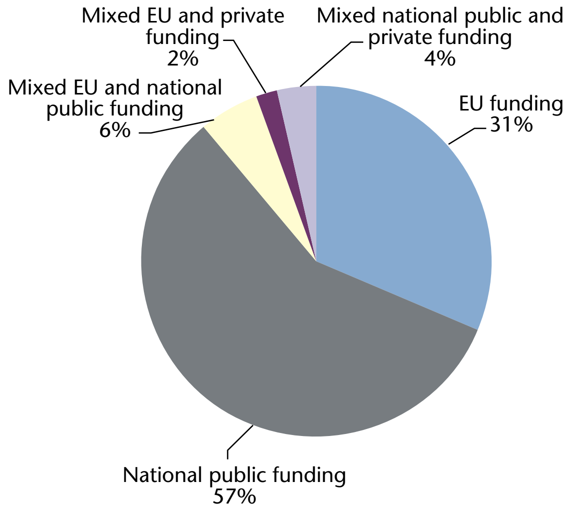
Moderate private sector participation can be interpreted in different ways. On the one hand, it could indicate that industry is not yet involved in nanotechnology because the research is still of a basic character. On the other hand, if the research within the networks is not pre-competitive and relies on knowledge exchange, the involvement of industry is less likely, because of the not direct economic benefit. However, neither of these explanations would seem sufficient. It is more probable that industry is involved in and contributes to the networks on an informal basis, rather than as an official initiator.

The following analysis takes a look at each country's financial contribution to nanotechnology research and development. Table 6.3.6 provides estimates of governmental support to nanoscience and nanotechnology in Europe.

Governmental support for nanoscience and nanotechnology research has increased in all countries in recent years. The average annual growth rates differ from –10% in Denmark to +55% in Italy and 213% in Ireland. The steep increase in Ireland was brought about by the launch of a special nanotechnology programme in 2000. For Europe in total, the average annual growth rate is 12%.

In comparison to other key countries involved in developing nanotechnology, European public funding for nanotechnology research appears moderate. In the US, government support for nanotechnology more than doubled from 1997 to 2000. This was mainly due to the National Nanotechnological Initiative to the amount of 150 million US dollars launched by the US President in 1999. The 2002 budget for nanotechnology enacted by Congress rose to about 600 million US dollars from an initial request for 520 million US dollars. The budget is to be distributed among different government departments, including Defence, Energy, Transportation, Agriculture and Justice, as well as national institutes or agencies such as environmental protection

Figure 6.3.30 Funding sources of nanotechnology networks in Europe



Source: DG Research
Data: www.cordis.lu/nanotechnology
Third European Report on S&T Indicators, 2003

(EPA), aeronautics and space (NASA), health (NIH), standards and technology (NIST), and the National Science Foundation (NSF) (Roco, 2001).

In China, not included in the table but identified earlier as one of the best performing countries in nanoscience, government support for nanotechnology in the National Nanotechnological Initiative amounts to 2 billion RMB[23] in the next five years. This is equivalent to about 50 million euro per year, and is a fourfold increase in comparison to the previous five years. Together with the other most active Asian countries, Japan and South Korea, government support for nanotechnology is expected to amount to 800 million US dollars, which will be twice the figures for 2001. The contribution made by Japan, with an increase of 20% to 30%, is quite moderate in comparison to the nanotechnology initiatives being undertaken in other emerging Asian economies (Roco, 2001).

At first glance, and in comparison with these figures, the contribution of the European Commission of between 23 and 29 million euro per year appears to be minor. However, this money is almost exclusively dedicated to international European co-operation in nanotechnology in the form of EU-wide research projects or EU-funded networks discussed in the previous section[24]. Moreover, this funding is additional to national funding. In the 5th Framework Programme (1999-2003), the European Commission's estimated contribution to nanotechnology amounts to 225 million euro, and will increase remarkably in the 6th Framework Programme (Cordis Focus, No. 162, 2000).

[23] *Renminbi – people's money. The currency used by the indigenous population.*
[24] *Networks funded by programmes COST, PHARE, BRITE-EURAM, ESPRIT, IST, IHP, etc.*

Table 6.3.6 Estimated governmental support for nanoscience and nanotechnology (€ in million)

Country	1997	1998	1999	2000
Belgium	0.9	1.0	1.1	1.2
Denmark	3.0	1.9	2.0	2.0
Germany	47.0	49.0	58.0	63.0
Greece	0.2	0.2	0.3	0.4
Spain	0.3	0.3	0.4	0.4
France	10.0	12.0	18.0	19.0
Ireland	0.4	0.4	0.5	3.5
Italy	1.7	2.6	4.4	6.3
Netherlands	4.3	4.7	6.2	6.9
Austria	1.9	2.0	2.2	2.5
Portugal	0.2	0.2	0.3	0.4
Finland	2.5	4.1	3.7	4.6
Sweden	2.2	3.4	5.6	5.8
UK	32.0	32.0	35.0	39.0
European Commission	23.0	26.0	27.0	29.0
EU-15 total	129.6	139.8	164.7	184.0
US	116.0	190.0	255.0	270.0
Japan	106.0	135.3	156.5	175.0

Source: Compañó (2000), DG Research
Data: For the EU: national ministries, see also footnote in Compañó (2000), p. 16. Data for Japan provided by MITI, JST, STA, Monbusho. Data for the US received from NSF, NASA, EPA, NIH, NIST.
Note: Data is estimated by calculating all nanotechnological research projects and programmes as well as institutional support in the distinct countries. Due to incomplete data and differences in the definition of nanotechnology, the difference in actual numbers could range from 10% more or 10% less than the given numbers. According to R. Compañó, most data is probably underestimated.

Third European Report on S&T Indicators, 2003

The contributions by national governments of the EU-15 Member States are significant and follow different strategies. Germany is pursuing a strategy of trying to bundle the nanotechnology competencies of about 150 universities and research institutes with the same number of companies in six "Centres of Competence", with annual funding of 50 million euro for research projects between 1999 and 2003. The UK has supported a variety of networking activities, starting with the LINK Nanotechnology Programme (LNP) and the National Initiative on Nanotechnology (NION) in the early 1990s. The aim of LNP is to improve the linkages between public and private research, and to increase private sector expenditure dedicated to nanotechnology research. NION's aim has been to increase public awareness of nanotechnology, and to create a national nanotechnology community, comprising about 86 public and private participants in 27 projects (Meyer, 2000). France has no special nanotechnology programme, but is increasing its funding for nanotechnology research programmes in about 40 physical and 20 chemical national research centres. Efforts in supporting nanotechnology by establishing networks and funding science-industry linkages within nanotechnology research projects are also found in the Netherlands, Sweden, Finland, Belgium and Spain (Roco, 1999).

Several conclusions can be drawn from the data analysed in this section. The main conclusion is that nanotechnology is an emerging technology, with great progress being made in the science rather than in specific applications. Nevertheless, technological achievements can be observed and new products based on nanotechnology are already making their impact in markets (Bachmann 1998). Several EU-15 Member States are among the most important players in nanoscience and nanotechnology. Efforts to support nanotechnology do not only rely on scientific excellence, but also on co-operation between scientists and industrial researchers in order to strengthen the innovation process. And co-operation is not restricted to the EU and associated countries such as Switzerland, Israel or the Candidate countries – there are important partners in Asia as well as in America. The leading countries have significant potential for future technological and economic competitiveness in nanotechnology.

Networks in nanotechnology

Initiatives supporting research and innovation in Europe increasingly take into account the importance of embedding of research projects into regional economic and scientific structures, so as to promote technological progress and economic growth. Spatial proximity can help co-operation and networking aimed at transforming scientific knowledge into industrial applications within regions. The success story of Silicon Valley in microelectronics is a perfect example for how best to create and exploit knowledge, to enhance technological development, and to attract investment and intelligence into a region. As a science-based technology with widespread applications in nearly all industries, nanotechnology is an area that can benefit from this regional approach, and a number of recent public and private policy actions in support of nanotechnology have been based on this idea.

Since 1998 the German Federal Ministry for Education and Research (BMBF) has funded six "*Centres of Competence*" in six different sub areas of nanotechnology. Initially created as virtual centres with central co-ordination units, they very soon evolved into superregional networks with close links to and fruitful impulses from the regional economic and scientific environments. Regions, which developed in this way, are Aachen, Braunschweig/Hannover, Dresden/Chemnitz, Hamburg, München, Münster and Saarbrücken (www.nanonet.de). The idea of regional linkages is also reflected in the Institute of Nanotechnology, founded in 1998 and located at the Forschungszentrum Karlsruhe (FZK), which was the result of the agreement concerning co-operation in nanotechnology research between the universities of Karlsruhe, Germany and Strasbourg, France and the FZK. It marks a starting point in the evolution of the *upper Rhine region* around Strasbourg and Karlsruhe towards a regional, and at the same time international "nano-valley" (www.fzk.de/nano).

The regional idea of a nano-valley with a strong involvement of industry can be found in the region around *Grenoble*, where microelectronic companies agreed to co-ordinate their research on nanoelectronics. The industrial investment amounts to 7.5 billion euro for the next five years, and is recognised as the most important industrial investment in France in the last decade (Le Monde, 16.4.2002, www.minatec.com). Another French regional centre of nanotechnology can be found in the *region around Lyon*. The "Lyon Nano-Opto-Technology Center" (http://nanoptec.univ-lyon1.fr) involves mostly local university institutes and research centres. Furthermore, the CNRS has developed research programmes on nanostructured materials and nanoparticles at about 20 chemistry and 40 physics laboratories involving a total of 500 researchers in France (www.cnrs.fr/cw/fr/prog/progsci/nanosciences.html). These laboratories co-operate closely with the industry.

In the smaller EU Member States, research networks are not explicitly regional, but they are often located around an excellent university, public research institute or company research laboratory. The DIMES institute at the *Delft* University of Technology (www.dimes.tudelft.nl) and the Philips Research Institute in *Eindhoven* (www.research.philips.com) are amongst the most active research centres in the Netherlands. In Belgium, one network could be called local in the sense that the research institutes are regionally concentrated, because they are all located at the Flemish-speaking Catholic University of *Leuven* (KUL). The network "Molecular nanotechnology: Individual molecules and molecular templates" has a strong involvement of Belgian firms (such as Agfa Gevaert) in the fields of microelectronics and photography (www.fys.kuleuven.ac.be/vsm/ini). In *Lund*, Sweden, there is a nanometer consortium which is imbedded in interdisciplinary materials consortia and nanochemicals programme (www.nano.ftf.lth.se). In *Uppsala*, Sweden, the Ångström consortium analyses surface nanocoatings and the University (together with the Royal Institute of Technology - KTH) works on clusterbased and ultrafine particle materials (www.angstrom.uu.se).

The networks mentioned are just a selection of networks with a regional focus. There are several other networking initiatives in the EU countries, which are more virtual, on national or international levels. For instance in Spain, the national network *Nanospain* includes 83 members from government, universities and industry from all over the country. On the European level, the network nanoforum (www.nanoforum.org) tries to bundle nanoscientific and nanotechnological knowledge, as do several initiatives of the Fifth Framework Programme and the upcoming Sixth Framework Programme (www.cordis.lu/rtd2002).

Conclusions

This chapter has attempted to provide some indications of the trends in Europe's development and commercialisation of technology. It has focussed mainly on Europe's performance in patenting and trade in high technology products, and on trends in two key technology fields.

Of course, this does not provide a complete picture of technological performance. For one thing, patents do not cover the whole range of technological innovations, and indeed much important innovative activity is non-technological in nature. Moreover, it is not just strength at the high-tech end of the market that will influence the EU's economic competitiveness; it is also crucial for more traditional medium and low-tech EU industries to be able to absorb new technologies so as to improve their products and processes. One should also bear in mind the growing importance of the service sector – which is less well covered by the available indicators - and the increasingly intensive use of knowledge by service companies.

Nevertheless, certain broad conclusions can be drawn. The end of the 1990s saw a strong increase globally in patenting activity and in trade in high-tech products. While Europe has, by and large, shared in this expansion in the production and commercialisation of technology, it cannot be considered to have achieved a position of general technological leadership. Instead, the picture is mixed and varies according to the field of technology or the Member State in question.

At the country level, it is the smaller Member States that show the greatest dynamism in terms of both patenting and high-tech trade. In particular, the six Member States that exceeded the US in terms of growth in exports of high-tech products between 1995 and 2000 were all "smaller" EU countries. However, these six countries still only accounted for a third of total EU high-tech exports in 2000, and the established industries in the larger Member States still account for much of the strong performance in areas such as Aerospace, Chemicals and Pharmaceuticals.

If one looks across fields of technology, there is also considerable variation. While the indicators presented here would appear to confirm that the EU is falling behind in the area of Computers and Electronics, its performance has been much stronger in Aerospace and Pharmaceuticals. Some of the smaller Member States in particular have developed niche areas in which they perform well: Ireland in Computers, Finland in Telecommunications, Denmark in Pharmaceuticals.

When set against the EU's relatively modest rise in business R&D spending in the latter half of the 1990s, Europe's technological productivity in terms of patents per unit of R&D expenditure has shown an encouraging increase. The initiative to introduce a Community patent should help to further stimulate the protection of inventions in the EU by reducing the cost of patenting, as well as encouraging business R&D and making it easier for firms to expand their activities to the European level.

The challenge for Europe in the future will also be to keep up with those key and emerging technologies that are likely to have a major economic or social impact. For the two technologies examined in this chapter there are encouraging signs but still much room for improvement. In biotechnology the US remains the world leader, but Europe has succeeded in closing the gap somewhat. Nevertheless, within Europe the biotech research base and financial markets are still fragmented, and product regulation varies widely. While there has been some progress in developing measures to address these problems, there is a need for a more comprehensive EU-wide approach in this key area. It has been addressed by the 'Communication on life sciences and biotechnology', a strategy paper issued in early 2002 by the European Commission.

Nanotechnology, although still emerging, is expected to become one of the key technologies of the 21st century. While it is early days yet, some new products based on nanotechnology have already made it to the market, and several EU countries are already among the leading actors in nanoscience and nanotechnology. Reinforced university-industry cooperation will be one of the key drivers of innovative activity in this field.

What is clear in these two fields, and can be increasingly observed in many other technology areas, is the importance of the interfaces and interactions between science, technology and innovation. There is now a widespread recognition that efficient flows of knowledge are an essential feature of the modern research and innovation system, whether it be university-industry collaboration, international cooperation in S&T, or mobility of students and skilled workers. The role played by multinationals in exploiting flows of knowledge across economies has also been seen: one in nine EU-owned patents were invented by an EU subsidiary abroad, while one in seven patents invented in the EU is owned by a non-EU multinational. Many of these same multinationals are key players in high-tech export markets.

Finally, as the EU moves towards enlargement, it is encouraging to see the Candidate countries emerging as one of the EU's major trading partners in high-tech products, a phenomenon also stimulated by strong flows of foreign investment in recent years.

SELECTED BIBLIOGRAPHY

Bachmann, G. (1998) *Innovationsschub aus dem Nanokosmos*. Düsseldorf, VDI-Verlag.

Biotechnology Industry Organization (BIO) (2000) *The economic contributions of the biotechnology industry to the U.S. economy*. Report prepared by Ernst & Young.

BMBF (2001) *Zur technologischen Leistungsfähigkeit Deutschlands*. Bonn.

Compañó, R. (ed.) (2000) *Technology Roadmap for Nanoelectronics*, European Commission IST Programme, Brussels.

Cordis Focus (2000) No. 162.

Ernst & Young, (2001) *Integration. Ernst & Young's eight annual European life sciences report.*

European Commission (2002) *An international benchmark of biotech research centers*, Final Report by the University of Sussex, SPRU CBSTII contract No. ERBHPV-CT-2000-03.

European Commission (2001) *Linking Science to technology – Bibliographic references in patents. Analysis of the science-technology interaction in the field of biotechnology*, Report by the University of Leuven, INCENTIM, CBSTII contract no. ERBHPV-CT-1993-03.

European Commission (2001) *Survey of Networks in Nanotechnology*, Brussels (www.cordis.lu/nanotechnology).

European Commission (2001) *Indicateurs brevets, les grands ensembles régionaux, la triade et les pays de l'UE*. Report by OST/FhG-ISI (Observatoire des Sciences et des Techniques/Fraunhofer Institute für Systemtechnik und Innovationsforschung). CBSTII contract no. ERBHPV-CT-2000-08.

European Commission, 1999, *Inventory of public biotechnology R&D programmes in Europe*, DG Research, EUR 18886/1.

Freeman, C. and Perez, C., (1988) 'Structural crisis of adjustment: business cycles and investment behavior', in: Dosi, G. *et al*. (eds.), *Technical change and economic theory*, London, Pinter, pp. 38-66.

Goodman, S. (2001) 'France boosts funding for biotechnology start-ups', *Nature* 414, 573.

Hullmann, A. (2001) *Internationaler Wissenstransfer und technischer Wandel - Bedeutung, Einflussfaktoren und Ausblick auf technologiepolitische Implikationen am Beispiel der Nanotechnologie in Deutschland*, Heidelberg, Physica.

Joy, B. (2000) 'Why the future doesn't need us', *Wired Magazine*, Issue 8.04, (http://www.wired.com/wired/archive/8.04/joy.html).

Meyer, M. (2000) *Hurdles on the way to growth. Commercializing novel technologies. The case of nanotechnology*, Espoo, Helsinki, University of Technology, Working Paper series 2000/1.

Office of Technology Assessment (OTA) (1991) *Biotechnology in a global economy*, OTA-BA-494, Washington DC, US Congress, Government printing office.

RAND (2001) *The Global Technology Revolution*, Report prepared for the National Intelligence Council (NIC) by the National Defence Research Institute (RAND) (Anton, P.S., R. Silberglitt and J. Schneider), Arlington, VA.

Roco, M.C. (2001) *National Nanotechnology Investment in the FY 2002 Budget*. Request by the President, Extras from AAAS report XXVI, Washington D.C. Updated version: December.

Roco, M.C. (1999) Research Programs on Nanotechnology in the World, in: *WTEC Panel Report on Nanostructure Science and Technology - Status and Trends in Nanoparticles, Nanostructured Materials, and Nanodevices*, Chapter 8. National Science Foundation, Washington D.C.

Rosenberg, Nathan, (1976) *Perspectives on technology*, Cambridge Univ. Press, Cambridge (Mass.)

Rosenberg, Nathan & Nelson Richard (1982), *Inside the black box: technology and economics*, Cambridge Univ. Press, Cambridge (Mass.)

Sal. Oppenheim (2001) *Mikrosystemtechnik und Nanotechnologie – Schlüsseltechnologien für Deutschland.*

Senker J. et al., (2001) *European Biotechnology Innovation Systems*. Final report, TSER Project No. SOE1-CT98-1117, http://www.susx.ac.uk/spru/biotechnology/ebis/ebisfinalreport.pdf

Sharp M. (1985) *The new biotechnology – European governments in search of a strategy*, Sussex European Paper No. 15, University of Sussex, SPRU.

Van Beuzekom B. (2001) *Biotechnology statistics in OECD member countries: an inventory*, OECD, STI working paper 2000/6.

VDI-Technologiezentrum (ed.) (2001) *Innovations- und Technikanalyse - Vorstudie Nanotechnologie*. Düsseldorf, VDI-Verlag.

Ziman, J. (1994) *Prometheus bound: science in a dynamic steady state*, Cambridge: University Press.

DOSSIER V
Patenting in the service sector

Section I The role of patents and other means of property protection for service companies[1]

The role of strategies to protect intellectual property applied by service companies has long been poorly defined or even neglected. There are mainly two reasons for this. Firstly, economic innovation analysis has for many years underestimated the extent to which service companies, or manufacturing companies with service activities, are engaged in innovation. Secondly, it was not understood that intellectual property rights (IPR) strategies and other measures to protect intellectual property fulfill a new and differentiated role in many service sectors, especially in the face of the emerging new economy.

The innovation within service companies or manufacturing industries with distinct service activities, is characterised by features that set it apart from traditional innovation in manufacturing companies. These features imply that the protective measures for new processes or products will be diverse and complicated.

- Services are intangible, i.e. they are hard to store and control, and therefore existing property rights regimes cannot guarantee them the same degree of protection as they can guarantee, for example, a new machine which lends itself to thorough examination and control.
- Services rely heavily on the use of information technology (IT), an area of technology in which the protection of intellectual property is complicated, mainly because of the speed of change in the IT sector and the complex network of interrelationships in the field.
- Services are highly client-intensive, posing the problem of clearly defining a product and a process in advance.
- Services were highly regulated for a long time but deregulation and liberalisation have now underscored the necessity of protecting their knowledge base in order to gain competitive advantage.
- Innovation activities in services do not rely much on internal R&D activities but rather on incremental and ad-hoc developments. Therefore, it is not common to find formal protection structures attached to the R&D departments of service-based companies.[2]

In order to understand the scope and range of protection activities, it is vital to differentiate what it is that is being protected in service companies, which is essentially the knowledge embedded in processes and products. Most importantly, it is the extent to which the knowledge is contained in tangible assets, for example in codes or technical artefacts, that determines the value and ability of patents to provide protection. The fact that many of the innovations in services are not part and parcel of tangible assets has two sets of implications for IPR strategies. Firstly, although patenting is an important protection option, IPR strategies in services have to be broader, and make more comprehensive use of trademarks, copyrights and informal mechanisms such as secrecy and short innovation cycles. These methods help to make intangible products more tangible, and help to create lock-in mechanisms or entry-barriers. Secondly, many innovation surveys continue to underestimate the role of innovation in the service industry because they have a bias towards tangible – and thus technological – innovations.

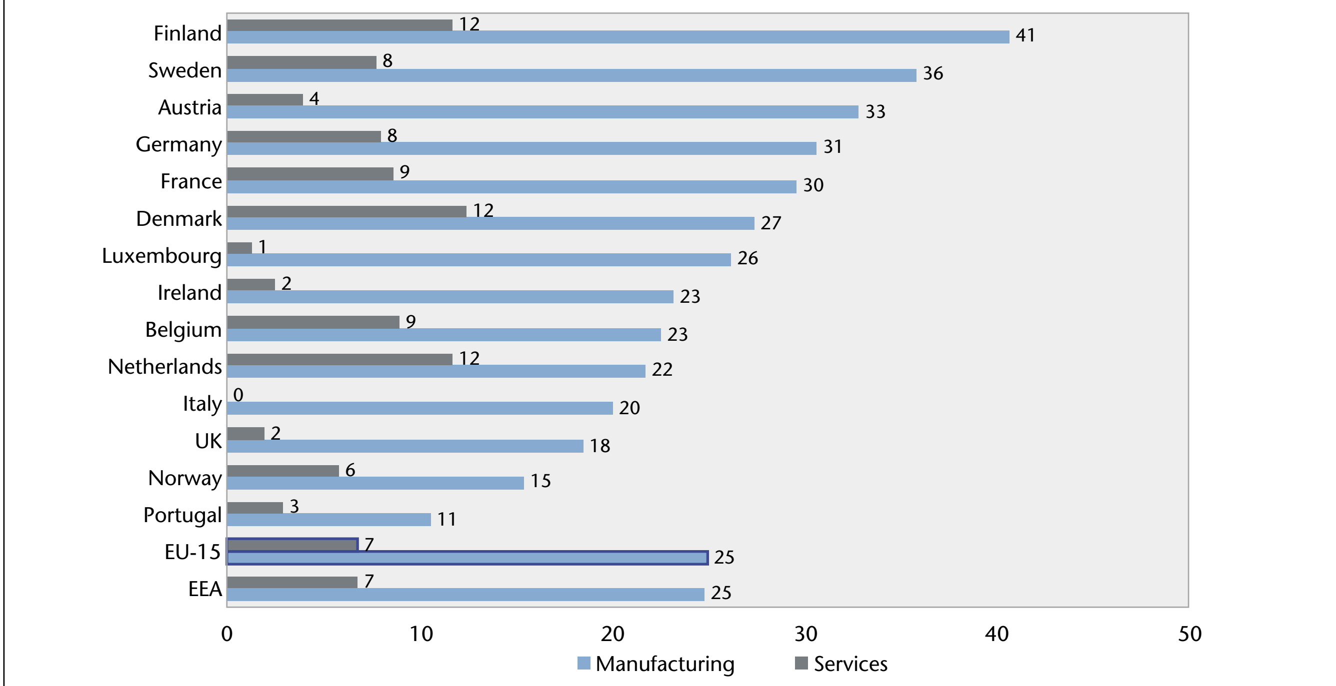
The literature on the use of protection mechanisms in service companies also shows that protection strategies, rather than patents, are gaining in importance in the service sector. This also confirms that while patents are very relevant, they do not have the same significance in the service industry as in manufacturing companies[3]. The Second Community Innovation

[1] This dossier is based on some provisional findings of a study on Patents in the Service Industries (see K. Blind et al., 2003). This study was prepared by a team coordinated by Fraunhofer-ISI, Karlsruhe, Germany.

