KEY FIGURES 2007 ON SCIENCE, TECHNOLOGY AND INNOVATION

TOWARDS A EUROPEAN KNOWLEDGE AREA

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Highlights

THE DIMINISHING WEIGHT OF EUROPE IN THE MULTI-POLAR WORLD OF SCIENCE AND TECHNOLOGY, AND ITS IMPLICATIONS FOR RESEARCH STRATEGIES

Two main trends justify policy action

The EU is at a crossroads, where only decisive policy actions will ensure that the route towards increased long-term economic growth and prosperity is the one that is followed. In particular two trends can be identified which make such policy actions necessary.

One the one hand, the EU suffers from a structural growth handicap

On the one hand, in spite of recent optimistic prospects for EU economic growth in 2007 and 2008, there is evidence that the EU suffers from a structural growth handicap. Since the mid-1990s the EU has no longer been catching-up with the US in terms of productivity. Indeed, the EU's labour productivity growth rate has fallen below that of the US for the first time since the end of World War II. This probably reflects an under-performance in the creation, diffusion, and utilisation of new knowledge over recent years.

On the other hand, a multi-polar world is arising, with new competitors and more evenly distributed sources of competitiveness …

On the other hand, with the rapid rise of -mainly Asian- newly emerging economies, a 'multi-polar world' is developing in which the sources of competitiveness such as technology and human capital are more evenly distributed than ever before. The EU represents a diminishing share of worldwide population, GDP and R&D investments (EU-27 accounts for 25% of global R&D expenditure compared with 29% ten years ago), and newly emerging economies are no longer competing on the basis of low-cost activities only. China is about to overtake the EU in terms of world share in exports of high-tech products. Since 2003, China has become the world's main exporter of computers. Regarding electronics and telecom, China has been ahead of the EU since 2004, and will probably overtake the US in 2007. Moreover, the increasing importance of newly emerging countries in globalised R&D is not only due to their rapid economic development and rising share in world GDP, but is also due to substantial increases in their R&D intensity (R&D expenditure as percentage of GDP).

… such as R&D, which is increasingly conducted outside the Triad

One of the most visible features of the new, multi-polar world is the internationalisation of R&D beyond the traditional borders of the Triad. This more global focus for R&D spending can be seen in the increasing diversification of the US's own outward R&D investment. US firms are targeting all major regions of the world and especially Asia, with the result that the EU's share in total US outward R&D spending has been decreasing significantly since the mid-nineties. This trend is expected to continue as the new, emerging market players continue to build up their science and technology systems and to open up their markets to foreign entrants. As a result, newly emerging economies such as China and South Korea already represent a non-negligible share of high-tech patent applications at the European Patent Office (in 2003, these two countries were responsible for 11% of EPO patent applications in 'Communication technology', and 5.5% in 'Semiconductors').

The EU therefore needs to increase the attractiveness of the European Research Area and to better capitalise on foreign knowledge development

The EU therefore needs to respond to the challenges and make the most of the opportunities provided by the new international division of labour. In particular, it has to take the necessary steps to increase substantially the efficiency and attractiveness of its internal, European Research Area, in order to remain an important location for internationally mobile R&D investments. Given this new international distribution of knowledge creation, Europe also needs to be in a better position to capitalise on foreign knowledge development.

TRANSITION TOWARDS KNOWLEDGE-INTENSIVE ECONOMIES: THE NEED TO INTENSIFY THE PACE OF LISBON-DRIVEN REFORMS

Member States increasingly consider R&D as a key policy priority, and take action to increase R&D intensity …

A common policy trend across EU Member States concerns the important place of R&D and R&D investment in the overall policy agendas. Under the influence of the Lisbon strategy (2000), the Barcelona '3%' objective (2002) for more investment in research in Europe (with increased private sector funding) and the renewed Lisbon strategy (2005), R&D is increasingly considered a key source for sustaining economic growth and welfare. Member States are developing commonly shared R&D policy objectives: recently, and consequent to the renewed Lisbon strategy in mid-2005, 26 Member States have set targets for their R&D intensities (i.e. R&D expenditure as percentage of GDP - each target is not necessarily 3%) for 2010 or other years. Bulgaria is the only Member State which does not have a target. If the Member States reach their objectives, the overall EU R&D intensity will have increased substantially to around 2.6% in 2010.