[2] The Community Innovation Survey in Germany (CIS II) reveals that only around 10% of the innovation expenditure is devoted to intramural R&D, cf. Ebling et al. (1999).

[3] Their innovations are widely protected by some kind of intellectual property rights. Industrial property rights ensure exclusive use in commerce and industry. Patents or utility models for inventions can be obtained as a means of ensuring the protection of technical inventions. The subject of such an industrial property right, for example, could be a product or manufacturing process. Industrial design, on the other hand, protects the aesthetic qualities that are expressed in the particular shape or form of a certain product, device etc.

Figure D5.1.1 Percentage of innovators having applied for at least one patent, 1996 (%)



Source: Eurostat/DG Enterprise Indicators, 2002
Data: CIS II
Note: S and I are not included in the service sector.

Third European Report on S&T Indicators, 2003

Survey (CIS II) provides convincing proof of this because only 7% of the innovating service companies surveyed had applied for a patent on at least one occasion[4]. In the manufacturing sector 25% of the innovators surveyed had submitted patent applications, which is more than three times higher than in the service sector. As shown in figure D5.1.1, Danish, Dutch and Finnish innovators are the top three in Europe, with over 10% of service companies making patent applications, while in the UK less than 3% of service firms had applied for patents.

A comparative study of UK companies[5], for example, also showed that although many service companies used patents and planned to apply for them more frequently, non-service companies on average had higher application rates and were more intent on further stepping up the rate. On the other hand, for service companies both copyright and trademarks are increasingly relevant, more so than for manufacturing companies, trademarks being slightly more important than copyright as a means of protection. These results are confirmed by other analyses[6]. However, a study of French service companies reveals a more critical attitude towards formal protection strategies, because fewer than 20% of the companies see patents, trademarks and other formal protection measures as an efficient way of guarding their innovations[7]. While this reflects the logic of patents, which protect technically applied, tangible knowledge, it also means that, in general, protection mechanisms in services do not provide the same scope for information on the innovations themselves as in the manufacturing sector, where patents are a rich source of detailed information.

[4] *Eurostat (2000), p. 39.*
[5] *For this study in the UK see Coombs and Tomlinson (1998).*
[6] *See for example Blackburn and Kitching (1998).*
[7] *Compare Djellal and Gallouj (2001).*

Section II Empirical evidence about patenting activities of service companies

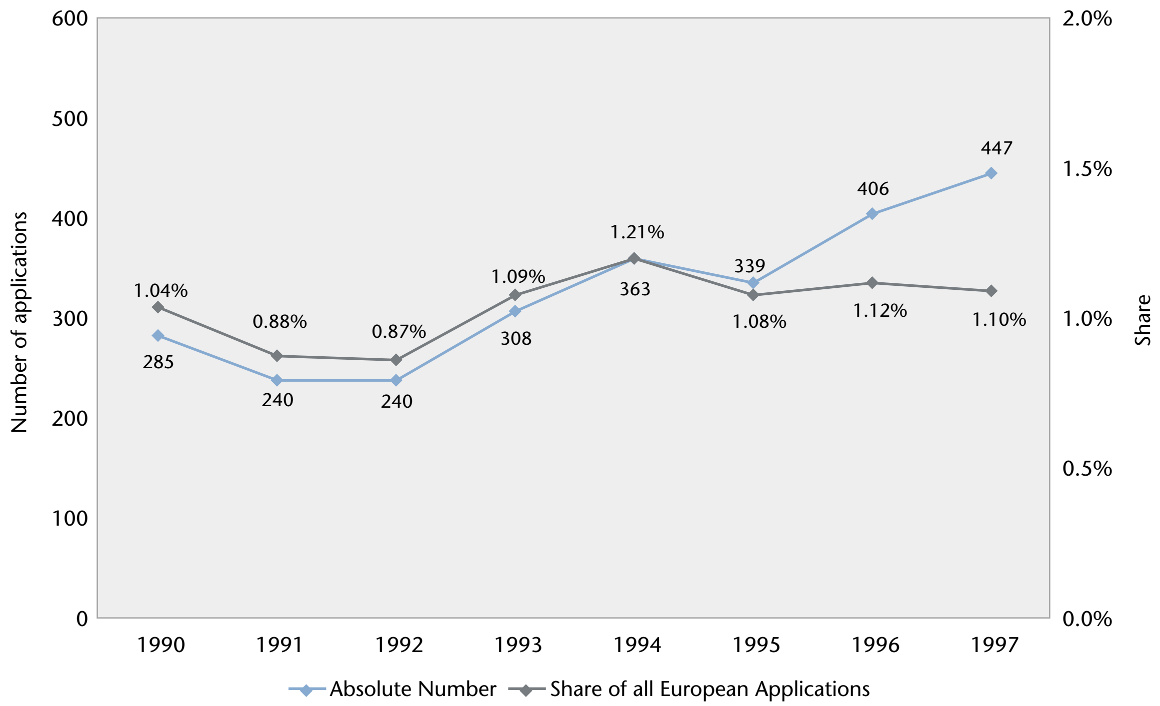
Before statistical evidence on the patenting activities of innovative service companies can be gathered, an adequate methodology is needed first. A patent inquiry covering all service companies in Europe was not feasible, so the approach used was to survey a sample of 50 of the largest service companies (excluding banks and insurance companies[8]) in Europe, using numbers of employees as a yardstick of size.

The results of the CIS II in fact showed that, unlike in the manufacturing sector, large companies in the service industry were only slightly more inclined to apply for patents than small and medium sized companies[9], which means that the influence of company size is limited.

From a methodological point of view a few other aspects must also be taken into account in such an inquiry. It was not possible to isolate the service companies among the thousands of patent applicants at the European Patent Office (EPO). The definition of a service company is a major problem: classical service industry firms include banks, insurance companies, transport firms and telecommunications providers but many manufacturers have also expanded their core businesses into service activities – Volkswagen, for example, has its own bank and Siemens has IT consultancies.

It is problematic to try to simply transfer the well-established output indicator "patents" from the manufacturing sector to the service sectors. Firstly, patents can only be granted for innovative technical solutions, which means that there are no service categories in the international patent classification (IPC). Therefore, the service companies whose products are based on innovative technologies that can be protected by patents are most likely to apply for patents. Recent developments in the information and communication technologies (ICT) form a major driving force of innovation in the service sector and create clear potential for growth in patenting. Whereas technology-based service companies may rely on patent applications, there are many service companies that are either only technology users or that provide services using low technological inputs. These companies make extensive use of a range of other methods to protect intellectual property, including trademarks, copyright, secrecy or market lead.

Figure D5.2.1 Patent Applications of 50 selected companies (1990-1997)



Source: Fraunhofer-ISI
Data: EPO

Third European Report on S&T Indicators, 2003

[8] *An explorative search in Esp@net did not find any banks and insurance companies among patent applicants.*
[9] *See Eurostat (2000), p. 38.*

After setting up the database of 50 companies, the next step consisted of identifying the patent applications made to the European Patent Office between 1990 and 1997 by companies in the sample. The data give a picture of aggregates and also differentiate between technology fields and company types.

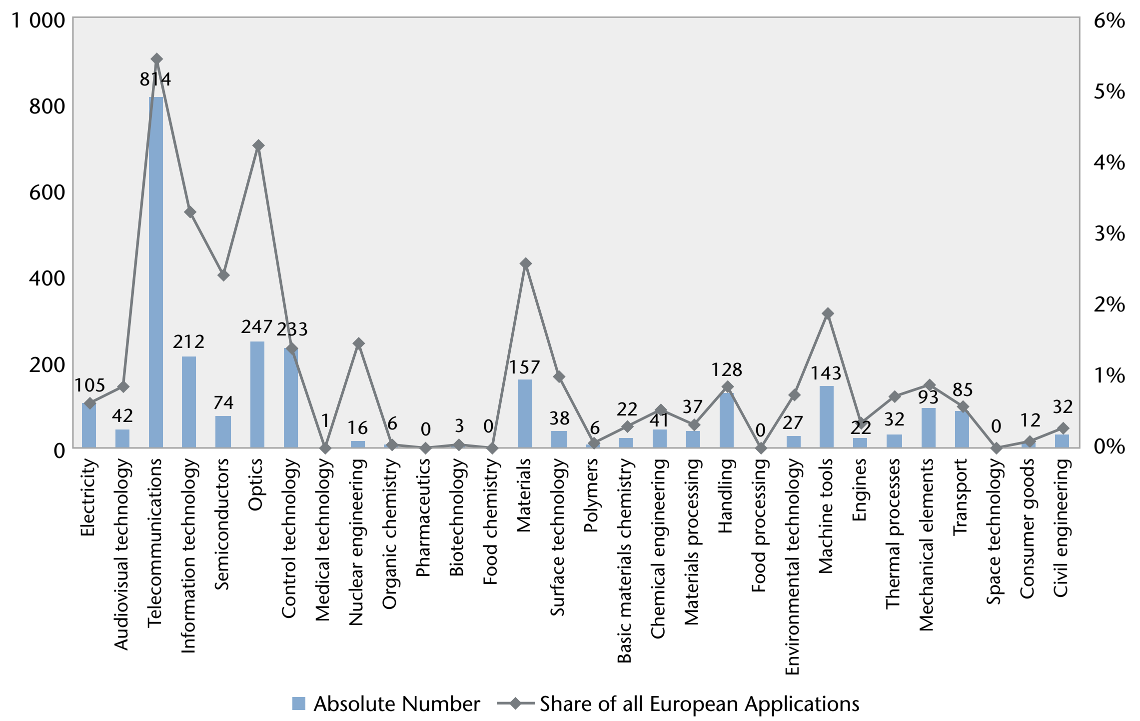
The first important result was that 44% of the sample applied for at least one patent during the survey period[10]. In figure D5.2.1, the overall number of patent applications by companies in the sample is depicted. The number of applications almost doubled over the period, starting with about 280 applications in 1990 and increasing to almost 450 applications in 1997. When compared to all the patent applications by the 15 EU Member States, the percentage share of the sample group is just over 1%.

Following confirmation of a slightly upward trend in patent applications in service companies, another interesting question concerns the technology fields that are opting for patents as a protective mechanism. Using the total sample, figure D5.2.2 reflects the focus of patent applications: telecommunications and IT make up almost 50% of all applications in the sample, and applications by "telecommunications" also tripled between 1990 and 1997. Other fields with significant applications are "materials" and "machine tools". Also reflected in the sample is the share of applications in relation to the total number of applications received from EU Member States. The average across all technology fields is around 1%, which is significantly exceeded by the "telecommunications" field.

The distribution of the applications across 30 technology fields is shown and the 50 company sample is categorised according to business activities. It turns out that more than 90% of the applications are from telecommunications companies that rely on modern telecommunications technology for service provision.

In addition to the analysis of EPO patent applications, patents granted by the US Patent and Trademark Office (USPTO) to business-related services owned by European companies were also analysed in order to validate the approach. The focus was on patents in USPTO class 705 (business services) and class 902 (electronic funds transfer) because these classes are closely linked to business or banking services. However, in both classes the number of patents granted to European firms turned out to be very small (figure D5.2.3).

Figure D5.2.2 Sum of Patent Applications between 1990 and 1997 of the sample in 30 technology fields

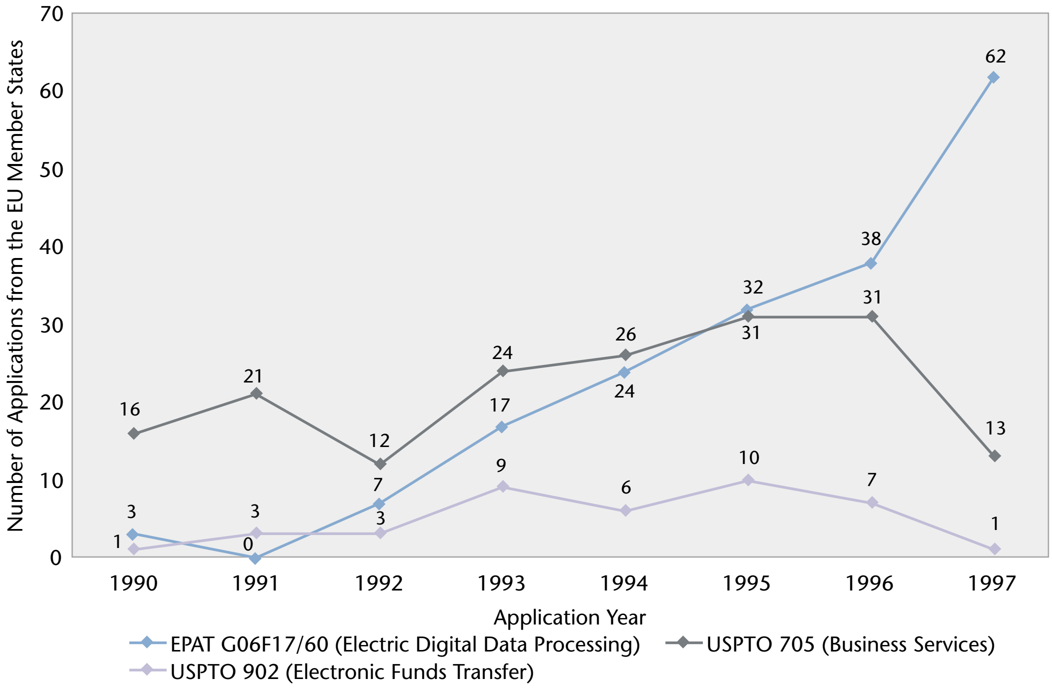


Source: Fraunhofer-ISI
Data: EPO

Third European Report on S&T Indicators, 2003

[10] *In the German CIS of 1999, less than 5% of the over 2 000 responding service companies had applied for national or European patents.*

Figure D5.2.3 European Patents in patent classes with close links to business services (USPTO)



Source: Fraunhofer-ISI
Data: EPO, USPTO

Third European Report on S&T Indicators, 2003

At the European Patent Office the time series in the class “Electric Digital Data Processing” G06F17/60 (the equivalent of USPTO 705) was identified as well. Here, a higher applications trend is evident. In general, patent applications to the European Patent Office show more positive growth than applications to the USPTO.

Finally, the companies having patents in either the two USPTO classes or the one IPC category at the EPO were analysed separately. In USPTO class 705, the two companies with the highest number of patents produced stamp machines. The only service companies in this class -with a small number of patents- were British Telecom and France Telecom. In class 902, Siemens Nixdorf and a cash card manufacturer had the highest number of patents. In IPC class G06F17/60 (EPO), IBM, Nortel and Siemens applied for patents as manufacturing firms while British Telecom and France Telecom applied as service companies.

These results do affirm the useful approach of analysing patent applications made to the European Patent Office. The database of 50 companies included big service companies such as British Telecom and France Telecom that applied for patents in the relevant categories. In the USPTO classes designed for service patents, IT manufacturers dominate the ranks of patent recipients while the number of patents owned by service companies is extremely limited.

Two main conclusions can be drawn from these empirical observations. First, patenting as a protective strategy has limited significance for service companies, which is a fact also supported by the recent results of the CIS II. Second, because of the diversity of the service sector, a wide range of technologies are important and this range cannot be confined to a limited number of patent subclasses, yet the broad technology fields covering ICTs are of major importance to most of the service companies.

Section III Preliminary conclusions about the role of patents for service companies

The analysis of patent applications by large European service companies confirms existing insights on the role of patents as protection devices for intellectual property in the service sector. Although almost half of the service companies in the sample had applied for a patent, the number of applications is relatively small compared to companies of the same size in the manufacturing sector. Furthermore, the number of patent applications made by the sample increased by more than 50%, although the percentage of the service company applicants among all European patent applications to the European Patent Office remained static. The range of applications in the technology fields shows a concentration among ICTs, especially in telecommunications, where applications have increased threefold from 1990 to 1997. Ninety percent of all patent applications came from the large telecommunications companies. In general, these observations confirm the hypothesis that only the service companies that rely on self-developed technologies are interested in protecting their technologies through patents.

Some policy conclusions follow from these insights. In general, the need to pursue a patenting strategy is significantly lower in the service sector than in the manufacturing sector. However, in many cases patents are also feasible and appropriate for the service sector, especially in the ICT field. Limited awareness of the use and benefits of patents in Europe might be a disadvantage in a future globalised service economy. Service companies should therefore be informed of the potential of the patent system and be encouraged to acquire the necessary skills to use the system in appropriate ways.

Selected Bibliography

Blackburn, R. and Kitching, J., Intellectual property management in the small and medium sized enterprise, *Small Business and Enterprise Development*, Vol. 5, No. 4, 1998.

Blind, K. et al. (2003) *Patents in the Service Industries*, final report of a study carried out under the coordination of Fraunhofer-ISI, contract n° ERBHPV2-CT-1999-06 (forthcoming).

Coombs, R. and Tomlinson, M., Patterns in UK Company Innovation Styles: New Evidence from the CBI Innovation Trends Survey. *Technology Analysis and Strategic Management*, 10, 295-310, 1998. The results reported here come from an unpublished note, "Analysis of 1999 innovation trends data". CRIC, University of Manchester.

Djellal, F. and Gallouj, F. (2001): Patterns of innovation organisation in service firms: postal survey results and theoretical models, *Science and Public Policy*, vol. 28, number 1, pp. 57-67.

Ebling, G.; Hipp, C.; Janz, N.; Licht, G.; Niggemann, H., Innovationsaktivitäten im Dienstleistungssektor – Ergebnisse der Innovationserhebung 1997, in: *Innovationsaktivitäten in der deutschen Wirtschaft* ed. by Janz, N. and Licht, G., Baden-Baden, Nomos, 1999, pp. 99-222.

Eurostat (2000), Statistics on innovation in Europe, Luxembourg, 2000.

Young, A. (1996) Measuring R&D in Services, STI Working Papers 1996/7, OECD, Paris, 1996.

DOSSIER VI
Science and Technology Linkage

The growing importance of scientific discovery for technological development has become a subject of much analysis and policy debate in recent years. The emergence of biotechnology in particular, as a prototypical “science-based technology”, has further stimulated inquiry into the increasing dependence of technology on science, and basic research in particular. As we enter the era of a “new” productivity paradigm, in which knowledge is the crucial “third” factor of production (the “softer” productivity factor), it is vital that this linkage be understood. In addition, adequate methodologies and parameters are required for measuring different dimensions of science and technology (S&T) interaction, so as to be able to shape and adapt innovation policies.

At the same time, the nature of the knowledge-generation process itself is evolving towards a more network-embedded process (Nohria & Eccles, 1993; Gibbons et. al., 1994; Meyer-Krahmer, 2000), with growing emphasis on partnerships, the interplay between knowledge demand and knowledge supply, and increasingly transdisciplinary and heterogeneous inputs. This can be seen in phenomena such as university-industry interactions and the advent of techno-scientific breakthroughs such as “nanotechnology” and “biomifarmatics” (e.g. DNA computing and protein-folding computation).

For the past two decades it has been clear that the linear model of knowledge creation, transfer, diffusion, and commercial application is no longer valid since it does not capture the complexity of the relationships involved along the chain (Kline, 1985; Gibbons et. al., 1994). Furthermore, there is a need to develop a more refined understanding of the complex interactions and co-evolution of S&T along the different stages of innovation.

Over the same period, governments have been taking a greater interest in the efficacy of publicly funded research, and have significantly reformulated their policies concerning government-supported scientific activity. This reformulation has been accompanied by shifts in research funding across fields of enquiry as well as between types of research (basic versus applied). The present constraints on public expenditure in general, coupled with the considerable investment required to sustain the econo-techno-scientific complex and the continuing debate on the effectiveness of government-supported scientific research, all enhance the need for more accountability and effectiveness in the area of publicly funded research (Papaconstantinou & Polt 1997; Hanusch, 1999; Ziman, 1994; Moed, 1989; Branscomb et al., 1999).

The perceived gap between Europe’s strong science base and its poor perfomance in terms of technological and industrial competitiveness (sometimes referred to as the “European Paradox”) has led policy-makers to seek additional insights into how, where, and why this “paradox” occurs, and the measures that might be taken to address this phenomenon. Does the European science system fail to produce the kind of research upon which advanced industrial economies have become increasingly dependent, or does its industry lack the ability and/or absorptive capacity to use the knowledge produced in the science sector effectively (Polt et al., 2000)? In either case, the interfaces between public research, technological development and commercial exploitation have to be better understood if improvements are to be made (e.g. through intermediary structures).

This dossier presents the results of a study carried out by the *Katholieke Universiteit Leuven – Incentim* (Verbeek et al., 2002) to explore the interaction between S&T using data on S&T linkage derived from patent documents. The dossier is structured in two sections. Section 1 examines the global interactions between various fields of S&T disciplines, while section 2 looks at the performance of the EU compared with its main partners in terms of S&T interaction.

Section I Exploring the links between science and technology

1. Measuring science and technology interaction

The analyses presented here focus on a specific form of S&T interaction: the presence of scientific research in the "prior art" description of a patented invention. It is a direct form of S&T interaction, which may be grasped through rich, plentiful, and directly available and accessible data: patents and publications (for more detail on the approach employed, cf. box, "What can scientific references in patents tell us?").

Patents and scientific publications are considered to be the closest possible measures of technological and scientific activity (OECD, 1994; Griliches, 1994), whereas the cross-citations between both activity spheres (references to "prior scientific art" in patents) form a useful bridge between one sphere and the other (technology to science and vice versa).

In particular, this bridge enables one to trace the linkages between specific fields of technology and related science disciplines, and to measure the science intensity of such linkages (in general, a higher number of science citations is observed when a particular technology field is more science-based). Moreover, as most scientific articles are published by universities and public research centres, and most patents are granted to industry, these linkages may provide an insight into the effectiveness of the interface between publicly funded research and the industrial exploitation of science.

It is important to stress, however, that no direct or causal relationship can be assumed to exist between interconnected patents and publications (Meyer, 2000). The mere presence of a scientific article cited in a patent does not necessarily mean that there has been a direct and linear knowledge transfer from the scientific discipline to the technology area of the invention (for example, some citations are simply references to the general scientific background).

In this regard, it may be asked whether science, in some cases, actually pushes technology, and if so, to what extent patent citations reflect this push. Traditionally, citation links between patents and publications are viewed as an indication of the contributions of science to technology (the linear approach). Recent findings do not contest the strong relationship between science and technology and its impact on economic progress. However, they do question the assumed direction of the knowledge flow between science and technology or, on another level, between academia and industry.

It is also becoming increasingly difficult to differentiate between science and technology. Disappearing boundaries between research disciplines and even research organisations, as well as the introduction of multi-specialty research teams with a strong focus on application, make it increasingly difficult to judge whether science pushes technology, technology pulls science, or whether science and technology co-evolve and cross-fertilise each other during various phases.

There are, indeed, early examples of science lagging behind technological development (technology-pull). The process of food preservation in tin-coated steel invented by Nicholas Appert in 1810, was explained much later in 1873 with the discovery of the role of micro-organisms in food spoilage (i.e. the birth of the science of bacteriology). As Meyer (2000) concludes, S&T interaction seems to be far more reciprocal than the linear model suggests. In this light, citations in patents tend to indicate the degree of closeness between S&T rather than a direct and causal scientific contribution to technological development.

Nevertheless, the data presented here does provide some valuable insights into the intensity of interaction and knowledge flows between scientific disciplines and technology fields, between the public research base and industry, and between countries.

Calculating and interpreting S&T linkages

What can scientific references in patents tell us?

This dossier looks at one specific form of S&T interaction: the presence of scientific research in the "prior art" description of a patented invention. The citations in patents of scientific work form a useful bridge from technology to science and vice versa.

In particular, citations of scientific publications in patents enable one to make a precise and detailed link between specific fields of technology and the scientific disciplines they cite, to measure the intensity of these linkages and to trace their evolution over time. The approach thus provides a basis for analysing knowledge exchange linkages (flows) between S&T, and allows one to touch upon the degree of diffusion of science into technology.

However, in interpreting the data, a number of factors need to be borne in mind:

- References to scientific publications in patents represent just one of a number of different forms of S&T interaction. The absence of paper citations cannot be interpreted as a lack of scientific interaction with the technology involved, because many knowledge flows are not visible in publications, patents or cross-references. On the contrary, this may indicate a different type of scientific interaction inherent in the nature and the stage of evolution (maturity) of the technology involved, e.g., contract research and consulting, joint publications, mobility of researchers between industry and science, collaborative research, use of public research facilities by industry, and the licensing of patents held by science to industry;

- the mere presence of science citations in patent documents does not necessarily imply a direct contribution to the invention (cf. Meyer, 2000), or a transfer of tacit knowledge. Nor does it indicate whether there has been direct contact between a scientist and an inventor;

- patent examiners tend to restrict their reading to a narrow range of specialties, and to be relatively unfamiliar with the wider literature; they frequently cite in secondary form (abstracts), probably because the availability of abstracts databases makes the search for "prior art" easier;

- the use of the same set of citations by one examiner in several different patents, suggests an occasional tendency to cite by rote, rather than by relevance. Moreover, some examiners and applicants/inventors may be affected by a national bias in their citing practice;

- citations in EPO patents are primarily examiner citations (however, examiner sometimes take over inventor citations, if they are relevant). Examiners tend to primarily cite other patents for describing the state of the art, as patents have a clearer structure than papers and they are more easily searchable. Only in cases where no appropriate patents can be found would the examiner look for other sources, in particular scientific publications (cf. Schmoch, 1991);

- a high level of citations to publications primarily indicates a strong relationship of a technology to basic research. A high level of citations to publications is often related to a high R&D intensity. However, in some areas (e.g. mechanical engineering), R&D intensity is quite high, but the level of citations to publications is low, as research primarily relates to applied issues whose output is already documented in patents (Schmoch, forthcoming).

How have the science-technology linkages been calculated?

The analyses presented here have been carried out by Incentim–K.U. Leuven as part of an EU-funded project to establish a comprehensive concordance between various fields in science and technology. More detail of this approach, and a fuller analysis of the data, can be found in their report (Verbeek et al., 2002). What follows is a summary of the main features of the methodology employed.

The analyses in this dossier are based on citations of scientific publications present in patent documents. If one considers patents as an indicator of, or proxy for, "technology" and publications as representing "science", the references to scientific publications in patent search reports can be used to gain insights into the science base of technology (cf. Collins & Wyatt, 1988; Schmoch et al., 1993; Narin et al., 1997; Meyer, 2000; Meyer-Krahmer, 2000; Tijssen et al., 2000; Grupp & Schmoch, 1992).

To explain how this information has been used for this purpose, it is useful to describe the structure of a patent. A patent document consists of three elementary parts:

- the title page or front page with bibliographic information;
- the text, which includes a description of the invention, preferred examples in detail, as well as drawings, diagrams, and flow charts;
- the claims.

Within the bibliographic information, references are made to the "prior art" in order to establish the originality and innovativeness of the invention. These include:

- references to other patents (technological "prior art");
- so-called non-patent references or NPRs (i.e. non-technological "prior art").

The second category (NPRs) covers citations to a broad collection of written material such as scientific papers, technical manuals, encyclopaedias, meeting reports, and company internal reports.

Figure D6.1.1 Distinction between the different types of reference to "prior art"

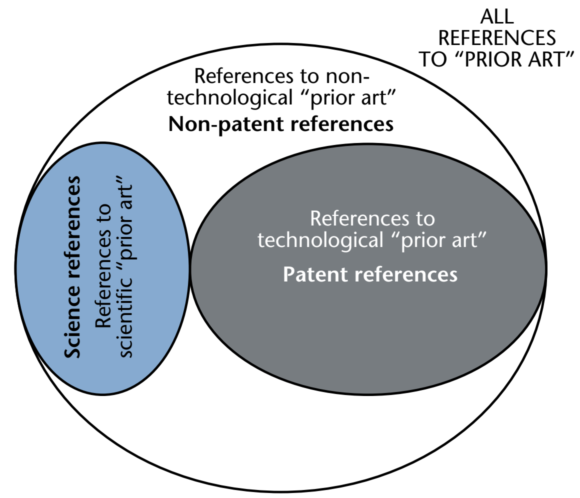


Figure D6.1.1 illustrates the distinction between the different kinds of references. Each patent is assigned one or more International Patent Classification codes (IPC codes), indicating the field of technology to which the patent relates, and each code is recorded in the patent document. The scientific discipline of a particular science reference appearing in a patent can also be derived from the science area of the journal in question. In this way, precise linkages can be traced between fields of technology and fields of science, as well as the intensity of these linkages in terms of frequency of citations to science.

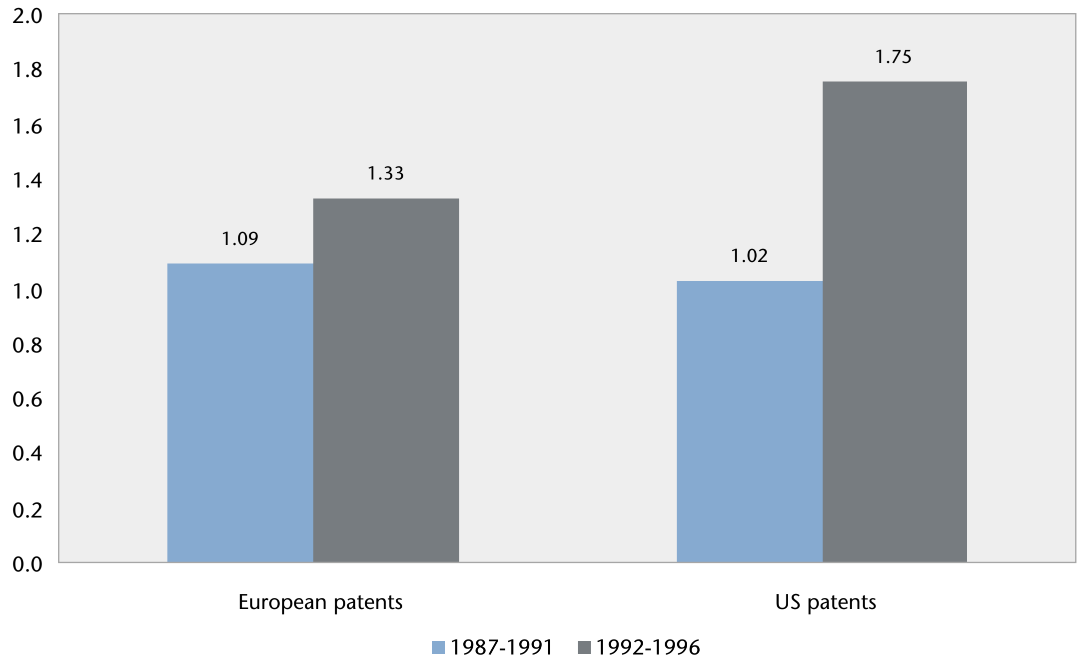
Two main types of indicator are presented in this dossier. The first is based on publications in scientific journals (the small oval[1] in figure D6.1.1), which represent the primary communication medium within the scientific community for exchanging and communicating scientific findings. These data could be considered as science citations of the purest form, and are used to establish the detailed matrix of linkages between S&T fields. The second type of indicator is based on the more broadly defined non-patent references (NPRs), which are often used as a convenient first indicator of the science intensity of a particular technology field.

2. The growing linkage between science and technology

There is strong evidence that in recent years science has become increasingly important for innovation. This trend is clear from the number of citations in patents to scientific work, which grew substantially in the 1990s, at both the European Patent Office (EPO) and the US Patent and Trademark Office (USPTO) (figure D6.1.2).

Moreover, this pattern of increased science-technology interaction is confirmed across most technology fields. Figure D6.1.3 shows the ten technology fields with the highest propensity to cite science in applications to the European Patent Office. All but two – Biotechnology and Information Technology (IT) – showed substantial growth in the mid 1990s in the average number of scientific articles in patents. Biotechnology remains the field with the strongest science intensity. Even in more traditional fields, such as transport

Figure D6.1.2 Average number of scientific articles in patents (all countries and technology fields)

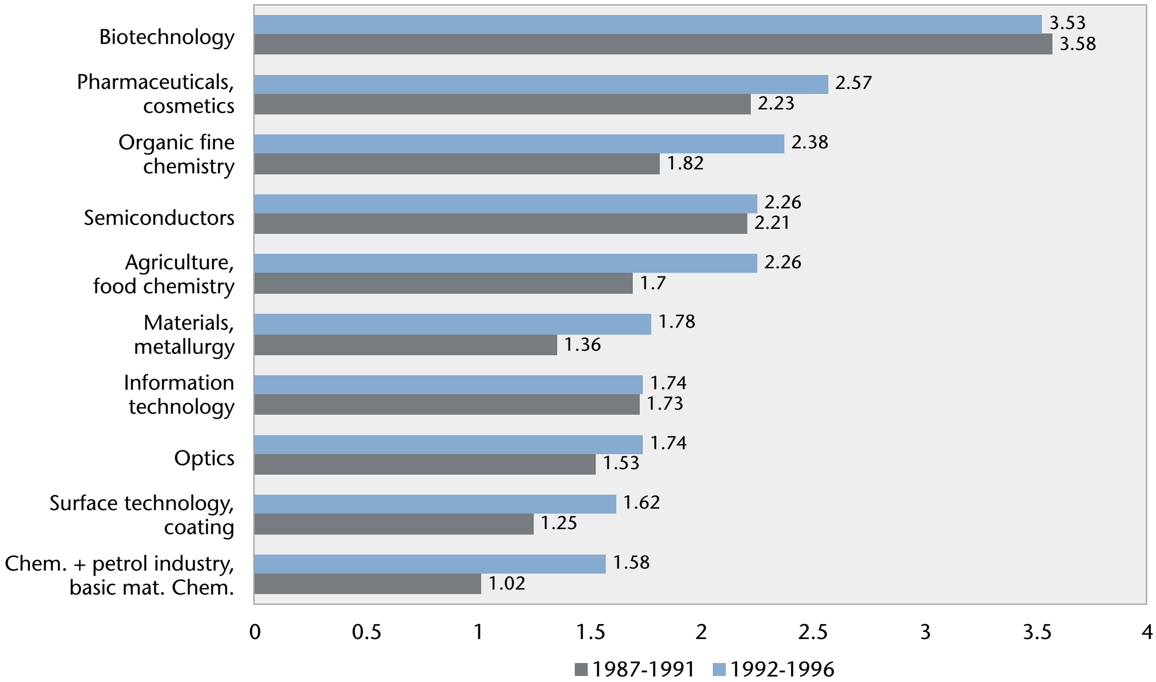


Source: DG Research
Data: EPO and USPTO data processed by Incentim-K.U. Leuven
Note: Data are by year of application.

Third European Report on S&T Indicators, 2003

[1] *Figure D6.1.1 is purely illustrative. The shapes representing different types of reference are not drawn in exact proportion to their real numbers.*

Figure D6.1.3 Average number of scientific articles in patents – 10 most science-intensive technology fields (all countries – applications at the European Patent Office)



Source: DG Research
Data: EPO data processed by Incentim-K.U. Leuven

Third European Report on S&T Indicators, 2003

and civil engineering (not shown on this graph), references to science have multiplied during the period in question.

Similar patterns can also be observed in US patent applications. Biotechnology is the interesting exception, showing a large increase in citations to science in US patents.

3. Which technology fields account for the most references to science?

Three technology fields – biotechnology, organic fine chemistry and pharmaceuticals – account for more than three-quarters of all references to science in European patents (figure D6.1.4).

Biotechnology patents lead in terms of science linkage. Although biotechnology inventions represent less than 5% of European patents, they are responsible for one-third of all science cited in patent documents. The next two fields – organic fine chemicals and pharmaceuticals – account collectively for slightly more than 10% of patents, but generate more than 45% of citations to scientific articles.

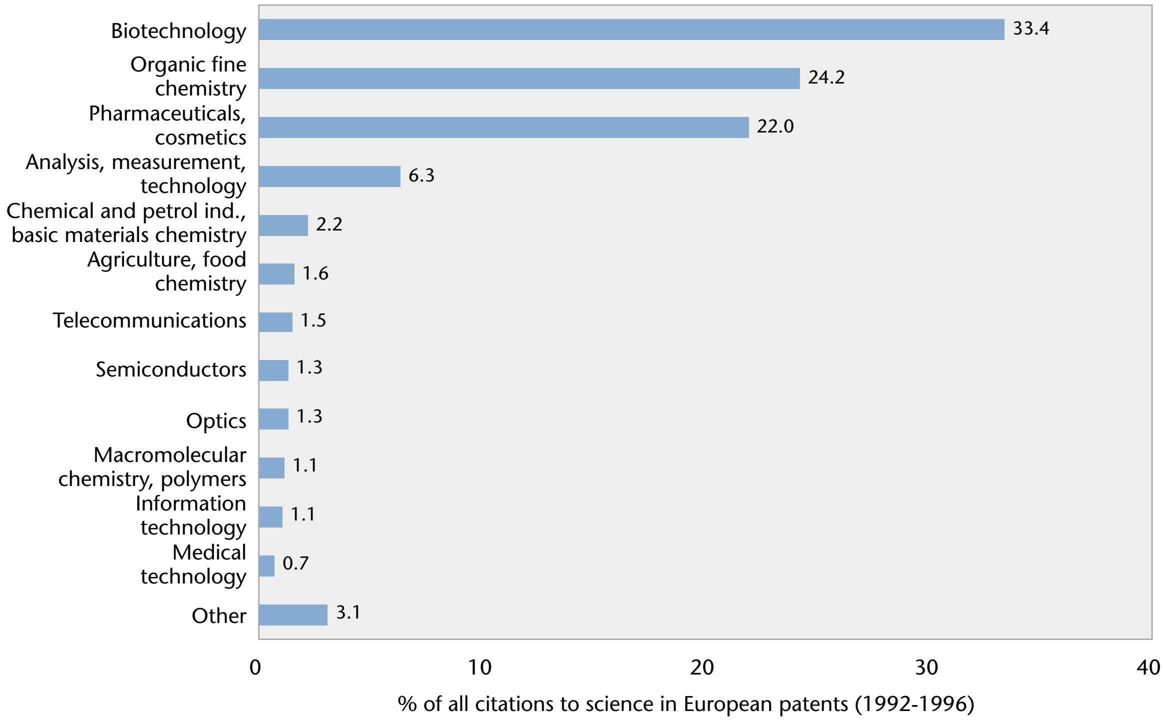
What is perhaps significant is that many of the fastest growing technology fields (cf. chapter 6) are also associated with high levels of science intensity. For example, patenting in the areas of telecommunications, biotechnology, pharmaceuticals and medical technology expanded strongly in the 1990s, suggesting that science is one of the key factors underlying high rates of inventive activity.

The main science disciplines cited by these technology fields are evident in table D6.1.1. Nearly one-third of science articles cited in biotechnology patents relate to the field of biochemistry and molecular biology, 20% to multidisciplinary journals[2], and almost 6% to immunology.

In general, developments in technologies related to chemistry and pharmaceuticals seem to build largely on research in the area of biochemistry and molecular biology. Another key science field is applied physics, which finds its application across a wide range of technologies, including semi-conductors, telecommunications and optics (as shown in table D6.1.1), as well as surface technology and coating, and electrical machinery and apparatus.

[2] *The major multi-disciplinary journals, Science and Nature, tend to focus on life sciences and chemistry, which is reflected in the citations from these fields to multi-disciplinary science in tables D6.1.1 and D6.1.3.*

Figure D6.1.4 Technology fields with the most citations to science (%)



Source: DG Research
Data: EPO data processed by Incentim-K.U. Leuven

Third European Report on S&T Indicators, 2003

Table D6.1.1 The top 10 science-citing technologies and the science fields they cite most often

Technology	Highest cited science fields
Biotechnology	Biochemistry & Molecular Biology (28.36%), Multidisciplinary (19.18%), Immunology (5.89%), Genetics & Heredity (5.50%), Virology (4.65%)
Organic fine chemistry	Biochemistry & Molecular Biology (24.15%), Multidisciplinary (16.54%), Immunology (7.57%), Pharmacology & Pharmacy (6.50%), Organic Chemistry (4.72%)
Pharmaceuticals, cosmetics	Biochemistry & Molecular Biology (18.22%), Multidisciplinary (14.92%), Immunology (8.98%), Pharmacology & Pharmacy (8.62%), Cancer (4.56%)
Analysis, measurement, technology	Biochemistry & Molecular Biology (17.82%), Multidisciplinary (13.34%), Immunology (8.59%), Electrical & Electronic Engineering (3.92%), Research & Experimental Medicine (3.76%)
Chemical and petrol industry, basic materials chemistry	Biochemistry & Molecular Biology (17.88%), Multidisciplinary (13.56%), Immunology (6.39%), Cancer (4.03%), Biophysics (3.73%)
Agriculture, food chemistry	Biochemistry & Molecular Biology (24.27%), Botany (16.92%), Multidisciplinary (11.23%), Food Science & Technology (8.60%), Microbiology (6.10%)
Telecommunications	Electrical & Electronic Engineering (40.78%), Telecommunications (27.61%), Optics (7.10%), Computer Applications& Cybernetics (5.96%), Applied Physics (5.73%)
Semiconductors	Applied Physics (43.44%), Electrical & Electronic Engineering (13.93%), Crystallography (6.01%), Materials Science (5.46%), Physics, Condensed matter (4.92%)
Optics	Applied Physics (33.01%), Optics (24.40%), Electrical & Electronic Engineering (19.38%), Crystallography (3.83%), Polymer Science (1.91%)
Macromolecular chemistry, polymers	Polymer Science (22.38%), Biochemistry & Molecular Biology (16.67%), Multidisciplinary (9.29%), Chemistry (6.67%), Organic Chemistry (6.43%)

Source: DG Research
Data: EPO data processed by Incentim-K.U. Leuven
Note: The table should be interpreted as follows: 28.36% of science articles cited in biotechnology patents relate to journals in the area of biochemistry and molecular biology, and 19.18% to multidisciplinary journals.

Third European Report on S&T Indicators, 2003

4. Which science fields are most cited in patents?

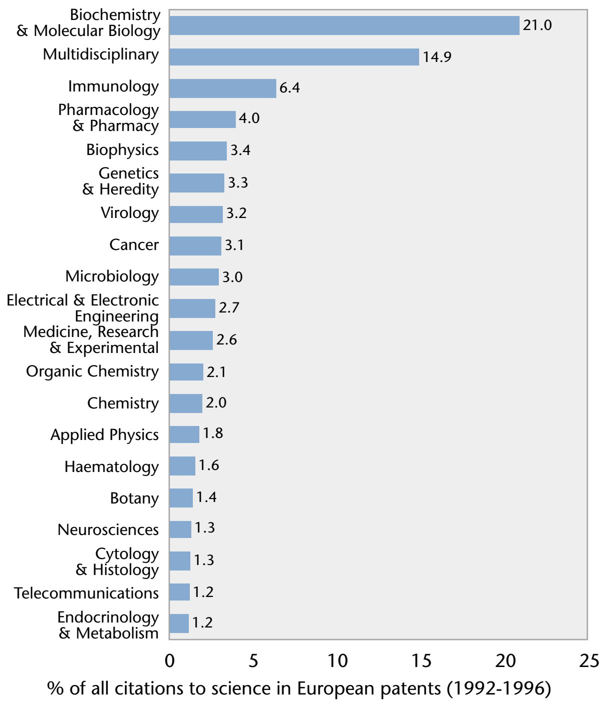
The analysis thus far has approached S&T interaction from the side of technology. However, using the approach developed for citations in patents, the interaction may also be explored by starting from the side of science.

From this perspective, one might ask which are the science fields that are most often cited in patent documents. Not surprisingly, the most cited disciplines are clustered around the life sciences, which are associated with high-citing technology fields such as biotechnology, pharmaceuticals and organic fine chemistry. Electrical and electronic engineering, as well as applied physics, are also frequently cited disciplines in information and communication technologies (ICT) related patents.

A better overview of S&T interactions may be obtained from table D6.1.3 which shows, for each of 30 technology fields, the structure of the science cited by patents in that technology field. The darkest squares show the most important (most cited) science fields for a particular technology.

The main science areas with a strong diffusion of science towards technological utilisation, which can be found around the central pillar of the table, are chemistry, clinical medicine,

Figure D6.1.5 The most cited science fields in European patents (%)



Source: DG Research
Data: EPO data processed by Incentim-K.U. Leuven
Third European Report on S&T Indicators, 2003

Table D6.1.2 The top 10 most cited science fields and the technologies that cite them most often

Science field	Highest citing technologies
Biochemistry & Molecular Biology	Biotechnology (42.07%), Organic fine chemistry (26.86%), Pharmaceuticals, cosmetics (17.68%), Analysis, measurement, technology (6.07%), Chemical and petrol industry, basic materials chemistry (2.48%)
Multidisciplinary	Biotechnology (39.93%), Organic fine chemistry (25.80%), Pharmaceuticals, cosmetics (20.32%), Analysis, measurement, technology (6.38%), Chemical and petrol industry, basic materials chemistry (2.64%)
Immunology	Biotechnology (28.80%), Pharmaceuticals, cosmetics (28.71%), Organic fine chemistry (27.73%), Analysis, measurement, technology (9.65%), Chemical and petrol industry, basic materials chemistry (2.92%)
Pharmacology & Pharmacy	Pharmaceuticals, cosmetics (44.36%), Organic fine chemistry (38.37%), Biotechnology (9.18%), Analysis, measurement, technology (3.25%), Chemical and petrol industry, basic materials chemistry (2.17%)
Biophysics	Biotechnology (38.88%), Organic fine chemistry (26.92%), Pharmaceuticals, cosmetic (19.06%), Analysis, measurement, technology (6.77%), Chemical and petrol industry, basic materials chemistry (3.18%)
Genetics & Heredity	Biotechnology (51.77%), Organic fine chemistry (22.73%), Pharmaceuticals, cosmetics (13.05%), Analysis, measurement, technology (4.06%), Agriculture, food chemistry (3.72%)
Virology	Biotechnology (45.07%), Pharmaceuticals, cosmetics (26.40%), Organic fine chemistry (20.27%), Analysis, measurement, technology (4.44%), Agriculture, food chemistry (1.78%)
Cancer	Biotechnology (31.79%), Pharmaceuticals, cosmetics (30.12%), Organic fine chemistry (26.41%), Analysis, measurement, technology (6.12%), Chemical and petrol industry, basic materials chemistry (3.80%)
Microbiology	Biotechnology (47.74%), Organic fine chemistry (21.33%), Pharmaceuticals, cosmetics (14.41%), Analysis, measurement, technology (6.05%)
Electrical & Electronic Engineering	Telecommunications (42.33%), Information technology (14.51%), Analysis, measurement, technology (11.65%), Optics (9.63%), Audio-visual technology (6.30%)

Source: DG Research
Data: EPO data processed by Incentim-K.U. Leuven

Third European Report on S&T Indicators, 2003

Table D6.1.3 Structure of science-technology interaction by field of technology, %

Science fields	Earth & Space Sciences	Agr., Biol., & Environment	Chemistry	Clinical Medicine	Eng.Tech. & Applied Sc.	Life Sciences	Physics	Mathe-matics	Multi-disciplinary
Biotechnology	0.1	4.4	2.0	21.3	0.2	52.8	0.1	0.0	19.2
Pharmaceuticals, cosmetics	0.0	2.5	5.7	42.4	0.2	34.0	0.1	0.0	14.9
Organic fine chemistry	0.0	2.8	10.8	28.8	0.2	40.6	0.1	0.0	16.5
Agriculture, food chemistry	0.1	33.4	2.1	4.2	0.8	48.1	0.0	0.0	11.2
Analysis, measurement, technology	0.4	1.5	6.3	29.0	6.6	32.4	10.3	0.0	13.3
Chem.+ petrol industry, basic mat.chem.	0.2	8.1	10.6	32.0	1.1	33.3	1.1	0.0	13.6
Agric.+ food processing, mach.+ appar.	0.0	15.6	3.9	15.6	3.9	41.7	0.6	0.0	18.9
Semiconductors	0.5	0.5	13.1	1.9	23.8	0.3	58.7	0.0	1.1
Telecommunications	0.6	1.9	1.0	2.5	77.0	0.7	15.7	0.2	0.3
Nuclear engineering	1.6	0.0	8.1	17.7	37.1	4.8	24.2	0.0	6.5
Information technology	1.2	1.0	1.2	6.8	71.1	5.4	11.4	0.2	1.7
Space technology, weapons	0.0	0.0	20.0	0.0	50.0	0.0	30.0	0.0	0.0
Optics	0.2	0.0	12.0	0.7	22.5	1.7	61.2	0.0	1.4
Medical technology	0.0	1.1	2.8	51.7	4.0	23.4	6.8	0.0	9.9
Surface technology, coating	1.7	0.6	32.8	1.7	16.9	2.8	39.0	0.0	4.5
Macromolecular chemistry, polymers	0.2	4.3	42.6	13.3	3.1	26.0	1.0	0.0	9.3
Audio-visual technology	0.0	0.0	0.0	2.9	63.8	0.0	32.6	0.0	0.7
Materials, metallurgy	3.4	0.0	29.9	3.4	34.0	2.7	19.7	0.0	6.8
Elec.mach. + apparatus, elec. energy	0.0	0.4	23.3	3.6	25.7	0.4	42.2	0.0	4.4
Chemical engineering	2.9	2.9	42.7	9.7	18.4	9.7	4.9	0.0	8.7
Environmental technology	30.3	0.0	15.2	0.0	9.1	45.5	0.0	0.0	0.0
Consumer goods and equipment	0.0	0.0	0.0	11.1	16.7	5.6	66.7	0.0	0.0
Materials processing, textiles, paper	0.0	0.9	32.7	12.4	13.3	28.3	8.0	0.0	3.5
Thermal processes and apparatus	0.0	0.0	9.5	19.0	38.1	9.5	19.0	0.0	4.8
Engines, pumpes, turbines	0.0	0.0	6.3	0.0	68.8	12.5	12.5	0.0	0.0
Mechanical elements	0.0	0.0	14.3	9.5	52.4	0.0	23.8	0.0	0.0
Civil engineering, building, mining	0.0	0.0	0.0	0.0	50.0	0.0	50.0	0.0	0.0
Handling, printing	0.0	0.0	4.3	0.0	43.5	21.7	30.4	0.0	0.0
Transport	0.0	0.0	0.0	0.0	80.0	0.0	20.0	0.0	0.0
Machine tools	0.0	0.0	0.0	0.0	60.0	0.0	30.0	10.0	0.0

High	High science interaction (>10%)
Medium	Medium science interaction (<=10 but >2%)
Low	Low science interaction (<=2%)

Source: Incentim - K.U. Leuven
Data: EPO ; data processed by Incentim - K.U. Leuven
Note: The table shows the structure of science citations for each technology field. All rows sum to 100%. It should be interpreted as follows : in biotechnology patents (first row) 52.8% of all citations to scientific publications relate to the life sciences, 21.3% to clinical medicine, etc.
The darkest squares indicate those science fields of most importance to a given technology (in terms of citations). The data are based on European patent applications for the years 1992-1996. Data relate to linked citations only.