… but the EU as a whole, as well as most of its Member States are not yet on track to meet their targets

Recent evidence on trends up to 2005 shows, however, that the EU is not yet on track to meet these targets. Only a small number of Member States (Austria, Denmark, Ireland, Germany and Finland) have over recent years experienced rates of growth which, if they are maintained, would be sufficient to advance these countries significantly towards their targets. A larger group of countries has experienced a positive average rate of growth since 2000, but will need to step up its efforts significantly if it is to deliver on the level of ambition reflected in these targets. An equally large group of countries has experienced a negative average rate of growth over the past five years and will therefore need to reverse a declining trend if it is to start progressing towards these targets. For these countries, the targets set are extremely ambitious: delivering on the ambition reflected in them will require strong commitment and radical reform packages.

Turning to the aggregate picture, EU R&D intensity, after a period of slow but continued growth between the mid-nineties and 2001, stagnated in 2001-2002 and even decreased slightly after that. In 2005, only 1.84% of GDP was spent on R&D in EU-27. If the current -negative- trend continues, by 2010 Europe's R&D intensity will have declined to its mid-nineties level of less than 1.80% of GDP.

If the current -negative- trend continues, by 2010 EU-27 R&D intensity will have fallen further behind, back to its mid-nineties level of less than 1.80% of GDP

As a result, R&D intensity in EU-27 remains at a lower level than in most of the other major world economies such as the US, Japan and South Korea. In these countries, and in spite of some minor, short-term fluctuations, the trend over the past decade has been much more positive, outpacing Europe's performance in R&D intensity growth. The R&D intensity gap with our main competitors has, therefore, not been reduced at all.

As a result, R&D intensity in EU-27 remains at a l lower level than in most other major world economies …

Moreover, new emerging economies such as China are rapidly catching-up. If current trends persist, it is expected that China will have caught up with the EU by 2009 in terms of R&D intensity. The Russian Federation has also increased its allocation of resources to R&D at a much faster pace than the EU since the mid-1990s.

… and new, emerging players will soon catch up with the EU

These recent trends show that the commitments made by (almost) all Member States in mid-2005 to increase their R&D intensities significantly up to country-specific targets, were more than appropriate. The fact that, on the whole, no significant progress has yet been made should encourage the Member States to intensify and/or deepen the pace of Lisbon–driven reforms.

The commitments made by Member States to increase R&D-intensity are therefore more than ever valid but should be reflected by intensifying the pace of reforms

THE NATURE AND DYNAMICS OF THE EU'S INDUSTRIAL STRUCTURE IS THE REASON FOR THE R&D INVESTMENT DEFICIT WITH THE US

More than 85% of the R&D intensity gap between EU-27 and its main competitors is caused by differences in the contributions from the business enterprise sector to the financing of R&D. Therefore, European Heads of State decided at the Barcelona Summit of March 2002 to increase not only the overall proportion of GDP devoted to R&D, but also to improve the private sector contribution to its financing. In particular they set the target of increasing the share of R&D expenditure funded by the business enterprise sector to two-thirds by 2010.

More than 85% of the R&D intensity gap between EU-27 and its main competitors is caused by lower contributions from business sector to the financing of R&D

Despite increased policy attention, the private

Moreover, the

sector contribution to the financing of R&D has not increased substantially over the past 10 years in the EU. R&D financed by the business sector remained at around 1% of GDP in the EU, without any noticeable variation over the decade. In 2004, the private sector financed 64% of total R&D in the US, 67% in China and 75% in both Japan and South Korea, but only 55% in the EU. In the US, despite a trend reversal in 2001-2002 in privately funded R&D, the trend over the past decade is clearly positive. In China too (and to a lesser extent also in Japan), the private sector has increased its involvement in the financing of R&D at a much faster pace than in the EU. Moreover, since 2000, the private sector contribution to the financing of R&D has even been decreasing in the EU.

private sector contribution has not increased substantially over the past decade. It has even been decreasing since 2000

Because of the importance of business-funded R&D in explaining the EU's R&D deficit, the report takes a closer look at business sector R&D. In spite of comparability problems between the EU and the US regarding the share of services in total business R&D, it can be estimated that at least three quarters of business R&D is performed by manufacturing industries in both regions.

At least 75% of business R&D is performed by the manufacturing industries

In the US, manufacturing R&D is more concentrated in high-tech industries than in the EU. In 2003, 55% of total manufacturing R&D in the EU and 70% in the US was carried out in high-tech industries. European industrial R&D is more likely to be concentrated in medium-high-tech manufacturing.