Third European Report on S&T Indicators, 2003

engineering technology and applied sciences, life sciences, and physics.

The more targeted nature of other science fields is also clear, for example, earth and space sciences, which interact predominantly with environmental technology, and to a lesser extent with materials/metallurgy and chemical engineering. Similarly, the broad science discipline of agriculture, biology and environment interacts mainly with the agro-food technologies. Mathematics is seen to be a special case, interfacing weakly with all technologies, although it clearly provides an indispensable support and tool for developments in many S&T fields.

Section II How is Europe performing in S&T interaction?

The first section of this dossier has analysed patterns and trends of S&T interaction at the global level. In the second section some of the differences between countries are explored, and an attempt is made to assess the performance of the EU in relation to its main partners.

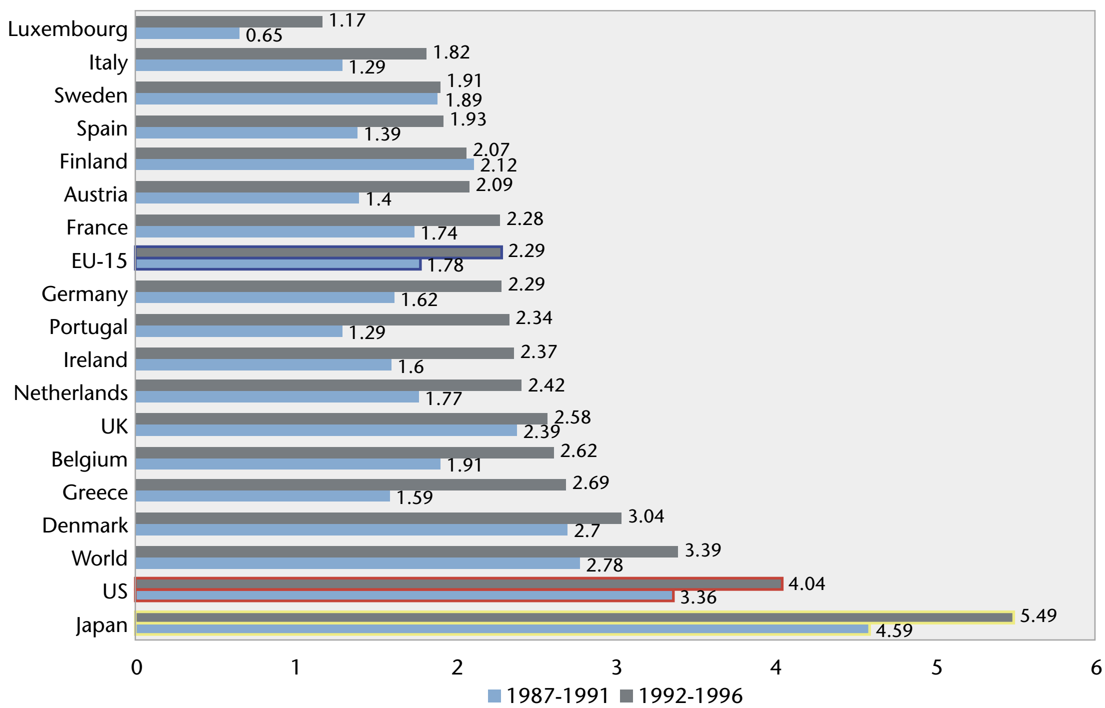
1. The growing science intensity of technology

The increasing interaction between S&T at the global level has not been restricted to one or two key players, but has been experienced by many countries. In both European and US patents (figures D6.2.1 and D6.2.2), the intensity of reference to scientific work increased significantly during the 1990s across all Member States and also in the US and Japan.

The EU's science intensity was much lower than that of the US, especially in European patents, where Japan posted the strongest science linkage of all (with around 5.5 science citations per patent during 1992-1996, compared with four in the US and just over two for the EU). However, looking at growth rates, the EU appears to be catching up: its science intensity has increased at a faster rate than that of the US and Japan in both the European and US patent systems.

It is particularly noticeable that Japan has a much higher science intensity for its European patents than for its US patents. This may be partly explained by Japan's greater focus on chemistry in its European patents compared with its US patents (figure 6.1.12)

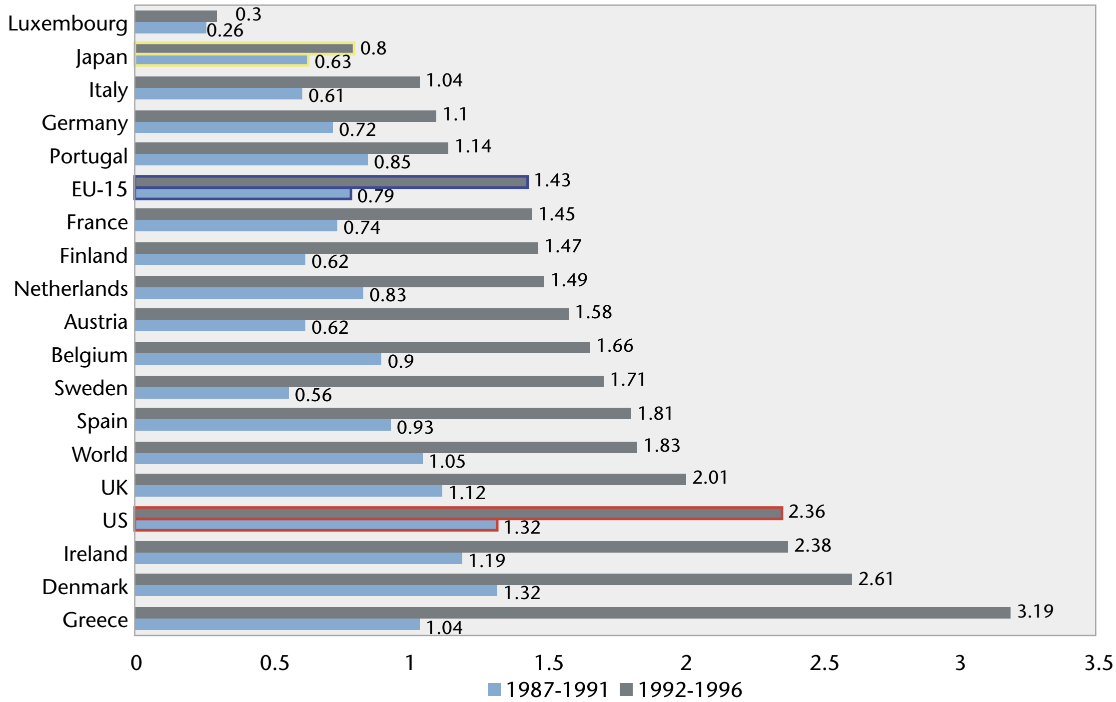
Figure D6.2.1 Average number of scientific articles in European patents



Source: DG Research
Data: EPO data processed by Incentim-K.U. Leuven

Third European Report on S&T Indicators, 2003

Figure D6.2.2 Average number of scientific articles in US patents



Source: DG Research
Data: USPTO data processed by Incentim-K.U. Leuven

Third European Report on S&T Indicators, 2003

This increasing linkage to science in patented inventions could be the result of several different trends. Firstly, the dramatic growth in patenting in fields with a very high science intensity (biotechnology, pharmaceuticals, medical technology, telecommunications) has helped to push up the science intensity of patents overall. However, as seen earlier, this trend is not isolated to two or three technologies, but is more broadly based. Moreover, there is evidence that the number of science citations in patents has not only increased in general; in those patents that cite science, the volume of citations has grown. In other words, science-based patents have become more science intensive.

This can be seen graphically in figures D6.2.3 and D6.2.4, which show the average number of citations to scientific journal articles in patents that cite science. The broad trend is clearly towards a still higher degree of science linkage in these science-based patents.

The broader question concerns the extent to which these measures of the intensity of science interaction during the invention process reflect countries' relative strengths and weaknesses in S&T interaction more generally. The data presented here, which focuses on an important form of linkage between S&T, also raises the intriguing question as to why Europe cites significantly less science in its patents than the US does.

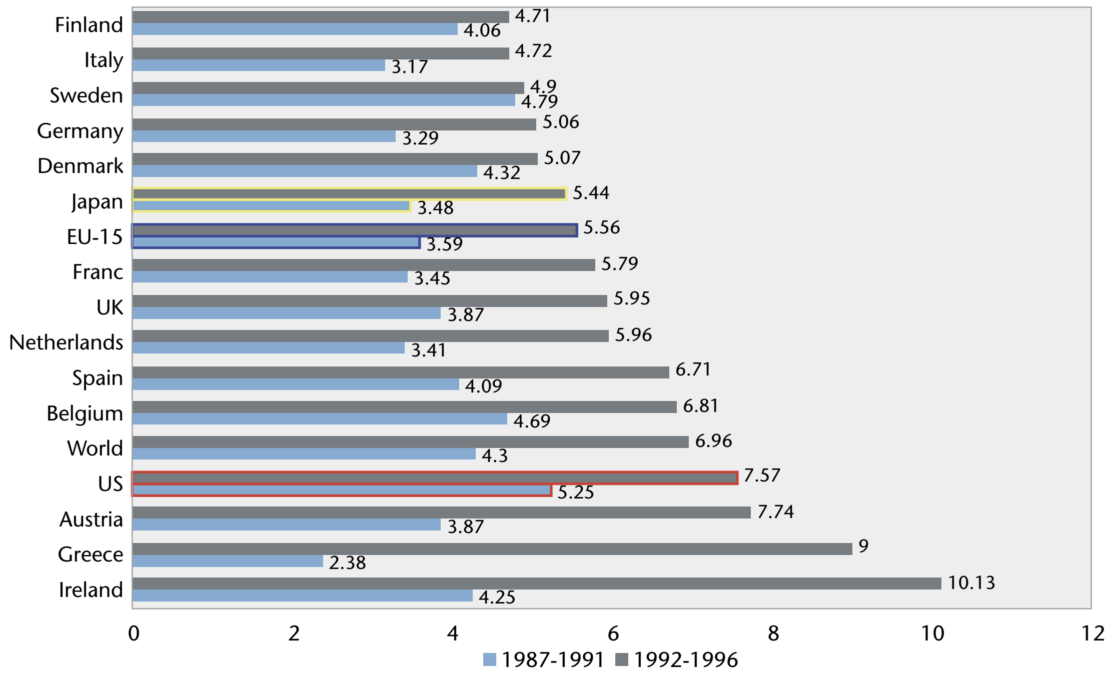
Part of this gap may be explained by the stronger US patenting performance in science-rich technology fields such as biotechnology and telecommunications. Europe has tended to generate fewer patents in such science-intensive areas, which may in part account for its lower overall propensity to cite science. Following this line of argument, it may be that the EU's strong growth in science intensity over the two periods in question is a result of Europe's gradual catching up in some of these science-based technologies.

On the other hand, an increasing orientation towards science-based technologies should not neglect other more traditional areas of strong economic performance. For example, in mechanical engineering – where the EU has quite a healthy performance in foreign trade – numbers of patents are still growing, suggesting that innovation is still a major factor of competitiveness in this area.

Structural factors may also play a part. Countries differ in the way their national innovation systems help to foster science-industry relations, notably in terms of various framework conditions such as institutional settings, legal and regulatory frameworks, and cultural attitudes. An important factor is also the capacity of industry to absorb and exploit scientific knowledge.

Without more data, one can only speculate about the degree in which the science-intensity gap between the US and

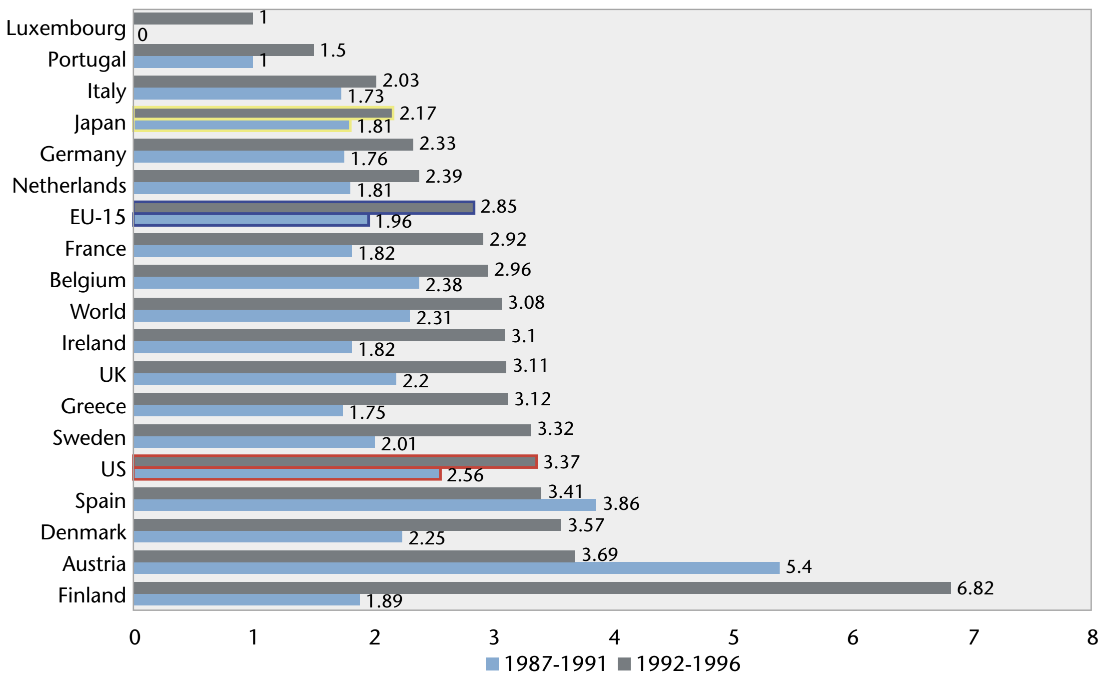
Figure D6.2.3 Are science-based patents citing more science?
(European patents - number of citations to science per science-linked patent)



Source: DG Research
Data: EPO data processed by Incentim-K.U. Leuven
Note: L and P linked patent numbers too low for analysis.

Third European Report on S&T Indicators, 2003

Figure D6.2.4 Are science-based patents citing more science?
(US patents - number of citations to science per science-linked patent)



Source: DG Research
Data: USPTO data processed by Incentim-K.U. Leuven

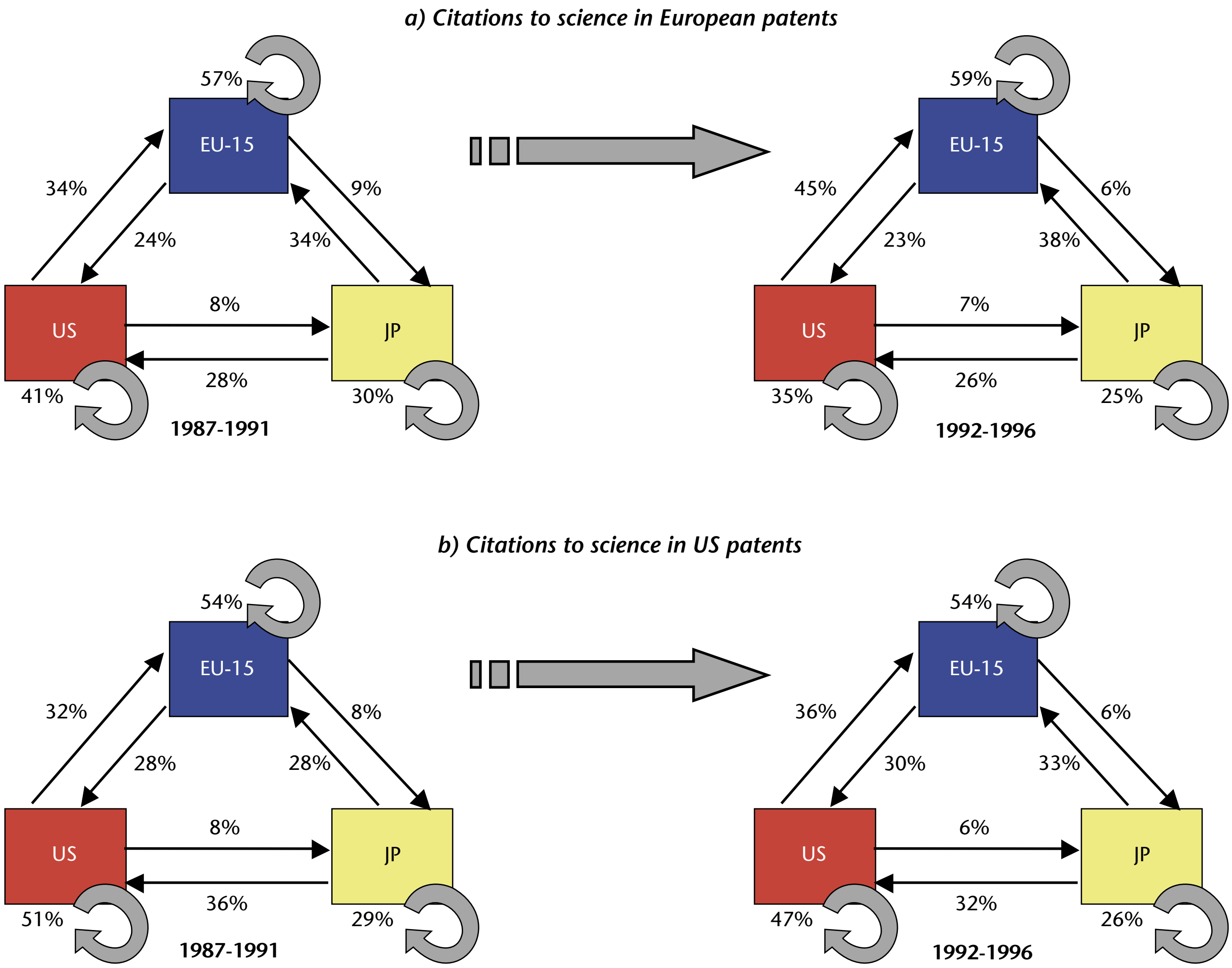
Third European Report on S&T Indicators, 2003

Europe is due to structural weaknesses in EU science-industry interactions. During the past decade, significant efforts have been made by EU Member States to adapt their infrastructures and to develop mechanisms in order to promote a more effective science-industry interaction (e.g., measures to encourage start-ups from public science, the reinforcement of public-private R&D collaboration, stimulation of IPR in public research institutes, the creation of technology centres, incubators, databases, and consulting networks). As such initiatives develop and intensify, one would hope to see an increased exploitation of science in EU patented inventions.

2. International flows and the use of scientific knowledge

So far, this dossier has analysed science linkages without considering the geographical origin of the science. However, the indicators presented here can also be broken down according to the country that has produced the scientific articles cited in patents. This makes it possible to capture international flows of scientific knowledge, from the "producers" of the knowledge (country of the author of the article) to the "users" (country of the inventor of the patented technology).

Figure D6.2.5 The supply and use of scientific knowledge within the Triad-Citations in patents to EU, American and Japanese science



Source: Incentim – K.U. Leuven
Data: EPO, USPTO; data processed by Incentim – K.U. Leuven
Note: The diagram should be interpreted as follows: In diagram a, during the period 1992-1996, 59% of the science cited by EU inventors in their patent applications to the European Patent Office related to scientific work carried out in the EU, while 23% related to US science and 6% to Japanese science.

Third European Report on S&T Indicators, 2003

Such an approach can help to shed light on a number of important issues, for example, the degree to which the European science base depends on research produced elsewhere. Is the domestic science base sufficiently developed to stimulate domestic technological application, and are Europe's own knowledge assets sufficient for it to play a significant role in highly science-dependent technologies?

Figure D6.2.5 presents the relation between the EU, the US and Japan as knowledge users/providers for the periods 1987-1991 and 1992-1996. Looking first at the use of domestically produced scientific knowledge, one sees that for the period 1992-1996, 59% of the science cited by European inventors in their patent applications to the European Patent Office related to scientific research carried out in the EU. This compares with 35% of US citations that related to research of US origin, and only 25% of domestic science citations by Japanese inventors.

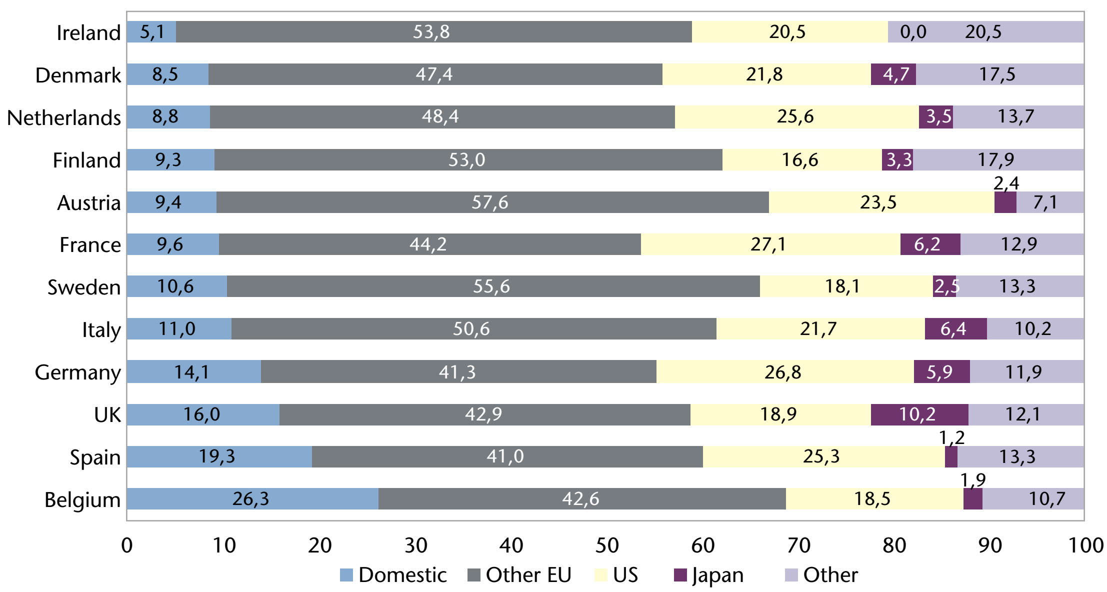
The strong national component in S&T linkage is also found in US patents, where the equivalent figures on domestic science citations are 54% for the EU, 47% for the US and 26% for Japan. These data confirm the findings of Narin and his colleagues (1997), who reported that each country's inventors in the US patent system cite their own country's papers two to four times more often than one would expect, when taking account of the country's scientific publication rate. This strong domestic component in the science-technology linkage suggests that inventors tend to build preferentially upon their own domestic science base, providing that the level of domestic science is sufficiently high.

However, one also observes the prominent role of European research in US and Japanese technological development. In patent applications at the EPO, 45% of all US inventor-cited scientific literature is of European origin (36% in US patents), indicating an important spillover from European research to US technological development. EU science is cited in 38% of European patents with Japanese inventors and in 33% of Japanese-invented US patents. It seems that this spillover of European science to US and Japanese technology is growing.

At the same time, Europe is also an important user of US research. Of the total number of articles cited in EU-invented European patent applications, 23% have been produced by American authors, while in US patents with an EU inventor, 30% of citations relate to US-produced science.

The strong dependence of Japanese technological progress on European and US originated research is also visible. Japan has the strongest propensity of the three to use foreign science, while Japanese research (at least in terms of scientific articles) has not penetrated significantly into European or US technology. However, language barriers may be an important factor here, as EPO and USPTO patent examiners tend to cite

Figure D6.2.6 Origin of scientific research cited in patents of EU Member States (European patent applications 1992-1996) (%)



Source: Incentim-K.U. Leuven
Data: EPO data processed by Incentim-K.U. Leuven
Note: The diagram should be interpreted as follows: Just under 10% of articles cited in French patent applications (at the EPO) relate to research produced in France, 44% to research produced in other EU countries, 27% to US-produced science, 6% to Japanese science and 13% to research by other countries. The volumes of patent citations for P, EL and L are comparatively low and have been excluded for analytical purposes.

Third European Report on S&T Indicators, 2003

Japanese publications only if they are covered by English-language abstract services.

An analysis of the situation at Member State level provides further, more nuanced results (figure D6.2.6). The citation of domestic research varies greatly from one country to another, depending partly on the relative size of the country's science base. While the larger countries tend naturally to have more references to domestic research, the position of Belgium, with the highest rate of domestic citation, is interesting. What is also striking is the importance of research in other EU Member States, which, according to the country concerned, varies between 40% to almost 60% of science citations in EU patent applications.

It appears that in EU countries the domestic component represents a much smaller proportion of the science base referred to in patents than is the case in the US. While this is unsurprising – since the US has a much larger science system than any individual EU country – it serves to emphasise the important role of scientific knowledge flows between Member States.

3. The interaction of technology with basic and applied research

The research cited in patented inventions may be of different types, from very basic to highly applied. The analysis presented in this section focuses on the "basic" character of the national science base, as reflected in patented technology.

The degree of linkage to basic research gives some indication of the extent to which the technology reflected in a country's patents is "leading edge". A basic research capability is also important for the development of a county's capacity for absorption, which enables it to take advantage of new basic research produced elsewhere, thus keeping up with the pace of scientific and technological developments.

In view of the role of basic research in technological development, the country of origin of this type of research can be considered of strategic importance to domestic technological development. Furthermore, the presence of nationally produced leading-edge research is also an indication of the effectiveness of investment in basic science (though it should never be the only indicator).

Just under two-thirds of the science base of European patents applied for by EU inventors consist of basic research (during the period 1992-1996). Moreover, it appears that 54% of all basic research involved in EU technological development has its roots in Europe, almost 32% originates in the US, and only 4% is of Japanese origin. Thus, not only can much of European technology be characterised as leading edge, but Europe also displays a high basic research capability. Applied research is involved in 31% of all science interactions.

US patented technology seems to have a stronger linkage with basic research than European technology (71%)[3]. US research institutes account for 54% of all basic research cited in US inventors' patents, but Europe still accounts for 32% of the basic research utilised in US patented technology. As such, Europe plays an equally important role as a facilitator of leading-edge technology in the US, and of that of the US in Europe. In Japanese technology, a slightly lower level of basic research is present (58% in 1992-1996). Compared to Europe and the US, quite a high share of research cited by Japanese inventors is of a more applied nature. The status of European research is once again demonstrated by the share of basic research it "exports" to the other regions. The US and Europe are largely successful in fulfilling the research needs of their own domestic industry. Japan, however, depends almost equally on US and European originated basic research.

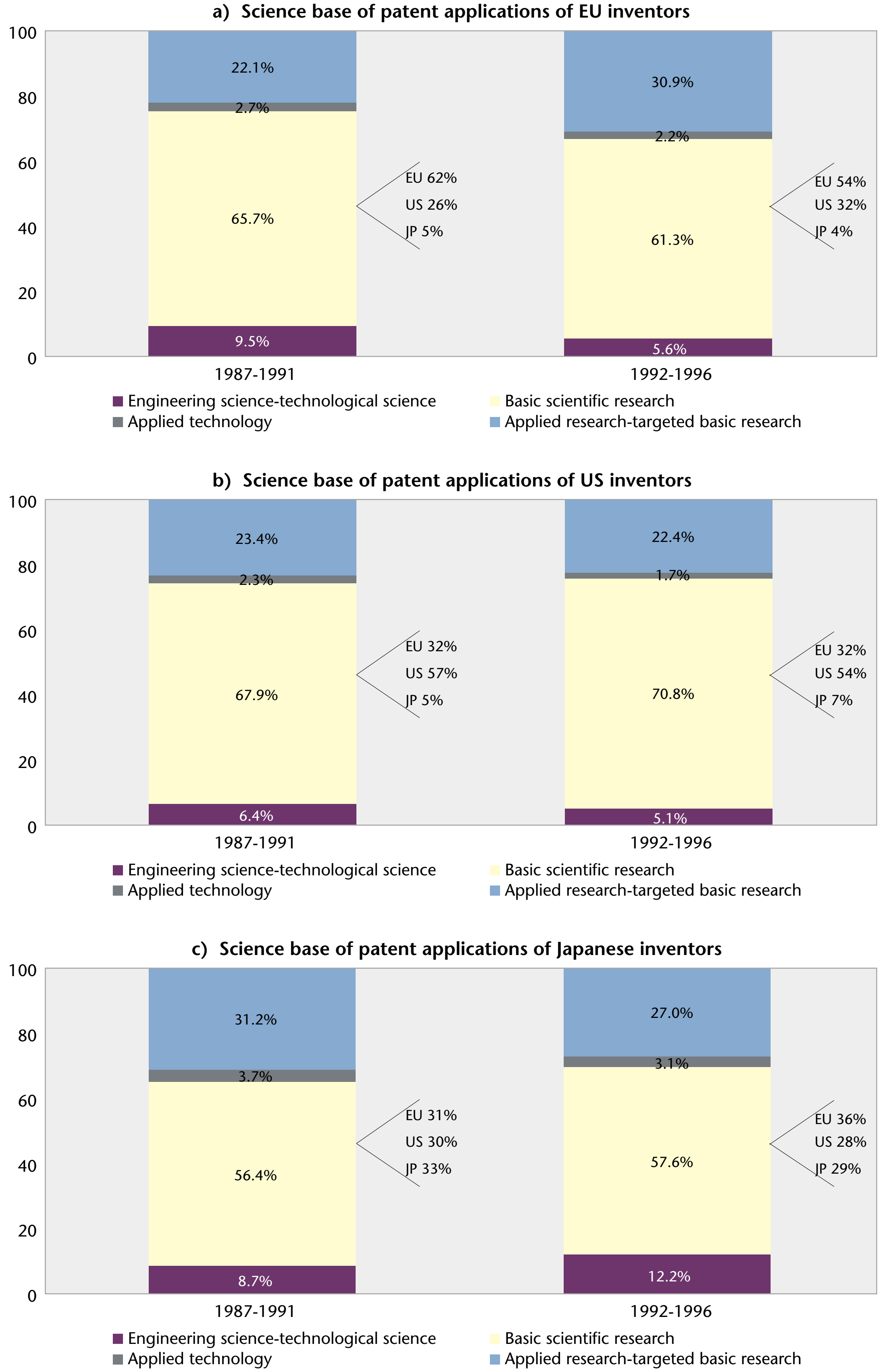
To summarise, European research is of high quality, and plays an important role in US and Japanese technological development. In terms of the intensity of basic research, Europe appears to be involved in leading-edge technology. The need of European industry for good quality basic research is to a high degree fulfilled locally. At the same time, the research capacity of Europe as an open market, appears to enable successful absorption of foreign research, which directly stimulates new scientific development.

Tracing "basic" research in technological development

By tracing the citations to scientific publications in patents, it is possible to learn more about the research orientation of a certain technology in a country. The approach used is to classify journals into four levels, varying from very basic to highly applied. The research typification is based on the orientation of the journal, and not necessarily on the factual content of the scientific paper. The approach also takes into consideration the origin of the basic research involved by looking at the address affiliation of the authors involved.

[3] *Similar calculations using patent applications at the USPTO (1992-1996) show the opposite trend: in US patents basic research accounts for 49% of science cited by European inventors, compared with 42% of science cited by US inventors.*

Figure D6.2.7 The science base of patent applications of EU, US and Japanese inverntors (%)



Source: Incentim-K.U. Leuven
Data: EPO data processed by Incentim-K.U. Leuven

Third European Report on S&T Indicators, 2003

Conclusions

Increases in science linkage have been experienced across most technology fields and across almost all EU countries, the US and Japan. The top citing technology fields are generally the newer technologies, with three fields – biotechnology, organic fine chemistry and pharmaceuticals – accounting for over three-quarters of all references to science in European patents.

The results in this dossier confirm the importance of a country's science base for its own industrial texture, as inventions are inclined to involve (i.e. cite) the national science base first, and foreign research second. The data also serve to underline the high status of European research, as measured by its role in worldwide patented technology.

In order to better exploit Europe's strength in basic research, new and improved linkages between science and technology need to be developed. This implies not only a closer interaction between public research/universities and industry, but also between different parts of the public research system (some of which focuses on applied as well as basic research). In this context there is a need to find ways of reducing the fragmentation and compartmentalisation of EU public research.

It is also crucial to lift the barriers between between disciplines and facilitate linkages. Transdisciplinarity and interdisciplinarity may be encouraged through improved intra- and inter-sectoral mobility of researchers, both on an international level and also between science and industry. Increased flexibility of research structures may also help, along with new approaches to project management and team working.

Strengthening the links between science and technology can help not only to enhance Europe's competitiveness, but also to increase its attractiveness as a place for researchers to work and as a place for firms to invest.

Selected Bibliography

Branscomb, L.M., Kodama, F. and Florida, R., (1999) *Industrializing Knowledge*, The MIT Press, Cambridge.

Braun, T., Glänzel W., and Schubert, A., (1991) 'The Bibliometric Assessment of UK Scientific Performance: Some Comments on Martin's 'Reply', *Scientometrics*, 20, 2, pp. 359-362.

Gibbons, M., Limoges C., Nowotny, H., Schwartzman, S., Scott, P. and Trow, M., (1994) *The New Production of Knowledge*, Sage, London.

Hanusch, H., (1999) *The Legacy of Joseph A. Schumpeter*, Edward Elgar, Cheltenham.

Kline, J., (1985) *The Non-Linear Model of Innovation*, Research Technology Management.

Meyer, M., (2000) 'Does science push technology? Patents citing scientific literature', *Research Policy*, 29 (3), pp. 409-434.

Meyer-Krahmer, F., (2000) *Increasing role of Basic Research for Innovation: The Case of Science Based Technologies. Empirical Evidence and Institutional Consequences'*, ISI Karlsruhe, Conference paper.

Moed, H.F., (1989) *The Use of Bibliometric Indicators for the Assessment of Research Performance in the Natural and Life Sciences*, Doctoraatsdissertatie Rijksuniversiteit Leiden, DSWO Press.

Narin, F., K.S. Hamilton and Olivastro, D., 'The Increasing Linkage Between US Technology and Science', *Research Policy*, 26, 1997, pp. 317-330.

Nohria, N. & Eccles, R.G. (1993) '*Networks and Organizations'*, Harvard Business School Press.

OECD, (1994) *The Measurement of scientific and technological activities. Using Patent Data as Science and Technology Indicators'*, Patent Manual, OECD, Paris.

Papaconstantinou, G. and Polt W., (1997) *Policy Evaluation in Innovation and Technology: An Overview*, Volume based on the conference: 'Policy Evaluation in Innovation and Technology', OECD, Paris.

Polt, W., Rammer, C., Schartingner, D., Gassler, H., and Schibany, A., (2000) *Benchmarking Industry-Science Relations in Europe – The role of Framework Conditions*, Conference on: 'Benchmarking Europe's Industrial Competitiveness'; a benchmarking project on industry-science relations (ISR).

Schmoch, U., (1991) 'Tracing the knowledge transfer from science to technology as reflected in patent indicators', in *Scientometrics*, Vol. 26, No. 1, pp. 193-211.

Schmoch, U. (forthcoming), *Hochschulforschung und Industrieforschnung. Perspektiven der Interaktion*, Berlin, Sigma.

Schmoch, U., Strauss, E., Grupp, H. and Reiss, T., (1993) *Indicators of the Scientific Base of European Patents*, Report to the European Commission, EUR 15 330 EN, OPOCE, Luxembourg.

Tijssen, R.J.W., Buter, R.K. and Van Leeuwen, Th.N., (2000) 'Technological relevance of science: validation and analysis of citation linkages between patents and research papers', *Scientometrics*, 47, pp. 389-412

Verbeek, A., Debackere, K., Luwel, M., Andries, P., Zimmermann, E., Deleus, F., (2002) 'Linking Science to technology: Using bibliographic references in patents to build linkage schemes', *Scientometrics*, Vol. 54, No. 1-2.

Verbeek, A., J. Callaert, P. Andries, K. Debackere, M. Luwel, R. Veugelers (2002), *Science and Technology Interplay - A Modelling approach on a regional level*, Final Report to the EC DG Research, Brussels.

Ziman, J., (1994) *Prometheus Bound. Science in a Dynamic Steady State*, Cambridge University Press, Cambridge.

PART II
Concluding remarks: Policy implications and perspectives

The second Part of the Report has examined the performance of the European Union in science and technology. This concluding section takes a look at some of the policy challenges facing Europe in this context. It begins with some of the policy influences that have affected scientific output and impact, including public R&D investments in specific fields and in research infrastructure, as well as policies towards patenting and research commercialisation. The section goes on to discuss the importance of Europe's performance in S&T in the transition to the knowledge economy – and in particular in achieving the ambitious objectives set at Lisbon – and the crucial role that public policies (including research policy) can play in this regard.

S&T performance: policy developments and challenges

National and international science and technology policies have evolved considerably in recent years. Yet, while many promising new measures have been undertaken, some tensions have emerged within science policy, for example between encouraging higher scientific productivity in terms of publications, and pushing researchers towards commercialisation and patenting. Policy makers are increasingly aware of the conflictual nature of certain aims, and are seeking to develop a clearer view about what they are trying to achieve, and at what price.

Investment and the rise in scientific publications

From a policy perspective it seems clear that the rise in the number of publications from the European science base reflects past investments in the early 1990s. Whether or not this trend will continue, remains to be seen. The growth in funding does not seem very stable. The weaker public and private investments in R&D in the second half of 1990s will probably have a negative effect on numbers in the coming years – that is, if no other effects counterbalance such downward pressures. In fact, it seems remarkable that these increases have been realised despite the fact of no real increases in public R&D spending.

It seems reasonable to assume that competition for scarce resources has caused these increases. If publications raise visibility quickly, it is relatively simple for researchers to generate another publication or two. If policy makers prefer co-publications, this seems manageable as well. However, this simplistic reasoning is only viable over short periods. It is one thing to publish one or two additional publications per year. However, the demand for constant increases, while funding remains stable or even decreases, is likely to become counterproductive in terms of quality of the research and of the publications. Furthermore, it might lead to exploitation of research staff, and especially of younger researchers.

Improving research infrastructure

It should be borne in mind that research infrastructure is a key component in undertaking excellent research. It does not make sense to employ ten post-doctorates if there is only one computer available for them to use. Very often the condition of research facilities is the factor that sets the limits on research productivity and knowledge transfer. A second aspect that should not be overlooked is the fact that if the research environment is not very attractive, and competition for funding is taking a lot of valuable research time, jobs in European scientific institutions become less and less attractive. International research centres such as CERN and the European Molecular Biology Laboratory (EMBL) in Heidelberg are also attractive because of an excellent research infrastructure. The same applies to several top US research universities that attract a lot of European talent.

A second important issue relates to the scale and efficient use of research infrastructures. Many European research centres are of a small scale, and to become more attractive at the international level they need to network and cooperate more effectively so as to achieve a "critical mass" and to optimise the use and synergies between these infrastructures.

Reconciling conflicting aims

If carefully designed, competitive financing seems to be a means to induce higher quality research and also higher productivity. However, researcher productivity seems to follow the law of diminishing returns. This is because the output from public R&D investment is limited by time restrictions, available infrastructure, and last but not least the scope of duties. Therefore, there are trade-offs of which policy makers should be aware. There are conflicts between the goals of achieving quantity and quality of research output, and ensuring that researchers are supported in effectively carrying out their educational and knowledge transfer duties.

Patents, as another tangible outcome of the R&D process, are less amenable to comparative measurement than scientific output. It may take several years for a science-based invention to become a successfully granted patent. Moreover, a high level of patenting is concentrated in only a few technology areas and industrial sectors (e.g. biotechnology). Similar to the situation found in US, European policy makers have been pushing for intensified industry-science relationships within Europe, marked by increasing levels of (university) patents. However, the policy-driven aim of increasing the budgets of public research institutions in Europe by stimulating more aggressive patenting behaviour, may have the same negative effect on publication output as in the US. This may show up in relatively decreasing European publication outputs in years to come.

In the US there has been a paradigm shift in policy since the early 1980s, when public research institutions were allowed to cooperate with industry and to own the results of their research. When some research universities made fortunes through licensing agreements with industry, the demand to push industry-university relationships, and the pressure to perform research on the application-oriented end, proved to be positive for the technological performance of universities. Since 1980, patenting by US public universities has risen dramatically – with some unintended results: despite the increasing numbers of university patents, their quality (measured by scientific citations in a patent) has decreased (Henderson, 1998). Second, the increase of university patents might have an impact on the decreasing publication numbers, and as such have a counterbalancing effect.

It is clear that the policy demand for researchers to become involved in more science transfer brings trade-offs, such as those between publications and patents. At the same time, some evidence suggests that the emphasis on patenting will not necessarily lead to the establishment of commercially more valuable patents.

Balancing the diffusion and protection of knowledge

Underlying much of this debate are the twin aims of stimulating the effective diffusion of knowledge within national innovation systems, while at the same time providing inventors and innovators with the instruments necessary to protect their investment and profit from the fruits of their research.

The increasing emphasis on exploiting the results of public research – in terms of commercialisation and technology transfer to business enterprises – raises the issue of whether in certain cases research results are diffused better through open publication than through patents[1]. The need to carefully balance protection and diffusion of knowledge also arises in relation to the allocation and use of intellectual property rights in international research collaborations. This poses important policy challenges, especially where public research institutions are involved, since IPR agreements between project partners can play a crucial role in determining the nature and success of research collaborations, and can also be viewed as a mechanism for facilitating longer-term relationships between companies and public research actors.

A number of initiatives have been launched in recent years to encourage and facilitate the use of patents by small to medium sized enterprises, including reducing patent fees and promoting the use of patents as a source of information on the state of the art in a technology area. Among the important barriers still faced by small firms is the often high cost of protecting their patents against infringement at national and international levels, which is all the more significant since most patent litigation brought before the courts is filed by SMEs. Some firms may therefore decide to use other methods of protection, including secrecy, which may arguably slow down the diffusion of technical knowledge in certain cases (although this is subject to debate).

Looking ahead, the creation of a Community Patent (cf. box 'Proposal for a Community Patents' in chapter 6), now a high priority on the EU agenda, should help to redress a certain number of weaknesses. On the one hand, it should reduce the cost of patenting for firms, while at the same time offering a clearer legal framework in the event of litigation. Lightening the burden on business in this way, and reducing the complexity and uncertainty associated with patenting, should encourage more European inventors to apply for patents, stimulate innovative activity and help firms expand their activities to the European level.

The policy debate outlined above has to some extent revolved around the perception that, while the European Union has a strong science base, it needs to do more to translate this into technological and commercial success: a concept referred to as the "European Paradox". This idea, first developed in the preparatory work for the 1st edition of the European Report on S&T indicators (1994), has received considerable attention from policy makers. The phenomena in question are highly complex, and require very detailed analysis, including at country and sectoral level (see the dedicated section of the 2nd edition of the Report (1997)). The latest data in the present report suggest some positive trends at the end of the 1990s

[1] *See for example the discussion in Mowery D.C. et al., 'The growth of patenting and licensing by US universities : an assessment of the effects of the Bayh-Dole act of 1980', Research Policy, 30, pp. 99-119, 2001. The authors question whether the trend towards widespread patenting and restrictive licensing terms may in some cases hamper, rather than promote, technology transfer from universities to industry.*

and the beginning of the new millenium (for example, in EU patenting performance, and in efforts to encourage the creation of university spin-offs). Nevertheless, there is still a perception that the EU is under-performing in its ability to exploit and commercialise science. For policy makers', and indeed for most citizens, this is the bottom line; they are not interested in the generation and diffusion of knowledge per se, but rather its impact on the economy and society.

From science and technology to growth and employment ...

A strong performance in science and technology is not an end in itself, but rather represents an important and necessary pre-condition for generating improvements in economic growth, employment and social welfare. This ultimate goal was acknowledged by EU heads of state meeting at the Lisbon Summit of March 2000, who set the goal for the EU to become the most competitive knowledge based economy in the world by the end of the decade, to create more and better jobs and to achieve sustainable growth.

For this transition towards a knowledge-based economy to be effective, it must be supported by extensive restructuring of the production system and of the relationships between economic players. In particular, boosting competitiveness means directing investments towards high-tech, highly knowledge intensive activities, and modernising traditional branches of the economy by disseminating new technologies. It demands ever higher, more diversified skills on the part of operators to create, absorb and disseminate knowledge and convert it into economic activities in order to safeguard competitiveness in the knowledge-based economy.

The objectives set by the Lisbon Summit imply a significant long-term increase in productivity. It will depend on innovation in promising fields, for example expanding markets, and on maintaining skills in other areas of activity to ensure consistent, dynamic development of relations between different sectors of activity, either directly or indirectly. In relation to human capital, it is important not only to ensure an adequate supply of graduates with knowledge in those scientific disciplines required in the future, but also to improve the conditions for carrying out research in Europe, so that young graduates will be attracted to a career in research as research scientists or engineers.

At the same time, faster conversion of scientific results, or new knowledge, into innovations is a sine qua non for attaining, maintaining or increasing competitiveness in sectors with markets extending beyond Europe. Such competitiveness entails improving productivity not only in the sectors concerned, but in all activities.

Increasing investment in research is a vital starting point for bringing about the structural changes required in the coming years. Europe falls behind the US and Japan in the level of its investment in R&D. Although Member States are obliged to adhere to the fiscal and budgetary disciplines of the Stability and Growth Pact, which can entail difficult choices for public expenditure, it is nonetheless vital that public funding of R&D does not fall. At the same time, measures must be put in place to improve the incentives for enterprises to invest in research, with a view to increasing the proportion of R&D expenditure funded by the business sector. The gap between the EU and the US in business financed R&D is principally due to the smaller number of EU firms involved in high-tech sectors. Individually, EU high-tech companies invest as much as their US counterparts, but they are simply fewer in number, hence the need to find more ways of encouraging the rapid emergence of start-ups and innovative SMEs.

However, an effective economic environment for innovation is only possible if firms, governments and other institutions work together in a coherent and complementary way as a *system*. Making the transition to the knowledge-based economy therefore requires efforts to improve coherence and coordination, and here public policy has a key role to play.

The main thrust of the European Research Area (ERA) initiative is to increase coherence and coordination within the European research system. This is brought about by improving openness and participation in national as well as European research programmes, and stimulating mobility and links between research actors.

What is becoming increasingly clear, however, is that research policy alone is not enough. Europe's strategic goal set at the Lisbon summit also requires stronger coordination across several areas of public policy.