In the US, manufacturing R&D is more concentrated in high-tech industries …

The reason behind this different distribution of manufacturing R&D is not a lower 'industry-specific' R&D intensity in the EU. High-tech, medium-high-tech and medium-low-tech manufacturing industries appear to have very similar R&D intensities in both the EU and the US (even identical in the case of medium-high-tech and medium-low-tech industries).

… although high-tech industries in the EU are as R&D intensive as in the US

Therefore, the higher concentration of business R&D in high-tech manufacturing industries in the US largely emanates from differences in industrial structure between the EU and the US. In the US, high-tech industries account for a much larger share of both industrial value added and GDP than in the EU. In the US, high-tech manufacturing industries represent 28% of industrial value added (3.7% of GDP) compared with 19% (3.1% of GDP) in the EU. Conversely, medium-high-tech industries in the EU account for 24% of industrial value added (3.8% of GDP) compared with 19% (2.6% of GDP) in the US. In the EU, the industrial texture is more concentrated on medium-high-tech, medium-low-tech and low-tech activities

The higher concentration of R&D activities in high-tech industry in the US largely emanates from differences in industrial structure (i.e. high-tech industry larger in the US)

Examining differences within high-tech industries between the EU and the US, it appears that ICT manufacturing industries

ICT manufacturing industries explain almost the entire EU explain almost the entire R&D funding gap between the EU and the US, not necessarily because they tend to be more R&D intensive in the US, but mainly because of their larger size.

R&D funding deficit, mainly because of their larger size in the US

Similarly, the higher concentration of R&D expenditure in medium-tech industries in the EU is primarily caused by two sectors: 'Machinery and equipment' and, to a lesser extent, 'Electrical machinery and apparatus'. These two sectors have similar R&D intensities on both sides of the Atlantic, but they are twice as big in the EU as in the US. Here again, structural differences and the larger size of the industrial sectors seem to account for the largest part of the differences between the EU and the US.

Similarly, the higher concentration of R&D in medium-tech industries in the EU is mainly explained by structural differences

SME's represent a higher share of total business R&D expenditure in the EU than in the US. However, after adjusting for differences in industrial structure between the EU and the US (i.e. correcting for the higher share of SME's in GDP in the EU than in the US), it appears that the situation of European SMEs vis-à-vis their American counterparts regarding average R&D intensity does not significantly differ from the situation of larger companies. In other words, from a static point of view, there is no *SME-specific* R&D intensity deficit.

From a static point of view, there is no 'SME specific' R&D intensity deficit

SME's, however, can grow and become major, critical players in their sector. Therefore, differences in industrial structure have an important dynamic component to be considered: 22% of the US companies which are now in the world top 1000 in terms of market capitalization were created after 1980, compared with only 5% of their European counterparts. Of those US companies which were created after 1980 and are now in the world top 1000, 70% are IT companies. These figures reflect the fact that, in the US more so than in the EU, many new, R&D-intensive firms, active in high-tech industries were able to develop, grow rapidly and become key economic players. The lack of a similar dynamic in the EU plays a significant role in the EU/US R&D investment deficit.

From a dynamic point of view, the growth path of SME's is crucial: the lack of rapidly growing SME's in the EU plays a significant role in the EU-US R&D investment deficit

THE IMPORTANT ROLE OF THE PUBLIC SECTOR

Although domestic R&D efforts are largely financed by the business enterprise sector in the EU and the US, the role of government in the financing of R&D should not be underestimated. High R&D-intensive countries such as Finland, Sweden, Denmark, Austria, Germany, the United Kingdom, the US or Japan are characterised by a high level of involvement from the private sector in the funding of their R&D activities. In these countries, however, the level of government-funded R&D is also among the highest, showing that the roles of private and public

High R&D-intensive countries maintain a relatively high level of public R&D support …

sectors are fully complementary.

… while in low R&D-intensive countries publicly-funded R&D is critical for creating and developing S&T infrastructures

Moreover, in low R&D-intensive countries, government-funded R&D is higher than business-funded R&D. Government funding of R&D is critical for creating and developing S&T capabilities (a prerequisite for catching up with countries at the technology frontier) and for supporting research projects with high expected social benefits, which the private sector may not find sufficiently attractive.

Therefore, it remains crucial to increase public funding of R&D to help private R&D to develop further

R&D funded by government has remained very stable in both the EU and the US, but at a lower level in the EU (0.64% of GPD) than in the US (0.83% of GDP). Therefore, the overall public effort to fund R&D in the EU must be increased as well in order for private R&D activities to develop further and grow on a solid science base.