Firstly, macro-economic stability policies need to be developed and implemented in greater coordination with the supporting structural policies that can make important contributions to the knowledge-based economy, such as those relating to taxation, employment, enterprise, competition, education, research and innovation.

Secondly, there is a need for more coordination between these structural policies so that they reinforce and complement each other. For example, the Barcelona objective of raising research expenditure to 3% of GDP by 2010 can only be met if the education system produces the necessary graduates who can be recruited as research scientists and engineers; increasing the mobility of skilled workers depends on developments in migration policies; and encouraging high-tech start-ups requires, among other things, dynamic industrial policies.

Along a third axis, continued efforts are required to encourage more synergies between policies at regional, national and European levels. The European Union has an important role here for providing the appropriate framework conditions for such coordination to take place.

In other words, the strengthening and modernisation of research policy is a necessary step for delivering the Lisbon objectives, but is insufficient on its own. It is only through developing a more coherent framework of public policies, that the EU will be able to meet its ambitious targets for 2010, and thus respond to the expectations of European citizens in relation to the knowledge-based economy, growth, employment, social cohesion and sustainable development.

ANNEXES

Composite indicators: Methodological annex to chapter 1

The use of composite indicators to assess progress towards the knowledge-based economy is an emerging and pioneering field. Such indicators have already been successfully used at both national and international level in a number of different policy fields where it is necessary to summarise complex multidimensional phenomena[1]. By aggregating a number of different variables, composite indicators are able to summarise the big picture in relation to a complex issue with many dimensions.

In the framework of the Commission's Structural Indicators exercise[2] it was decided that it would be useful for the Commission services to investigate and develop composite indicators of the knowledge economy. A number of Commission services have been involved and consulted during the development work including DG Education, Eurostat, DG Information Society and DG Enterprise. External technical assistance with the refinement of the methodology was provided by Anthony Arundel and Catalina Bordoy of MERIT. The Applied Statistics Group of the Joint Research Centre also contributed significantly to reviewing different approaches and testing the sensitivity of the chosen method[3]. This co-operation resulted in the production of two new indicators: a composite indicator of investment in the knowledge-based economy, and a composite indicator of performance in the transition to the knowledge-based economy. This Report presents some first preliminary results emerging from this work on composite indicators.

What do the composite indicators tell us?

The composite indicators used here are a weighted average of a number of component or sub-indicators. They reveal several things:

1) For any given year, they show the position of the country concerned (as the mean of the various base indicators) compared with its partners: if one country's composite index is higher than another's, the country with the higher index is in a better position;

2) If we follow one particular indicator for several years, it shows us how the country is progressing over time. If the index is higher in year *n*+1 than it was in year *n*, the country's performance (or capacity) has improved over that period;

3) The value of an index during year *n* shows the position of the country compared with the European average in the reference year (1995 in this case):

   - a positive index means that the position of the country in year *n* is above the European average for 1995;
   - a negative index means that the position of the country in year *n* is below the European average for 1995.

Component indicators and their weights

The composite indicators are calculated using the component indicators and weights[4] listed below.

---

[1] *For example: · United Nations, Human Development Report, 2001 [Human Development Index, Technology Achievement Index]. · International Institute for Management Development, The World Competitiveness Yearbook (2000 and 2001), Lausanne. · Nistep, Composite Indicators: International Comparison of Overall Strengths in Science and Technology", Report No 37, Science and Technology Indicators 1994, A Systematic Analysis of Science and Technology Activities in Japan, January 1995. · World Economic Forum, Pilot Environmental Performance Index, Yale Center for Environmental Law and Policy, 2002. · Alan L. Porter, J. David Roessner, Xiao-Yin Jin and Nils C. Newman, Changes in National Technological Competitiveness: 1990-93-96-99, (available on Internet). · Michael E. Porter and Scott Stern, The New Challenge to America's Prosperity: Findings from the Innovation Index, Council of Competitiveness, Washington DC, 1999. · Progressive Policy Institute, The State New Economy Index, www.neweconomyindex.org/states, 2000.*

[2] *Communication from the Commission : Structural indicators, COM(2001) 619 final, Brussels, 30 October 2001.*

[3] *State-of-the-art Report on Current Methodologies and Practices for Composite Indicator Development, Joint Research Centre - Applied Statistics Group, Ispra, June 2002 (www.jrc.cec.eu.int/uasa/prj-comp-ind.asp).*

[4] *These are the weights used for the calculation of the positions of EU Member States. The weights used for the growth rates and for comparisons with the US and Japan are slightly re-adjusted owing to non-availability of some variables or time series (see section below on data availability).*

Table A.1 Component indicators and weightings for the composite indicator on investment in the knowledge-based economy

Sub-indicators	Type of knowledge indicator	Weight
Total R&D (GERD) per capita	Knowledge creation	2/24
Number of researchers per capita	Knowledge creation	2/24
New S&T PhDs per capita	Knowledge creation	4/24
Total Education Spending per capita	Knowledge creation and Knowledge diffusion	4/24 3/24
Life-long learning	Knowledge diffusion : human capital	3/24
E-government	Knowledge diffusion : information infrastructure	3/24
Gross fixed capital formation (excluding construction)	Knowledge diffusion : new embedded technology	3/24

Source: DG Research
Data: Key Figures, 2002

Third European Report on S&T Indicators, 2003

Table A.2 Component indicators and weightings for a composite indicator on performance in the knowledge-based economy

Component indicators	Conceptual group	Weight
GDP per hour worked	Productivity	4/16
European and US patents per capita	S&T performance	2/16
Scientific publications per capita	S&T performance	2/16
E-commerce	Output of the information infrastructure	4/16
Schooling success rate	Effectiveness of the education system	4/16

Source: DG Research
Data: Key Figures, 2002

Third European Report on S&T Indicators, 2003

The technique adopted here is to base weights of sub-indicators on a conceptual understanding of the phenomenon that we are trying to measure. Each composite indicator contains a number of "conceptual groups". These conceptual groups may contain one indicator or several. The different conceptual groups are given equal weightings, while within each group the components indicators are also accorded an equal weight[5]. For example, the investment composite indicator contains two conceptual groups: knowledge creation and knowledge diffusion, both of which receive an overall weight of 12/24 (table A.1), the component indicator "total education spending" contributing to both groups (4/24 to creation group and 3/24 to the diffusion group). The performance composite indicator has four "conceptual groups" which are equally weighted (table A.2).

Whilst this system may not correspond to the *theoretically ideal* set of weights that we would choose if we knew precisely the contribution of each component indicator to explaining the knowledge-based economy (which is impossible to estimate whatever method we use), it has the advantage of being clear, transparent and conceptually coherent.

Calculation method

All methods of calculating a composite indicator must transform indicators that are measured in different units into the same unit. For example, indicators measured in terms of euro, percentage, and per capita must be transformed into a single measurement unit. The method used here for the composite indicators of the knowledge-based economy is to calculate z-scores (standardized units of the number of standard deviations from the mean).

To be precise, if x^t_{ji} is the value of the jth component indicator for country i at time t, and if for each component indicator one calculates the standardized z-score:

$$y^t_{ji} = \frac{x^t_{ji} - x^0_{j\,EU}}{\sigma^0_j}$$

where $x^0_{j\,EU}$ is the EU average, and σ^0_j the standard deviation, of the component indicator j at time 0 (in the calculations of the

[5] *With the exception of R&D expenditure and numbers of researchers which are given the weighting of one instead of two component indicators because of the close link between these two variables (most of R&D expenditure is researchers' salaries).*

composite indicators presented here the base year 0 has been chosen as 1995).

The composite indicator I_i^t of a country i is then calculated as the sum of these standardized values y_{ji}^t weighted by the coefficients q_j (whose sum is equal to "1", so that the composite indicator is commensurable with its components), i.e.

$$I_i^t = \sum_{j=1}^{m} q_j y_{ji}^t$$

where m = number of component indicators.

The growth rate is calculated using the transformation without the "centring" element, i.e.

$$y'^{t}_{ij} = \frac{x_{ij}^t}{\sigma_j^0} \text{ instead of } \quad y_{ij}^t = y'^{t}_{ij} - \frac{x_{j\,EU}^0}{\sigma_j^0} = y'^{t}_{ij} - y_j^0$$

To arrive at this non-centred value we have to add the following, $I_0^0 = \sum_{j=1}^{m} q_j y_j^0$

to the value of the composite indicator for each country. This operation purely re-scales the indicator along the same axis.

If we take then, $I'^{t}_{i} = I_i^t + I_0^0$, the annual average growth rate of the composite indicator between 0 and t is

$$\tau_i^{t/0} = \left(\frac{I'^{t}_{i}}{I'^{0}_{t}} \right)^{1/t} - 1$$

Data availability

The availability of complete time series for all countries and component indicators is very important for the calculation of composite indicators, since gaps in data are compounded when aggregating across many variables, countries and years. An important criterion for the selection of the component indicators (along with quality and comparability) was therefore the completeness of the datasets.

Nevertheless, comparable data for some component variables (e-commerce, e-government, education expenditure, lifelong learning, schooling success rate) were not available for the US and Japan, and the indicator calculated for comparisons with these countries excludes these components and uses a re-adjusted weighting. Since certain component indicators are only available for one year (no time series), growth rates are calculated excluding these indicators, and the weights have been re-adjusted accordingly.

Human resources in S&T: Methodological annex to chapter 4

S&E graduates defined and education statistics

The *Manual on the measurement of human resources devoted to S&T (Canberra Manual)* provides guidelines on the definitions and categories of fields of study in natural sciences, engineering and technology, medical sciences, agricultural sciences, social sciences, humanities, and other fields. The first five fields are defined as core to HRST and the rest as extended for S&T, depending on the level of education (Canberra manual, paragraph 3.2.3).

In chapter 4, the selection of fields of study most relevant for S&T is narrower. The fields of study regarded are science and engineering. Science includes natural science, i.e. life sciences and physical sciences – mathematics, statistics and computing. Engineering covers engineering and the engineering trade, manufacturing and processing, as well as architecture and building[6] S&T, in a very narrow sense, consists only of science and engineering.

A further breakdown of disciplines includes medical sciences and agriculture (aggregated as health and food sciences) and a broad area of social sciences – behavioural sciences, law and business administration, humanities (including arts) and education. All analyses that include a finer breakdown of all fields of study provide a breakdown of five fields (sciences; engineering; S&E; health and food sciences; social sciences, humanities and education). A table containing the breakdown of the different fields of study, belonging to S&E and to S&T, can be found at the end of this annex (table A.3).

It should be borne in mind that there was a major change from the International Standard Classification of Education, ISCED 1976 to ISCED 1997. ISCED defines fields of study as well as levels of education. ISCED 1976 levels 5, 6 and 7, which include undergraduate, graduate and PhD degrees are relevant to human resources in S&T. In ISCED 1997, the classification of higher education has changed to 5B, 5A and 6, whereas the single levels are not comparable with the 1976 levels. The ISCED 1997 codes can be interpreted as follows: ISCED 5B is a tertiary level degree with practical, technical or occupational qualification. ISCED 5A is a tertiary level, theoretically based degree, which allows postdoctoral studies and prepares for further careers as researchers. Only ISCED 5A qualifies for ISCED 6, which comprises PhDs and other postgraduate diplomas. As the ISCED classification changed in 1997, only very limited dynamic analyses of graduates are possible at present. Actual across country analyses can only be done with the new classification (ISCED 1997) for the

[6] *According to ISCED 1997. The ISCs are ISC42, ISC44, ISC46 and ISC48 for science and ISC52, ISC54 and ISC56 for engineering.*

latest three available years, 1998, 1999 and 2000. With the old classification (ISCED 1976) periods of time analysed stop at 1997. Any comparison of the two periods including the most recent data has to be treated carefully due to the lack of comparability of the two ISCEDs.

Education expenditure: Data and Definitions

Comparing the education efforts of each country is not an easy exercise. Cumulative data on private expenditure on education and training are difficult to access. This kind of expenditure, both from enterprises and individuals, represents in some countries a significant part of the total expenditure on education. Because of the diversity of national education systems and the peculiarities of accounting systems, data public expenditure on education are not wholly comparable. For instance, the duration of compulsory schooling and the definition of what public expenditure covers are not necessarily identical in all countries (for more details about international differences, cf. UNESCO, 1995).

Nevertheless, as far as developed countries are concerned, major efforts were made during the second half of the 1990s by the OECD to achieve reasonable comparability of the data (OECD, 2001, pp. 5-7). The analyses in Chapter 4, Section III rely principally on the database gathered by Eurostat and the OECD concerning their Member States (and published in Eurostat, 2000d; OECD, 2001). The data not only have a higher degree of comparability but they are also more recent than UNESCO data[7].

According to the methodology of these two institutions, expenditure on education is classified into two categories. On the one hand, the “expenditures on educational institutions” regroups both public and private expenditure on schools and universities, education ministries and other agencies directly involved in providing and supporting education.[8] It includes:

- “direct instructional expenditure” such as teachers’ salaries or school materials;
- “indirect instructional expenditure” (such as spending on ancillary services such as meals, transport to schools);
- “expenditure on research and development”, which can be of significant importance in tertiary education.

The “expenditure on education outside educational institutions” refers to all private expenses for purchases of educational goods (e.g. books) or services (e.g. tutoring), and for students’ living costs, whether or not they are subsidised. This section is limited to “expenditure on educational institutions”, from both public and private entities, and for all levels of education (pre-primary, primary, secondary, post-secondary, non-tertiary and tertiary).

[7] *Whereas data from the latest UNESCO publications is limited to the period before 1994, figures from Eurostat and OECD are available until 1996 and 1998, respectively.*

[8] *Please note that the indicators give the financing institution (which can be public or private), independently from who is performing the education activity.*

Researchers and R&D personnel

Researchers and R&D personnel are defined according to the guidelines of the OECD manuals, specifically the *Proposed standard practice for surveys of research and experimental development* (Frascati Manual) of 1993. According to the Frascati Manual, research scientists and engineers (RSEs) or in short researchers, are “professionals engaged in the conception or creation of new knowledge, product processes, methods and systems, and in the management of the projects concerned” (Frascati Manual 1993, paragraph 5.4.2.2).

The International Standard Classification of Occupation (ISCO), 1988, is used for the definition of researchers. The group of researchers is formed by the ISCO 2, “professional occupations”, and ISCO 1237, “research and development department managers”. Together with “technical and associated professionals” (ISCO 3), the researchers form the R&D personnel. Although technical and associated professionals may have a university degree or researchers may have low formal qualifications combined with extensive in-service job experience, some correspondence between researchers and higher education is assumed in the definition of researchers (Frascati Manual 1993, paragraph 5.6).

The Frascati definition is the basis for the Eurostat/OECD data on researchers and R&D personnel, which are analysed as key statistics in this report. Additionally, some data from the Community Labour Force Survey (CLFS) are used, which among others also provides data for employment by occupation, for instance ISCO2 and 3. Starting from this ISCO classifications, one important specific of the CLFS is its definition of human resources in S&T (HRST), which is explained below.

Human Resources in S&T data in the Eurostat Community Labour Force Survey

The Community Labour Force Survey (CLFS) is carried out in all EU Member States and the Candidate Countries. The surveys are conducted on an annual or quarterly basis, depending on the requirements of individual countries. Some of the variables that are of interest in HRST studies include gender, employment status, occupation, working environment, type of work, level of education, nationality and country of residence. Eurostat centralises the results of the surveys and publications statistics in NewCronos, but other departments of the Commission can also obtain information on specific data. The information provided by these surveys is very interesting. They yield insight into gender issues, drawing on the work of the Commission on the status of women in employment, as well as employment status (employer, employee, unemployed), occupation (according to ISCO 1988), working environment (size of the undertaking and its main activity), type of work (activity in the undertaking) and seniority. The same questions are asked as in the previous year, which makes it possible to analyse occupational mobility (and the occupational trends of the unemployed), level of education, nationality and country of residence.

The disadvantage of a survey is, of course, that unlike a census, only a limited number of people are questioned regularly, and the sample may even change over time. The results can be used only if a certain number of people meet the conditions which are analysed. Otherwise, there is no guarantee that the results will have statistical significance. This is why DG Research calls for bigger samples of people who have reached certain levels of education (university graduates or equivalent), in order to follow their professional careers. Unfortunately, the objective of this survey is much more general, since it covers the whole of the population. It cannot be expected to satisfy all demands, as it would require a specific survey.

The results of these surveys are not always compatible with national macroeconomic figures. Therefore, caution must be exercised in the way in which the results are used. In this respect, it is important to clarify that CLFS uses a different definition of HRST, which can be extracted from Eurostat's NewCronos database.

The Eurostat-NewCronos' HRST definitions align with the Canberra Manual definitions of S&T, which in its broadest sense includes *all* fields of study; in its narrowest sense, only natural sciences, engineering, medical sciences, agricultural sciences and social sciences (for ISCED 6/7, cf. Canberra Manual paragraph 3.2.3). The Canberra Manual recommends that, for macro-measurement of HRST, ISCED fields of study be grouped into the following seven broad fields of study in S&T: natural sciences; engineering and technology; medical sciences; agricultural sciences; social sciences; humanities; and other fields. Scientific and engineering programmes are defined as more directly relevant to S&T activities than humanities or other fields.

NewCronos applies the definitions and guidelines as set out in detail in the Canberra Manual and and uses the following nomenclature produced by Eurostat to define the different HRST groups as follows:

- the group 'HRST' includes all people who have higher education qualifications (at least ISCED5B) *or* are working in R&D, i. e. ISCO2/3;
- the group 'HRSTE' (education) includes all people with higher education in a field of study which the Canberra Manual broadly defines as S&T (which does not correspond to the S&E graduates analysed in this report);
- the group 'HRSTO' (occupation) includes all people working as professionals or technicians. This definition includes ISCO 2 and 3 and does not fully correspond to the definition of R&D personnel in the Frascati manual, because it does not include the "research and development department managers" – ISCO 1237);
- the group 'HRSTC' (core) is the overlap between ISCED 1976 5, 6, 7 or ISCED 1997 5B, 5A, 6 and ISCO 1988 2, 3. This core group includes all personnel with higher education in terms of the Canberra Manual's definition of S&T, who are working as professionals or technicians. This group does not correspond fully with the researchers analysed in this report, because of the absence of ISCO 1237 group in HRSTC and the lack of formalised qualification categories in the Frascati definition of researchers;
- the HRST also covers 'Scientists and Engineers'. Scientists and Engineers are defined as people who work in physical, mathematical and engineering occupations or life science and health occupations. This group does not correspond with the Frascati concept either and should not be confused with it;
- finally, there is a group of 'HRSTU' (unemployment) which includes all unemployed HRSTE.

Although the most of the groups do not correspond fully with the key indicators on human resources in S&T analysed in Section I, Chapter 4, some of the CLFS data can nevertheless be used if labelled and interpreted correctly. The above-mentioned HRSTE and the HRSTC data are analysed in Section II. To avoid ambiguity, these categories will be called "population with higher education" (HRSTE), and if occupied, "higher qualified S&T employees" (HRSTC), HRSTU data are used to analyse the "unemployment of population with higher education". Furthermore, in Section IV on international mobility, the HRSTO data are used to analyse the "S&T employees". In general, the abbreviation HRST will be reserved exclusively for the NewCronos data, stemming from the CLFS. In this report, it is not used as an abbreviation for the expression, "human resources in S&T".

Table A.3 Definition of S&E, correspondence between ISCED 1997 and 1976, and Eurostat classes (* Eurostat's definition of S&T)

Broad field	Sub field	Disciplines	Includes (according to ISCED 1997)	ISCED 1997	ISCED 1976	Eurostat classes (acc. to ISCED 1976)
1. Science and Engineering (S&E)	1a. Science	1.a.a Natural sciences	Life sciences (biology, microbiology, biochemistry, biophysics, zoology)	42	42	Natural sciences*
			Physical sciences (physics, chemistry)	44		
		1.a.b Mathematics and computing	Mathematics and statistics, computing	46, 48	46	Mathematics*, computer sciences*
	1b. Engineering		Engineering and engineering trades (electrical engineering, other engineering sciences), manufacturing and processing (food and drink processing, textiles, clothes, materials), architecture and building (construction, civil engineering)	52, 54, 58	52, 54, 58	Engineering*, architecture*
2. Health and food sciences	2a. Health sciences		Medicine, medical services, nursing, dental services	72	50	Medical sciences*
	2b. Agriculture		Agriculture, forestry, fishery and veterinary sciences	62, 64	62	Others
3. Social sciences, humanities and education	3a. Social sciences, business and law		Social and behavioural sciences, (economics, political sciences, sociology, demography, psychology, ethnology, geography), journalism and information, business and administration, law	31, 32, 34, 38	30, 34	Social sciences
					38	Law
	3b. Arts and humanities		Arts (fine arts, performing arts, graphic arts, design), humanities (religion and theology, native languages, literature, history, archaeology, palaeontology, philosophy, ethics)	21, 22	18, 22, 26	Humanities, applied arts, religion
	3c. Education		Education	14	14	Education science and teacher training
4. Others			Basic programmes, literacy and numeracy, personal development, home economics, social services, personal services, environmental protection, security services, transport and communication	01, 08, 09, 66, 76, 81, 84, 85, 86, 70	66, 78, 84, 89, 70	Others incl.: agriculture excl.: transport and communication* (belongs to engineering in ISCED 1976)
Not known or unspecified			Not known or unspecified	(99)		Field of study not known
Total of all disciplines			Total S&T (broad sense) + others + not known or unspecified	01, 08, 09, 14, 21, 22, 31, 32, 34, 38, 42, 44, 46, 48, 52, 54, 58, 62, 64, 72, 76, 81, 84, 85, 86, (99)		

Third European Report on S&T Indicators, 2003

Bibliometric analysis: Methodological annex to chapter 5

Measuring scientific performance

Bibliometrics is usually defined as the application of mathematical and statistical methods to the entire scientific literature - books and documents included (Pritchard, 1969). It has become a generic term for a range of approaches directed at quantifying output levels, collaboration patterns and impact characteristics of scientific research (OECD, 1997). When authors publish, they reveal what they are doing, with whom they did it, and when and where it was done. These literature-based measures enable systemic comparisons of scientific performance of institutions, countries and regions across a range of scientific fields (e.g. May, 1997).

Most bibliometric studies are based on the analysis of research papers, and citation links between those papers, published in international scientific and technical journals that are processed by the Institute for Scientific Information (ISI) for its series of international, multidisciplinary bibliographic databases. These 'citation indexes' contain selected information from all the research papers (title and abstract, author names, author affiliations, reference list, etc.) published in about 12 000 'sources'. Some 8 000 of these sources are fully peer-reviewed international scientific and technical journals, the remainder being conference proceedings.

Although the ISI databases are quite large in terms of the number of indexed journals, the collective content of these ISI-covered journals is not always a good reflection of all worldwide scientific publication output and research activity, especially in the social and behavioural sciences, law, and the humanities. The databases are biased in favour of English language journals. Non-English language journals are not as comprehensively indexed, and they contain a larger number of minor US journals than minor European journals. The result is that research publications from English-speaking nations (the US in particular) dominate the databases. Nonetheless, one may assume that the international journal publications in these databases provide a satisfactory representation of internationally accepted ('mainstream') research, especially high-quality 'laboratory-based' basic research in the natural sciences, medical sciences and life sciences conducted in the advanced industrialised nations.

Bibliometric indicators

The most commonly used journal-based bibliometric indicators are publication counts and citation counts. The number of scientific papers published in those international journals provides estimates of the volume of research activity and related knowledge production. Counts of the publications contained in the ISI databases do not necessarily equate to levels of research activity, but rather to the production of publicly available, research-based, codified knowledge for the international research community. Where publication counts measure output, counting the citations received by those papers provides a quantification of the transfer and utilisation of knowledge.

There are many reasons for one research article to cite another, not all of which are directly related to the scientific quality of the cited work or the contributing researchers and institutions (e.g. Weinstock, 1971). The basic premise is that a frequently cited paper has had a greater influence on subsequent research activities than a paper with no citations or only a few. The (relative) number of citations is also often considered a proxy measure of visibility in the scientific community. References in the scientific literature to research papers are also used to measure the impact of research and scientific quality.

It is important to keep in mind that both publication propensities and citation rates may vary considerably between fields, disciplines and within institutions. Scientific research is usually performed within an institutional context, in most cases a university or research institute. Thus the efforts and recognition of the individual researchers affiliated with that research institution are reflected in the scientific output and prestige of the institution as a whole. By aggregating the publication output and citations at this institutional level, one can measure and compare the institutional output and scientific reputation attributable to those researchers as a group.

Methodology and indicators used in this report

The basic bibliographic data used in this report were processed by the Centre for Science and Technology Studies (CWTS) at Leiden University in the Netherlands. The data was sourced from the following interrelated set of the ISI databases: the Science Citation Index®, Social Science Citation Index®, and six Specialty Citation Indexes® - Computer Science and Mathematics, Biochemistry, Biotechnology, Chemistry, Neurosciences, and Materials Sciences. The publication records were taken from the CD-ROM editions of the ISI databases (ISI-CDE). The 2000 editions cover more than one million papers and some 18 million citations.

The contents of the ISI databases were incorporated in the CWTS information system and further processed and tailored for large-scale comparative bibliometric studies. In this study, CWTS uses only the research articles, reviews, notes and letters published in those journals. The CWTS analyses cover all journals in the ISI databases that meet three key criteria: (1) they are (almost) fully covered by ISI over an extended period of time; (2) they are assigned to a scientific discipline by ISI; and (3) the papers in those sources contain author address information and reference lists.

Papers are attributed to the contributing authors, institutions and countries according to the information available in the affiliate address(es) listed in the heading of the paper, as supplied by the author(s).

Publication and citation counting schemes

There is no fair method to determine how much money, effort, equipment and expertise each researcher, institute or country has contributed to a paper and the underlying research effort. Dividing up a paper between the participating units is therefore to some extent arbitrary. The basic assumption is that each author, main institution and country listed in the affiliated addresses have made a non-negligible contribution. Each paper is therefore assigned in full to all unique authors, institutions and countries listed in the address heading. When this 'whole counting' scheme is used, the data should be read as the number of papers in which a certain unit occurs. Hence, whole counts introduce multiple counting of all papers, for instance two or more countries in the case of international scientific collaboration. Double counting of units within the same aggregate level is avoided (e.g. countries within the same geographic region).

In its analysis, CWTS has counted the number of citations a given paper has received from all other papers in the database. No restrictions are made on the citing items in compiling the citation counts, other than that they are recorded from ISI-indexed journals covered by the CWTS information system. If the cited paper has been produced by several units, the citations are also counted as whole counts and assigned in full to each of the units. However, the absolute number of citations received is determined by many factors, especially field-dependent citation practices. Hence, citation frequencies are not very informative without international reference values. CWTS has computed a normalised field-dependent citation impact value - the 'citation impact score' - indicating whether the citation impact is above or below international average in the corresponding field or subfield. The average citation rates are differentiated for each of the four major document types.

CWTS adopts two reference levels as a world baseline:

(1) journal(s) used by the publishing 'unit' (author, university, country etc.) – the 'journal citation score' (JCS);

(2) the entire set of journals of the (sub)field – the 'field citation score' (FCS).

The CWTS citation analysis includes all papers and their citations received within a variable 'citation window'. This system has the great advantage of being able to adapt to field-dependent citation speeds and can incorporate data for recent publication years. Such a window, say 1993-1999, contains all journal papers published in that time-interval, where the citations to those papers accumulate at a varying rate using a variable time span: the 1993 papers define a seven-year time interval (1993-1999), those published in 1994 a six-year window (1994-1999), and the citations to most recent papers published in 1999 are limited to (part of) 1999.

Trend analyses of different measurements comprise a system of moving variable citation windows, in which each successive publication year is covered in full by a series of variable citation window lengths as time progresses. For example, an overlapping series of three-year windows: 1993-1995, 1994-1996, etc. Many research fields require citation windows of at least three to four years to produce reliable citation impact data on scientific visibility and influence.

The CWTS counting procedures also deal with the fact that many ISI-covered journals are assigned to more than one (sub)field. The absolute numbers of papers and citations published in these journals are split up accordingly.

Classification system of research areas

Scientific areas are defined by unique groupings of ISI-covered journals. This classification system follows the traditional academic division of research fields. It is not country-specific but is designed to provide an internationally acceptable division in areas and sub-areas. Each sub-field is assigned to only one discipline, which in turn is designated to one of the broad fields. The hierarchical classification system consists of three layers: 11 broad scientific fields, 26 disciplines and 178 sub-fields. The top-layer of broad fields has been designed specifically for this report.

Each sub-field consists of one or more of the ISI-defined sets of scientific or technical journals, the Journal Categories. Each journal category contains a collection of journals covering the same or closely related research topics or areas. Quite a few of those scientific journals are assigned to multiple journal categories. Therefore, wide-scope journals are sometimes assigned to more than one discipline and even multiple broad fields. The prestigious general journals with broad multidisciplinary scopes, such as Nature and Science, are assigned to a broad journal category of their own, denoted by ISI as 'Multidisciplinary', which is listed in table A.4 as the 12th 'broad field'.

However, like most international classification systems of research areas, this system contains a trade-off of various conceptual issues and technical considerations. Furthermore, this revised system differs significantly from the three-layer classification system used in the previous two editions of the European Science and Technology Indicators Reports, which were technology-oriented rather than science-oriented. One of the most marked alterations is the shift of the large sub-field "Biochemistry and Molecular Biology" from the discipline "Biotechnology" and its corresponding broad field "Engineering" to the new discipline and broad field of "Basic Life Sciences".

Table A.4 CWTS hierarchical field classification system: broad fields, disciplines and sub-fields1

1. ENGINEERING SCIENCES

Electrical Engineering
Engineering – Electrical and electronic
Telecommunications
Materials Science
Materials Science – General
Materials Science – Biomaterials
Materials Science – Ceramics
Materials Science – Characterization and testing
Materials Science – Coatings and films
Materials Science – Composites
Materials Science – Paper and wood
Materials Science – Textiles
Metallurgy and metallurgical engineering
Metallurgy and mining
Civil Engineering
Construction and building technology
Engineering – Civil
Engineering – Environmental
Engineering – Marine
Transportation
Mechanical Engineering
Engineering – Mechanical
Mechanics
Welding technology
Engineering – Industrial
Engineering – Manufacturing
Robotics and automatic control
Instruments and Instrumentation
Instruments and Instrumentation
Microscopy
Photographic technology
Fuels and Energy
Energy and fuels
Engineering – Petroleum
Nuclear science and technology
Geological Engineering
Mining and mineral processing
Geological engineering
Chemical Engineering
Engineering – Chemical
Aerospace Engineering
Aerospace engineering and technology
Other Engineering Sciences
Engineering – General
Ergonomics
Operations research and management science

2. PHYSICS AND ASTRONOMY

Physics
Acoustics
Crystallography
Physics – General
Physics – Applied
Physics – Atomic, Molecular and Chemical
Physics – Condensed matter
Physics – Fluids and plasmas
Physics – Mathematical
Optics
Thermodynamics
Physics – Miscellaneous
Physics – Nuclear
Physics – Particles and fields
Spectroscopy
Astronomy
Astronomy and astrophysics

3. CHEMISTRY

Chemistry
Chemistry – General
Chemistry – Analytical
Chemistry – Applied
Chemistry – Inorganic and nuclear
Chemistry – Miscellaneous
Chemistry – Medicinal
Chemistry – Organic
Chemistry – Physical
Electrochemistry
Polymer Science

4. MATHEMATICS AND STATISTICS

Mathematics
Mathematics – General
Mathematics – Applied
Mathematics – Miscellaneous
Statistics
Statistics and probability
Social sciences – Mathematical methods

5. COMPUTER SCIENCES

Computer Sciences
Computer applications and cybernetics
Computer Science – Artificial intelligence
Computer Science – Cybernetics
Computer Science – Hardware and architecture
Computer Science – Information systems
Computer Science – Interdisciplinary applications
Computer Science – Software, Graphics, Programming
Computer Science – Theory and methods

6. EARTH AND ENVIRONMENTAL SCIENCES

Earth Sciences
Geochemistry and geophysics
Geography
Geology
Geosciences – General
Geosciences – Interdisciplinary
Remote sensing
Meteorology and atmospheric sciences
Mineralogy
Oceanography
Paleontology
Environmental sciences
Ecology
Environmental sciences
Limnology
Water resources

7. BIOLOGICIAL SCIENCES

Biology
Biology – Miscellaneous
Biology – General
Botany
Entomology
Marine and freshwater biology
Mycology
Ornithology
Plant sciences
Zoology

8. AGRICULTURE AND FOOD SCIENCES

Agriculture and food sciences
Agricultural experiment station reports
Agriculture – General
Agriculture –Dairy and animal science
Agriculture – Soil science
Fisheries
Food science and technology
Forestry
Horticulture
Nutrition and dietetics
Veterinary medicine
Veterinary sciences

9. BASIC LIFE SCIENCES

Basic Life Sciences
Biochemical research methods
Biochemistry and molecular biology
Biomethods
Biophysics
Biotechnology and applied microbiology
Cell biology
Developmental biology
Genetics and heredity
Microbiology
Reproductive biology
Reproductive systems
Health Sciences
Drugs and addiction
Hygiene and public health
Nursing
Public – Environmental and occupational health
Rehabilitation
Substance abuse
Dentistry
Dentistry and odontology

10. BIOMEDICAL SCIENCES

Biomedical Sciences
Anatomy and morphology
Andrology
Cytology and histology
Embryology
Immunology
Infectious diseases
Engineering – Biomedical
Medicine – Research and experimental
Neurosciences
Parasitology
Pathology
Radiology and nuclear medicine
Physiology
Virology
Pharmacology
Pharmacology and pharmacy
Toxicology

11. CLINICAL MEDICINE

Clinical Medicine
Allergy
Anesthesiology
Cardiac and cardiovascular system
Cardiovascular system
Chemistry – Clinical and medicinal
Clinical neurology
Critical care
Dermatology and venereal diseases
Drugs and addiction
Emergency medicine and critical care
Endocrinology and metabolism
Gastroenterology and hepatology
Geriatrics and gerontology
Hematology
Medical informatics
Medical laboratory technology
Medicine – General and internal
Medicine – Miscellaneous
Obstetrics and gynecology
Oncology
Ophthalmology
Orthopedics
Otorhinolaryngology
Pediatrics
Peripheral vascular disease
Psychiatry
Respiratory system
Rheumatology
Sports science
Surgery
Transplantation
Tropical medicine
Urology and nephrology
Vascular diseases

12 MULTIDISCIPLINARY

Comprises of broad, general journals with a multidisciplinary collection of papers, notably the highly prestigious and highly influential journals Nature, Science, and Proceedings of the National Academy of Science

Third European Report on S&T Indicators, 2003

Selection of the EU's most active research-performing institutions

The selection comprises the top 20 main research-performing institutions – i.e. physical and legal entities at the highly aggregated level– in each of the largest EU-15 countries (France, Germany, Italy, Sweden, Netherlands, Spain and United Kingdom) and the top 10 in the smaller EU-15 countries. The following step-wise procedure was adopted to generate a representative set of the largest institutions in each country while taking into account the relative size of disciplines:

Step 1 – Select the main institutions contributing the largest number of publications in ISI-covered journals for each separate discipline. The disciplines are defined by journal sets according to the CWTS field classification system. The procedure is restricted to the disciplines belonging to the natural sciences, medical sciences, life sciences, mathematics and statistics, and engineering (table A.4).

The publication counts are based on the number of papers published in the four-year time-interval 1996-1999 and on a full counting scheme whereby each paper is attributed in the full to each of the main institutions listed in the author address(es). International research institutions are excluded. A lower threshold of 60 papers is set per discipline (an average of 15 per year) in order to be included in the selection. Luxembourg-based institutions were excluded due to insufficient numbers of papers.

Step 2 – If step 1 does not provide the required number of institutions for a country, this procedure is repeated for the 2nd in the ranking of each discipline. This process is continued with the 3rd in the ranking, and so forth, until the required number of institutions is reached. In case of ties or an excess of additional entries in the last stage of the selection, the remaining positions go to those institutions with the largest numbers of papers in the corresponding discipline.

Hence, the absence of an institution's name in the final selection indicates that the institution was not amongst the most actively publishing in any discipline, or it did not meet the lower output threshold. This discipline-dependent selection criterion ensures that the larger institutions active in the less prolific disciplines (e.g. the engineering sciences) are also included. The selection of these main research institutions was based solely on the number of their (co-)authored research papers published in scientific and technical journals indexed by ISI, irrespective of the citation impact of those papers or the productivity of the research personnel producing these papers. Hence, the institutions on this list do not necessarily have higher impact scores and/or higher productivity rates than those excluded from this selection.

An alternative calculation of relative citation scores

When ranking countries by field, the relative citation impact factor is widely used. However, it has been shown that there is a power law relationship between the number of publications and their recognition in terms of number of citations across disciplines, countries and institutions (Katz, 2000). This means that there is a strong non-linear increase in the amount of citations as the number of publications increases. What does this discrepancy in the citation frequency distribution mean in terms of citation impact scores and associated relative scientific standing of countries? In general terms it is argued that a so-called "Mathew effect" exists, meaning that countries that already have a high standing and receive many citations will receive even more (the positive effect) and vice versa (the negative effect).

Apart from these stratification processes, which occur in many sectors of society, reward systems and communication patterns within science may also play a role. This is reinforced by the self-citation propensities of authors, institutes and countries, where the size of the entity will affect the magnitude of the effect. Researchers in large countries such as the US, with large and diverse scientific communities, are more likely to cite domestic researchers. When taking this power law into account in normalising citation frequencies and creating an adjusted relative citation impact, the results are quite perplexing.

This has been shown within the UK research system. Here, if the number of publications of an institution doubles, the recognition – in the form of citations – increases by an average of 2.19. In the life sciences it increases by as much as 2.27. Basically, this leverage effect for countries, fields and institutions can be calculated. Of course, factors such as citation windows and thresholds will still influence the new indicator, but the relatively strong effect of large countries or institutions, in terms of publication output, can be largely eliminated if the power laws are taken into account. While the very large US system leads with the highest relative citation impact scores in 70 of the 150 or so fields defined by the Institute for Scientific Information (ISI), this number is reduced to 16 when using the adjusted relative citation impact system. The UK, which previously led in 26 disciplines, leads in just 20 according to the adjusted relative citation impact system. Big winners are Germany and France which jump from 10 and 12 fields, respectively, to 35 each (table A.5).

Table A.5 Relative citation impact and adjusted relative citation impact

	World						Adjusted relative citation impact					
Field	*c/p*	U.S.	EU	UK	F	D	World	U.S.	EU	UK	F	D
Immunology	*6.83*	**1.30**	0.93	1.10	0.90	0.97	2.01	1.85	1.78	1.94	0.85	**2.16**
Neurosciences	*4.94*	1.16	1.00	**1.19**	1.03	0.92	1.33	1.06	1.28	**1.38**	1.04	1.30
Physics	*4.55*	**1.85**	1.17	1.20	1.44	1.37	1.23	**1.88**	1.40	1.43	1.36	1.67
Biochemistry & molecular biology	*7.51*	**1.31**	0.96	1.19	0.86	1.14	1.64	1.43	1.55	1.74	0.85	**2.01**

Source: DG Research
Data: ISI, Katz (2000)(treatments)

Third European Report on S&T Indicators, 2003

A significant change is visible when comparing the data by using the two systems, especially at the top of a ranking within the fields. In physics, countries such as the US, the UK, Germany and France drop in rank when the adjusted relative citation impact system is used, while countries such as Spain and Sweden rise considerably (table A.6).

The differences between the two calculation methods appear to be stronger the larger the publication size and number of citations. It seems to be a valid method which can be particularly helpful at the level of institutions, where funding decisions are often linked to performance measurements.

Table A.6 Relative citation impact and adjusted relative citation impact in the field of physics

Physics, ranked by					
relative citation impact			adjusted relative citation impact		
1	CH	1.89	1	CH	1.96
2	US	1.64	2	IS	1.63
3	IS	1.43	3	NL	1.57
4	NL	1.37	4	CA	1.35
5	UK	1.33	5	S	1.34
6	D	1.31	6	UK	1.21
7	CA	1.30	7	US	1.17
8	F	1.18	8	E	1.17
9	S	1.14	9	AU	1.16
10	I	1.13	10	D	1.07
11	E	1.09	11	F	1.03
12	AU	1.00	12	I	1.03
13	JP	0.97	13	PL	0.92
14	PL	0.87	14	JP	0.85
15	BR	0.66	15	BR	0.75
16	RU	0.66	16	IN	0.61
17	IN	0.59	17	RU	0.56
18	KR	0.48	18	KR	0.56
19	TW	0.39	19	TW	0.38
20	CN	0.38	20	CN	0.37

Source: DG Research
Data: ISI, Katz (2000)(treatments)

Third European Report on S&T Indicators, 2003

Glossary: Country abbreviations and groupings

By geographical areas

(Countries given without abbreviation do not appear in this Report as single countries)

Europe

EU-15 Member States: Belgium (B), Denmark (DK), Germany (D), Greece (EL), Spain (E), France (F), Ireland (IRL), Italy (I), Luxembourg (L), The Netherlands (NL), Austria (A), Portugal (P), Finland (FIN), Sweden (S), The United Kingdom (UK)

Candidate countries: Bulgaria (BG), Cyprus (CY), Czech Republic (CZ), Estonia (EE), Hungary (HU), Latvia (LV), Lithuania (LT), Malta (MT), Poland (PL), Romania (RO), Slovakia (SK), Slovenia (SI), Turkey (TR)

EFTA countries: Iceland (IS), Norway (NO), Switzerland (CH), Liechtenstein

Other Europe: The Russian Federation (RU), Ukraine (UA), Albania, Andorra, Armenia, Azerbaijan, Belarus, Bosnia and Herzegovina, Channel Islands, Croatia, Faeroe Islands, Georgia, Greenland, Isle of Man, Macedonia (Former Yugoslavian Republic of), Moldova, Monaco, San Marino, Serbia and Montenegro

America

North America: Canada (CA), Mexico (MX), The United States of America (US), Bermuda

South America: Argentina (AR), Brazil (BR), Chile (CL), Venezuela (VE), Bolivia, Colombia, Ecuador, Guyana, Paraguay, Peru, Suriname, Uruguay

Other America: Antigua and Barbuda, Aruba, Bahamas, Barbados, Belize, Cayman Islands, Costa Rica, Cuba, Dominica, Dominican Republic, El Salvador, Grenada, Guatemala, Haiti, Honduras, Jamaica, Netherlands Antilles, Nicaragua, Panama, Puerto Rico, St. Kitts and Nevis, St. Lucia, St. Vincent and the Grenadines, Trinidad and Tobago, Virgin Islands

Asia

South East Asia: China (CN), Indonesia (ID), Japan (JP), South Korea (KR), Malaysia (MY), The Philippines (PH), Singapore (SG), Thailand (TH), Taiwan (TW)

Other Asia: India (IN), Israel (IL), Pakistan (PK), Afghanistan, Bahrain, Bangladesh, Bhutan, Brunei, Cambodia, Iran (Islamic Republic), Iraq, Jordan, Kazakhstan, Kuwait, Kyrgyz Republic, Lao PDR, Lebanon, Macao, Maldives, Mongolia, Myanmar, Nepal, Oman, Qatar, Saudi Arabia, Sri Lanka, Syrian Arab Republic, Tajikistan, Turkmenistan, United Arab Emirates, Uzbekistan, Vietnam, West Bank and Gaza, Yemen (Republic)

Africa

South Africa (ZA), Algeria, Angola, Benin, Botswana, Burkina Faso, Burundi, the Cameroon, Cape Verde, Central African Republic, Chad, Comoros, Congo (Democratic Republic), Congo (Republic), Ivory Coast, Djibouti, Egypt (Arab Republic), Equatorial Guinea, Eritrea, Ethiopia, Gabon, the Gambia, Ghana, Guinea, Guinea-Bissau, Kenya, Lesotho, Liberia, Libya, Madagascar, Malawi, Mali, Mauritania, Mauritius, Mayotte, Morocco, Mozambique, Namibia, Niger, Nigeria, Rwanda, São Tomé and Principe, Senegal, Seychelles, Sierra Leone, Somalia, Sudan, Swaziland, Tanzania, Togo, Tunisia, Uganda, Zambia, Zimbabwe

Oceania

Australia (AU), New Zealand (NZ), American Samoa, Fiji, French Polynesia, Guam, Kiribati, Marshall Islands, Micronesia, New Caledonia, Northern Mariana Islands, Palau, Papua New Guinea, Samoa, Solomon Islands, Tonga, Vanuatu

By free trade or economic area

European Union (EU-15)

Belgium (B), Denmark (DK), Germany (D), Greece (EL), Spain (E), France (F), Ireland (IRL), Italy (I), Luxembourg (L), The Netherlands (NL), Austria (A), Portugal (P), Finland (FIN), Sweden (S), The United Kingdom (UK)

EU Candidate countries

Bulgaria (BG), Cyprus (CY), Czech Republic (CZ), Estonia (EE), Hungary (HU), Latvia (LV), Lithuania (LT), Malta (MT), Poland (PL), Romania (RO), Slovakia (SK), Slovenia (SI), Turkey (TR)

European Free Trade Association (EFTA)

Iceland (IS), Norway (NO), Switzerland (CH), Liechtenstein

North American Free Trade Association (NAFTA)

Canada (CA), Mexico (MX), The United States of America (US)

Developed Asian Countries (DAC)

Japan (JP), South Korea (KR), Singapore (SG), Taiwan (TW)

Association of South East Asian Nations (ASEAN-4)

Indonesia (ID), Malaysia (MY), The Philippines (PH), Thailand (TH)

GLOSSARY: OTHER ABBREVIATIONS AND ORGANISATIONS

ANBERD	Analytical BERD section the STAN data prepared by OECD
ANVAR	Agence Nationale pour la Valorisation de la Researche, France
ARCS	The Austrian Research Centre Siebersdorf
ASEAN	Association of South East Asian Nations
BAs	Business Angels
BECU	Billions of ECU
BE	Business Enterprise
BERD	Business enterprise expenditure on R&D
BMBF	Federal Ministry for Education and Research, Germany
BMC	Biomedical Centre, Lund
BRIC	Biotechnological Research and Innovation Centre, Copenhagen
CBSTII	Common Basis for Science, Technology and Innovation Indicators
CEA	French Atomic Energy Commission
CEC	Commission of the European Communities *(also referred to in the text as the European Commission and the Commission - senso stricto all three forms mentioned refer to the college of Commissioners rather than the services of the Commission, however, in most cases in this Report they three names mean the services of the Commission)*
CERN	European Council for Nuclear Research, Geneva, Switzerland
CESPRI	Centre for Research on Innovation and Internationalisation, University Bocconi, Milano, Italy
CIS	Community Innovation Survey
CISTP	Center for International Science and Technology Policy, The George Washington University, US
CLFS	Community Labour Force Survey
COM(xx)yyy	Official Commission document reference number
COST	European co-operation in the field of scientific and technical research
CREST	Committee on research, science and technology (which advises both the Commission and the Council of Ministers)
CSFs	Community Support Frameworks
CWTS	Centre for Science and Technology Studies, Leiden University, the Netherlands
DAC	Developed Asian Countries
DAE	Developed Asian Economies
DG	Directorate General (see below for further details)
DIMES	Delft Institute of Microelectronics and Submicron Technology, Delft, Netherlands
DSTI	OECD Directorate for Science, Technology and Industry
DTI	Department of Trade and Industry, UK
EC	European Community
ECU	European Currency Unit (precedent of the Euro)
EconLit	American Economic Association's electronic bibliography of economics literature
EDEP	Equally Distributed Equivalent Percentage
EEA	European Economic Area
EFTA	European Free Trade Association
EIB	European Investment Bank
EIF	European Investment Fund
EIT	Economies in Transition
EMBL	European Molecular Biology Laboratory, Heidelberg, Germany
EMBO	European Molecular Biology Organisation
EMEA	European Agency for the Evaluation of Medicinal Products
EMU	European Monetary Union
EP	European Parliament
EPO	European Patent Office (also abbrev. as EPAT)
ERA	European Research Area
ERDF	European Regional Development Funds
ESA	European Space Agency
ESF	European Science Foundation
ETAN	European Technology Assessment Network
ETH	Swiss Federal Institute of Technology
EU	European Union
EU-12	the 12 members of the European Union immediately prior to 1995 taken as a whole
EU-15	the 15 members of the European Union post 1995 taken as a whole
EUR xxxx yy	Official reference number for document published by the European Commission
EUROSTAT	Statistical Office of the European Communities
EVCA	European Venture Capital Association
FAO	Food and Agriculture Organisation of the United Nations
FCS	Field citation score
FDI	Foreign direct investment
FDA	Food and Drug Administration, US