LESS OPPORTUNITIES FOR HIGH-TECH VENTURE CAPITAL

Less Venture Capital for start-ups in the EU, especially at early-stage

In order to allow Europe to achieve its R&D potential, the creation and expansion of new firms in high-technology sectors is essential: it is therefore of utmost importance to ensure that the right conditions exist for "New Technology-based firms" to flourish in the same way in the EU as they do in the US. There is, however, some evidence that shows less will on the part of the EU financial markets to fund new sectors and new firms than is the case in the US. In 2005, US total Venture Capital investment (as percentage of GDP) was almost 40% higher than the amount invested in the EU. EU-US differences are even more marked when only early-stage investment is considered: early-stage Venture Capital investment (as percentage of GDP) is at a level in the US that is 64% higher than in the EU.

High-tech Venture Capital investment in the US is targeted at more mature projects generating higher profits

Moreover, although the number of high-tech companies benefiting from early-stage Venture Capital investment is much larger in Europe (twice as many as in the US in 2003), the average investment in a technology company is much larger in the US (in 2003, the average deal size in a high-tech company was about 9 times higher than in the EU), and there is a significant disparity between the US and the EU in the profitability of early stage Venture Capital investment (with average internal rates of return being about 30 to 50 times higher in the US). Therefore, the main problem for Europe consists less of an underperforming Venture Capital industry (supply side) than of the level of development of projects prior to early-stage financing (demand side). In other words, the financing of the commercialisation of technological innovation cannot be solved solely through actions aimed at strengthening Venture Capital funds specialised in early stage investment. It needs to be assessed in a more systemic way, improving the links between universities and industry and the quality of mechanisms for technology transfer.

RESEARCH EXCELLENCE: THE EU REMAINS SECOND BEHIND THE US, BUT EXCELS IN TRADITIONAL DOMAINS

The EU is the world's largest producer of scientific output, accounting for 38% compared with 33% for the US, 9% for Japan and 6% for China. However, this EU leadership disappears when one adjusts for size and input: the US produces significantly more scientific publications per million population and per university researcher, or as compared to the respective level of public R&D expenditure.

The EU s the world's largest producer of scientific output, but this leadership is forfeited when one adjusts for size and input

Moreover, the EU lags behind the US in terms of citation scores and highly-cited scientific publications, two proxies used to assess the impact of Europe's scientific output in the world. Compared to the US, the EU has lower impact scores in all scientific disciplines examined, and generates relatively less high-impact scientific publications than the US. Finally, EU universities are very much underrepresented in the top rank of the world's largest universities (i.e. 386 world universities having published at least 5000 articles between 1997 and 2004). In the group of the 25 universities with the highest citation impact, all universities are from the US and in the group of 76 universities with a citation impact score above 1.5, 67 (88%) are located in the US and only 8 (11%) in the EU.

Moreover, the EU lags significantly behind the US in almost all scientific disciplines in terms of citation impact scores and highly-cited publications

The EU scores particularly well (i.e. field-normalised citation impact score above 1.0) in rather 'traditional' scientific fields, such as in chemistry, astronomy, physics and engineering sciences (i.e. civil engineering and 'materials sciences'), while lagging most behind the US in new, fast-emerging fields. In nanotechnology, for instance, the EU is the most active region (i.e. over the years 1998-2001, it had the largest world share of scientific publications in nanotechnology, almost twice that of the US), but data on citation impact over the period 1991-2000 reveals again a clear US dominance.

The EU scores particularly well in traditional disciplines, but has much lower impact in new, fast-emerging scientific fields

SCIENTIFIC OUTPUT IS MORE DISPERSED ACROSSS SCIENTIFIC DISCIPLINES IN THE EU THAN IN THE US

Scientific output, as measured by scientific publications, appears to be more evenly distributed across all fields of science in the EU than in the US. This is a potentially rich resource in the medium and long term, but supplementary efforts are required to ensure that both public research and industrial R&D are not too fragmented.

The scientific knowledge base is more dispersed in the EU than in the US

KNOWLEDGE FLOWS FROM SCIENCE TO TECHNOLOGY ARE WEAKER IN THE EU

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, a number which grew substantially in the 1990s, at both the European (EPO) and US Patent offices (USPTO). Comparing the EU with the US in this regard, however, shows that in EU countries the linkage between patented inventions and the science base is much weaker than in the US: European science is relatively underrepresented among publications that provide key contributions to technological developments. This gap is particularly evident in some fields with a close Science-Technology interconnectedness such as lasers, semiconductors and biotechnology. Moreover, the propensity of European technology to build upon US scientific developments is generally higher than the propensity of US technology to rely upon European science.