FP1	First Framework Programme for Research, Development and Demonstration Activities (1984 - 1987)
FP2	2nd Framework Programme for Research and Technological Development (1987-1991)
FP3	3rd Framework Programme for Research and Technological Development (1990 - 1994)
FP4	4th Framework Programme for Research and Technological Development and Demonstration (1994 - 1998)
FP5	5th Framework Programme for Research, Technological Development and Demonstration (1998 - 2002)
FP6	6th Framework Programme for Research, Technological Development and Demonstration (2002-2006)
Fraunhofer-ISI	Fraunhofer Institute for Systems and Innovation Research, Karlsruhe, Germany
FTE	Full-time equivalent
FZK	Forschungszentrum, Karslsruhe, Germany
GBAORD	Total government budget appropriations or outlays for R&D
GDP	Gross domestic product
GEM	Gender Empowerment Measure
GERD	Gross domestic expenditure on R&D
GOV	Government institutions
GOVERD	Government intramural expenditure on R&D
GNP	Gross national product
GSI	Gender Segregation Index
GUF	General University Funds
HC	Head count
HE	Higher education
HEFCE	Higher Education Funding Council, UK
HERD	Higher education expenditure on R&D
HES	Higher education sector
HRST	Human resources in science and technology (Eurostat and Canberra manual)
HRSTC	HRST core
HRSTE	HRST educated
HRSTO	HRST occupied
HRSTU	HRST unemployed
i2i	Innovation 2000 Initiative, a programme of the EIB
IAS	International Accounting Standards
ICT	Information and Communication Technologies
ID	Index of Dissimilarity
IET	Institute for Territorial Studies, Barcelona, Spain
IKERLAN	A private co-operative, Spain
ILO	International Labour Organisation
IMF	International Monetary Fund
INCENTIM	International Centre for Research on Entrepreneurship, Technology and Innovation Management, KUL, Leuven, Belgium
INPI	National Institute for Intellectual Property, France
INRA	National Institute for Agricultural Research, France
IPC	International Patent Classification
IPR	Intellectual Property Rights
IPO	Initial Public Offering
IRDAC	Industrial R&D Advisory Committee, European Commission
ISCED	International Standard Classification for Education
ISCO	International Standard Classification of Occupations
ISDB	International Sectoral Database (OECD)
ISI	Institute for Scientific Information, Philadelphia
ISIC	International Standard Industrial Classification
IT	Information Technology
IWT	Flemish Institute for Applied Research and Innovation
JCS	Journal citation score
JPO	Japanese Patent Office
JST	Science and Technology Corporation, Japan
KIBs	Knowledge Intensive Business Services
KTH	Royal Institute of Technology, Sweden
KUL	Catholic University of Leuven, Belgium
LFS	Labour Force Survey
LMU	Ludwigs-Maximilians Universität, Munich, Germany
LNP	LINK Nanotechnology Programme, UK
M&As	Mergers and Acquisitions
MAP	Multiannual Programme for Enterprises and Enterpreneurship
MECU	million ECU
MERIT	Maastricht Economic Research Institute on Innovation and Technology
MITI	Ministry of International Trade and Industry, now called METI, Japan
Monbusho	Ministry of Education, now called MEXT, Japan
MSTI	Main Science and Technology Indicators, OECD
NABS	Nomenclature for the Analysis and Comparison of Scientific Programmes and Budgets
NACE	General industrial classification of economic activities within the EC
NAFTA	North American Free Trade Area
NASA	National Aeronautics and Space Administration
NATO	North Atlantic Treaty Organisation
NCS	Nobel Centennial Symposia

NCRA-RJV	National Co-operative Research Act – Research Joint Ventures database, US
NIH	National Institute of Health, US
NION	National Initiative on Nanotechnology, UK
NIST	National Institute of Standards and Technology, US
NISTEP	National Institute of Science and Technology, Japan
NPL	Non-patent literature
NPRs	Non-patent references
NS	Nobel Symposia
NSB	National Science Board, US
NSF	National Science Foundation, US
NTBFs	New Technology Based Firms
NUTS	Nomenclature of Territorial Units for Statistics
NVCA	National Venture Capital Association
OECD	Organisation for Economic Co-operation and Development
OJ	Official Journal of the European Communities
OST	Observatoire des Sciences et des Techniques, Paris
OTA	Office of Technology Assessment, US
PCT	Patent Cooperation Treaty (also abbrev. as PCTPAT)
PhD	Doctorate of Philosophy degree
PISA	Programme for international student assessment (OECD)
PLT	Permanent and long-term
PPP	Purchasing power parities
PPS	Purchasing power standards
R&D	Research and development
RAE	Research Assessment Exercise
RJVs	Research Joint Ventures
RLA	Revealed Literature Advantage
RPA	Revealed Patent Advantage
RS	Relative specialisation (index)
RSE	Research scientists and engineers
RTD	Research and technological development
S&E	Science and engineering
S&T	Science and technology
SCI	Science Citation Index of ISI
SMEs	Small and medium sized enterprises
SITC Rev.3	Standard International Trade Classification, third revision
SPRU	Science and Technology Policy Research Unit, University of Sussex, Brighton, UK
SSAP	Statements of Standard Accounting Practice
STA	Science and Technology Agency, now called MEXT, Japan
STAN	OECD structural analysis programme and database
STI	Science and technology indicators
STOA	Scientific and technical options assessment programme of the European Parliament
STS	Scientific and technical services
TBP	Technology balance of payments
TIMMS	Third International Mathematics and Science Study
TM	Technology Management Faculty, University of Eindhoven, Netherlands
ULB	Free University of Brussels (French speaking), Belgium
USPTO	US Patent Office and Trademark Office
UN	United Nations Organisation
UNCTAD	United Nations Conference on Trade and Development
UNDP	United Nations Development Programme
UNESCO	United Nations Education, Scientific and Cultural Organisation
UNEP	United Nations Environment Programme
UNIDO	United Nations Industrial Development Organisation
WHO	World Health Organisation
WIS	Women in Science
WIPO	World Intellectual Property Organization
WTO	World Trade Organisation

Symbols used in this Report

:	no data available
-	zero
0	less 0.5 unit

Commission Services

Policies
Agriculture
Competition
Economic and Financial Affairs
Education and Culture
Employment and Social Affairs
Energy and Transport
Enterprise
Environment
Fisheries
Health and Consumer Protection
Information Society
Internal Market
Joint Research Centre
Justice and Home Affairs
Regional Policy
Research
Taxation and Custom Union

External relations
Development
Enlargement
EuropeAid - Co-operation Office
External relations
Humanitarian Aid Office
Trade

General Services
European Anti-Fraud Office
European Communities Personnel Selection Office
Publications Office
Press and Communication
Secretariat General

Internal Services
Budget
Financial Control
Group of policy advisers
Internal Audit Service
Joint Interpreting and Conference Service
Legal Service
Office for administration and payment of individual entitlements
Office for infrastructures and logistics – Brussels
Office for infrastructures and logistics – Luxembourg
Personnel and Administration
Translation Service

List of major studies under Common Basis for Science, Technology and Innovaton Indicators (CBSTII)

Project	Contractor	Start Date	End Date
Bilateral International R&D co-operation policies of the European Union Members States	Technopolis Limited (Brighton, UK)	23/12/1999	22/8/2000
Patents in the service industries	Fraunhofer-ISI (Karlsruhe, D)	23/12/1999	22/12/2002
Intergovernmental S&T co-operation in Europe	Technopolis Limited (Brighton, UK)	23/2/2000	22/10/2000
Development of bibliometric and patent indicators by gender	Biosoft (Balsamo, I)	23/2/2000	22/6/2001
Linking science to technology – bibliographic references in patents	Incentim (KUL, B)	23/2/2000	22/2/2002
Mergers and Acquisitions (M&A) and science and technology policy	Idea Consult (Brussels, B)	23/2/2000	22/2/2002
The brain drain – emigration flows for qualified scientists	MERIT (Universiteit Maastricht, NL)	23/2/2000	22/5/2002
Comparative analysis of public, semi public and recently privatised research centres	PREST (Victoria University of Manchester, UK)	8/3/2000	7/10/2001
Evolution of national public R&D policies in the European Union Members States	Pricewatherhouse Coopers Europe	8/3/2000	7/11/2001
International benchmark of biotech research centres	SPRU (University of Sussex, Brighton, UK)	8/3/2000	7/4/2002

List of major research contracts under Common Basis for Science, Technology and Innovaton Indicators (CBSTII)

Project	Contractor	Start Date	End Date
Network indicators: science, technology and innovation	CESPRI, Università Bocconi, Milano, I) +CWTS (Universiteit Leiden, NL) +MERIT (Universiteit Maastricht, NL)	1/2/2002	31/7/2004
Centres of European scientific excellence in industrial relevant research areas	CWTS (Universiteit Leiden, the Netherlands) +INCENTIM (Katholieke Universiteit Leuven, Belgium)	1/1/2002	1/1/2004
Development of a concordance between technology and industry classifications	Fraunhofer-ISI (Karlsruhe, Germany) +OST (Paris, France) +SPRU (University of Sussex, Brighton, UK)	1/1/2002	31/3/2003
The value of European patents: empirical models and policy implications based on a survey of European inventors	Scuola Superiore Sant'Anna (Pisa, I) +LMU (Munich, D) +IET (Barcelona, E) +SPRU (University of Sussex, Brighton, UK) +TU (Eindhoven, NL) +Centre Walras (Lyon, F)	1/1/2002	31/7/2004
Web Indicators for scientific, technological and innovation research	Royal Netherlands Academy of Arts and Science (Amsterdam, NL) + SPRU (University of Sussex, Brighton, UK) + CSIC (Madrid, E) + University of Wolverhampton (UK)	1/11/2002	30/11/2005
The structure of innovation and economic performance	University of Urbino (I) + University of Oslo (NO) + Fraunhofer-ISI (Karlsruhe, D) + TMCC (Eindhoven, NL)	1/12/2002	31/7/2004
Direct indicators for commercialisation of research	University of Ghent (B) + ARMINES (Paris, F) + University of Nottingham (UK) + Scuola Superiore Sant'Anna (Pisa, I) + Centre for European Economic Research (Mannheim, D) + GKI Economic Research (Budapest, HU) + Halmstad University (S) + Ecole de Mines (Paris, F)	1/1/2003	30/6/2005

European Commission

EUR 20025 — Third European Report on Science & Technology Indicators

Luxembourg: Office for Official Publications of the European Communities

2003 — XVII, 451 pp. — A4: 21,0 x 29,7 cm

ISBN 92-894-1795-1

Price (excluding VAT) in Luxembourg: € 77 (1 volume)

Venta • Salg • Verkauf • Πωλήσεις • Sales • Vente • Vendita • Verkoop • Venda • Myynti • Försäljning
http://eur-op.eu.int/general/en/s-ad.htm

BELGIQUE/BELGIË

Jean De Lannoy
Avenue du Roi 202/Koningslaan 202
B-1190 Bruxelles/Brussel
Tél. (32-2) 538 43 08
Fax (32-2) 538 08 41
E-mail: jean.de.lannoy@infoboard.be
URL: http://www.jean-de-lannoy.be

La librairie européenne/ De Europese Boekhandel
Rue de la Loi 244/Wetstraat 244
B-1040 Bruxelles/Brussel
Tél. (32-2) 295 26 39
Fax (32-2) 735 08 60
E-mail: mail@libeurop.be
URL: http://www.libeurop.be

Moniteur belge/Belgisch Staatsblad
Rue de Louvain 40-42/Leuvenseweg 40-42
B-1000 Bruxelles/Brussel
Tél. (32-2) 552 22 11
Fax (32-2) 511 01 84
E-mail: eusales@just.fgov.be

DANMARK

J. H. Schultz Information A/S
Herstedvang 12
DK-2620 Albertslund
Tlf. (45) 43 63 23 00
Fax (45) 43 63 19 69
E-mail: schultz@schultz.dk
URL: http://www.schultz.dk

DEUTSCHLAND

Bundesanzeiger Verlag GmbH
Vertriebsabteilung
Amsterdamer Straße 192
D-50735 Köln
Tel. (49-221) 97 66 80
Fax (49-221) 97 66 82 78
E-Mail: vertrieb@bundesanzeiger.de
URL: http://www.bundesanzeiger.de

ΕΛΛΑΔΑ/GREECE

G. C. Eleftheroudakis SA
International Bookstore
Panepistimiou 17
GR-10564 Athina
Tel. (30-1) 331 41 80/1/2/3/4/5
Fax (30-1) 325 84 99
E-mail: elebooks@netor.gr
URL: elebooks@hellasnet.gr

ESPAÑA

Boletín Oficial del Estado
Trafalgar, 27
E-28071 Madrid
Tel. (34) 915 38 21 11 (libros)
913 84 17 15 (suscripción)
Fax (34) 915 38 21 21 (libros),
913 84 17 14 (suscripción)
E-mail: clientes@com.boe.es
URL: http://www.boe.es

Mundi Prensa Libros, SA
Castelló, 37
E-28001 Madrid
Tel. (34) 914 36 37 00
Fax (34) 915 75 39 98
E-mail: libreria@mundiprensa.es
URL: http://www.mundiprensa.com

FRANCE

Journal officiel
Service des publications des CE
26, rue Desaix
F-75727 Paris Cedex 15
Tél. (33) 140 58 77 31
Fax (33) 140 58 77 00
E-mail: europublications@journal-officiel.gouv.fr
URL: http://www.journal-officiel.gouv.fr

IRELAND

Alan Hanna's Bookshop
270 Lower Rathmines Road
Dublin 6
Tel. (353-1) 496 73 98
Fax (353-1) 496 02 28
E-mail: hannas@iol.ie

ITALIA

Licosa SpA
Via Duca di Calabria, 1/1
Casella postale 552
I-50125 Firenze
Tel. (39) 055 64 83 1
Fax (39) 055 64 12 57
E-mail: licosa@licosa.com
URL: http://www.licosa.com

LUXEMBOURG

Messageries du livre SARL
5, rue Raiffeisen
L-2411 Luxembourg
Tél. (352) 40 10 20
Fax (352) 49 06 61
E-mail: mail@mdl.lu
URL: http://www.mdl.lu

NEDERLAND

SDU Servicecentrum Uitgevers
Christoffel Plantijnstraat 2
Postbus 20014
2500 EA Den Haag
Tel. (31-70) 378 98 80
Fax (31-70) 378 97 83
E-mail: sdu@sdu.nl
URL: http://www.sdu.nl

PORTUGAL

Distribuidora de Livros Bertrand Ld.ª
Grupo Bertrand, SA
Rua das Terras dos Vales, 4-A
Apartado 60037
P-2700 Amadora
Tel. (351) 214 95 87 87
Fax (351) 214 96 02 55
E-mail: dlb@ip.pt

Imprensa Nacional-Casa da Moeda, SA
Sector de Publicações Oficiais
Rua da Escola Politécnica, 135
P-1250-100 Lisboa Codex
Tel. (351) 213 94 57 00
Fax (351) 213 94 57 50
E-mail: spoce@incm.pt
URL: http://www.incm.pt

SUOMI/FINLAND

Akateeminen Kirjakauppa/ Akademiska Bokhandeln
Keskuskatu 1/Centralgatan 1
PL/PB 128
FIN-00101 Helsinki/Helsingfors
P./tfn (358-9) 121 44 18
F./fax (358-9) 121 44 35
Sähköposti: sps@akateeminen.com
URL: http://www.akateeminen.com

SVERIGE

BTJ AB
Traktorvägen 11-13
S-221 82 Lund
Tlf. (46-46) 18 00 00
Fax (46-46) 30 79 47
E-post: btjeu-pub@btj.se
URL: http://www.btj.se

UNITED KINGDOM

The Stationery Office Ltd
Customer Services
PO Box 29
Norwich NR3 1GN
Tel. (44) 870 60 05-522
Fax (44) 870 60 05-533
E-mail: book.orders@theso.co.uk
URL: http://www.itsofficial.net

ÍSLAND

Bokabud Larusar Blöndal
Skólavördustig, 2
IS-101 Reykjavik
Tel. (354) 552 55 40
Fax (354) 552 55 60
E-mail: bokabud@simnet.is

SCHWEIZ/SUISSE/SVIZZERA

Euro Info Center Schweiz
c/o OSEC Business Network Switzerland
Stampfenbachstraße 85
PF 492
CH-8035 Zürich
Tel. (41-1) 365 53 15
Fax (41-1) 365 54 11
E-mail: eics@osec.ch
URL: http://www.osec.ch/eics

BĂLGARIJA

Europress Euromedia Ltd
59, blvd Vitosha
BG-1000 Sofia
Tel. (359-2) 980 37 66
Fax (359-2) 980 42 30
E-mail: Milena@mbox.cit.bg
URL: http://www.europress.bg

CYPRUS

Cyprus Chamber of Commerce and Industry
PO Box 21455
CY-1509 Nicosia
Tel. (357-2) 88 97 52
Fax (357-2) 66 10 44
E-mail: demetrap@ccci.org.cy

EESTI

Eesti Kaubandus-Tööstuskoda
(Estonian Chamber of Commerce and Industry)
Toom-Kooli 17
EE-10130 Tallinn
Tel. (372) 646 02 44
Fax (372) 646 02 45
E-mail: einfo@koda.ee
URL: http://www.koda.ee

HRVATSKA

Mediatrade Ltd
Pavla Hatza 1
HR-10000 Zagreb
Tel. (385-1) 481 94 11
Fax (385-1) 481 94 11

MAGYARORSZÁG

Euro Info Service
Szt. István krt.12
III emelet 1/A
PO Box 1039
H-1137 Budapest
Tel. (36-1) 329 21 70
Fax (36-1) 349 20 53
E-mail: euroinfo@euroinfo.hu
URL: http://www.euroinfo.hu

MALTA

Miller Distributors Ltd
Malta International Airport
PO Box 25
Luqa LQA 05
Tel. (356) 66 44 88
Fax (356) 67 67 99
E-mail: gwirth@usa.net

NORGE

Swets Blackwell AS
Hans Nielsen Hauges gt. 39
Boks 4901 Nydalen
N-0423 Oslo
Tel. (47) 23 40 00 00
Fax (47) 23 40 00 01
E-mail: info@no.swetsblackwell.com
URL: http://www.swetsblackwell.com.no

POLSKA

Ars Polona
Krakowskie Przedmiescie 7
Skr. pocztowa 1001
PL-00-950 Warszawa
Tel. (48-22) 826 12 01
Fax (48-22) 826 62 40
E-mail: books119@arspolona.com.pl

ROMÂNIA

Euromedia
Str.Dionisie Lupu nr. 65, sector 1
RO-70184 Bucuresti
Tel. (40-1) 315 44 03
Fax (40-1) 312 96 46
E-mail: euromedia@mailcity.com

SLOVAKIA

Centrum VTI SR
Nám. Slobody, 19
SK-81223 Bratislava
Tel. (421-7) 54 41 83 64
Fax (421-7) 54 41 83 64
E-mail: europ@tbb1.sltk.stuba.sk
URL: http://www.sltk.stuba.sk

SLOVENIJA

GV Zalozba
Dunajska cesta 5
SLO-1000 Ljubljana
Tel. (386) 613 09 1804
Fax (386) 613 09 1805
E-mail: europ@gvestnik.si
URL: http://www.gvzalozba.si

TÜRKIYE

Dünya Infotel AS
100, Yil Mahallessi 34440
TR-80050 Bagcilar-Istanbul
Tel. (90-212) 629 46 89
Fax (90-212) 629 46 27
E-mail: aktuel.info@dunya.com

ARGENTINA

World Publications SA
Av. Cordoba 1877
C1120 AAA Buenos Aires
Tel. (54-11) 48 15 81 56
Fax (54-11) 48 15 81 56
E-mail: wpbooks@infovia.com.ar
URL: http://www.wpbooks.com.ar

AUSTRALIA

Hunter Publications
PO Box 404
Abbotsford, Victoria 3067
Tel. (61-3) 94 17 53 61
Fax (61-3) 94 19 71 54
E-mail: jpdavies@ozemail.com.au

BRESIL

Livraria Camões
Rua Bittencourt da Silva, 12 C
CEP
20043-900 Rio de Janeiro
Tel. (55-21) 262 47 76
Fax (55-21) 262 47 76
E-mail: livraria.camoes@incm.com.br
URL: http://www.incm.com.br

CANADA

Les éditions La Liberté Inc.
3020, chemin Sainte-Foy
Sainte-Foy, Québec G1X 3V6
Tel. (1-418) 658 37 63
Fax (1-800) 567 54 49
E-mail: liberte@mediom.qc.ca

Renouf Publishing Co. Ltd
5369 Chemin Canotek Road, Unit 1
Ottawa, Ontario K1J 9J3
Tel. (1-613) 745 26 65
Fax (1-613) 745 76 60
E-mail: order.dept@renoufbooks.com
URL: http://www.renoufbooks.com

EGYPT

The Middle East Observer
41 Sherif Street
Cairo
Tel. (20-2) 392 69 19
Fax (20-2) 393 97 32
E-mail: inquiry@meobserver.com
URL: http://www.meobserver.com.eg

MALAYSIA

EBIC Malaysia
Suite 45.02, Level 45
Plaza MBf (Letter Box 45)
8 Jalan Yap Kwan Seng
50450 Kuala Lumpur
Tel. (60-3) 21 62 92 98
Fax (60-3) 21 62 61 98
E-mail: ebic@tm.net.my

MÉXICO

Mundi Prensa México, SA de CV
Río Pánuco, 141
Colonia Cuauhtémoc
MX-06500 México, DF
Tel. (52-5) 533 56 58
Fax (52-5) 514 67 99
E-mail: 101545.2361@compuserve.com

SOUTH AFRICA

Eurochamber of Commerce in South Africa
PO Box 781738
2146 Sandton
Tel. (27-11) 884 39 52
Fax (27-11) 883 55 73
E-mail: info@eurochamber.co.za

SOUTH KOREA

The European Union Chamber of Commerce in Korea
5th Fl, The Shilla Hotel
202, Jangchung-dong 2 Ga, Chung-ku
Seoul 100-392
Tel. (82-2) 22 53-5631/4
Fax (82-2) 22 53-5635/6
E-mail: eucck@eucck.org
URL: http://www.eucck.org

SRI LANKA

EBIC Sri Lanka
Trans Asia Hotel
115 Sir Chittampalam
A. Gardiner Mawatha
Colombo 2
Tel. (94-1) 074 71 50 78
Fax (94-1) 44 87 79
E-mail: ebicsl@slnet.ik

T'AI-WAN

Tycoon Information Inc
PO Box 81-466
105 Taipei
Tel. (886-2) 87 12 88 86
Fax (886-2) 87 12 47 47
E-mail: euitupe@ms21.hinet.net

UNITED STATES OF AMERICA

Bernan Associates
4611-F Assembly Drive
Lanham MD 20706-4391
Tel. (1-800) 274 44 47 (toll free telephone)
Fax (1-800) 865 34 50 (toll free fax)
E-mail: query@bernan.com
URL: http://www.bernan.com

ANDERE LÄNDER
OTHER COUNTRIES
AUTRES PAYS

Bitte wenden Sie sich an ein Büro Ihrer Wahl/Please contact the sales office of your choice/Veuillez vous adresser au bureau de vente de votre choix
Office for Official Publications of the European Communities
2, rue Mercier
L-2985 Luxembourg
Tel. (352) 29 29-42455
Fax (352) 29 29-42758
E-mail: info-info-opoce@cec.eu.int
URL: publications.eu.int

15

KI-NA-20-025-EN-C

The Third European Report on Science and Technology Indicators presents a quantitative picture of where the European Union stands in relation to research and innovation at the start of the 21st century. With more than 450 pages of graphs, tables and comparative analyses, the Report relates current trends in European S&T to recent policy developments at the EU level and in the Member States, and compares the European Union's performance with that of its main partners. The primary focus of the Report is on Europe's transition to the knowledge-based economy. Part I of the Report examines EU investment in knowledge production, dissemination and absorption using an array of indicators including R&D expenditures, venture capital, education and human resources. Part II goes on to look at the "output" side in terms of Europe's performance in knowledge production, exploitation and commercialisation, where the indicators analysed include scientific publications, citations, Nobel prizes, patents, high tech trade and measures of science technology linkage.

Price (excluding VAT) in Luxembourg: € 77 (1 volume)

Amt für Veröffentlichungen

Publications.eu.int

ISBN 92-894-1795-1

9 789289 417952