In the EU, the linkage between technology (patented inventions) and the science base is much weaker than in the US, particularly in science-intensive fields

The contribution of private companies' to the production of scientific publications highly cited in patents is significantly lower in the EU than in the US. Compared to the US, the EU is characterised by a low degree of involvement of private companies in the conduct of research leading to publications cited in patents.

Compared to the US, the EU is characterised by a low involvement of private companies in publications heavily cited in patents

WEAKER HIGH-TECH PERFORMANCE IN THE EU

The EU's relatively weak presence in fast-emerging scientific fields with high promise and the lack of efficient science-technology linkages in the most science-intensive technologies largely explain why the US patents more than the EU in high-tech areas. While, overall, EU inventors apply for more patents at the European Patent Office than their US counterparts, they are less prolific when it comes to patenting in high-tech areas. The EU's share of total EPO patents stood at 38% in 2003, compared with 30% for the US. However, the EU share of high-tech patents was only 29% compared with 37% for the US, even though EU inventors have a non-negligible 'home advantage' at the EPO. The US is ahead of the EU in four out of the six high-tech areas: (1) computers and automated business equipment, (2) micro-organisms and genetic engineering, (3) lasers, and (4) semi-conductors.

The US patents more than the EU in high-tech areas at the European Patent Office

The current development of the nanotech market is a good illustration of Europe's difficulty in breaking through in new, high-tech industries. Notwithstanding the large public support for nanotech R&D in the EU (similar or even larger than that of the US or Japan), private investment in nanotech R&D remains very low compared with the US and

The level of public support for nanotech R&D in the EU is comparable to that in the US and Japan, but private investment in nanotech R&D

Japan: only one third of the total funding for nanotechnology R&D in the EU stems from private sources, compared with 52% in the US and two thirds in Japan. Private funding for nanotech R&D in the US is almost double that of the EU.

remains much lower

Moreover, the number of newly created nanotech companies, in particular the number of nanotech start-ups, has been significantly lower in Europe than in the US over recent years, leading to a much larger stock of companies currently operational in the US. Moreover, the majority of European nanotech companies are much smaller in terms of turnover than their US counterparts. With less and smaller nanotech companies, research efforts in the private sector are bound to be smaller in Europe than in America. It is not surprising therefore to find that America is by far the most active region in the world for registering patents in nanotechnology. In 2003, American applicants registered about 1200 nanotech patents, compared with slightly more than 400 from European applicants. Altogether, the European nanotech industry is clearly lagging behind.

In the US, nanotech companies are much more numerous and on average bigger than in the EU

Introduction

The EU at a crossroads

The European Union is at a crossroads, where only decisive policy actions will ensure that the route towards increased long-term economic growth and prosperity is the one that is followed. In particular two trends can be identified which make such policy actions necessary.

On the one hand, in spite of recent optimistic prospects for EU economic growth in 2007 and 2008, there is evidence that the EU suffers from a structural growth handicap. Since the mid-1990s the Union has no longer been catching up with the US in terms of productivity. Indeed, the EU's labour productivity growth rate has fallen below that of the US for the first time since the end of World War II. The fact that the EU's productivity is no longer catching up with that of the US is mainly due to the lower overall efficiency of the production process[1], which may reflect an under-performance in the creation, diffusion, and utilisation of new knowledge over recent years.

On the other hand, with the rapid rise of – mainly Asian – newly emerging economies, a 'multi-polar world' is developing in which the sources of competitiveness, such as technology and human capital, are more evenly distributed than ever before. The EU represents a diminishing share of worldwide population, GDP and R&D investments, and newly emerging economies are no longer competing on the basis of low-cost activities only. The EU therefore needs to respond to the challenges and make the most of the opportunities created by the new international division of labour.

The structural growth handicap of the EU and the emergence of new competitors, which are at the same time important partner countries, have created a need for decisive policy actions to address the EU's structural weaknesses and to reposition the Union in the new reality of a multi-polar world.

Knowledge is a key engine for productivity and long-term economic growth

The diverging growth patterns in the output performances of the EU compared to the US, together with the increasing challenges and new opportunities created by the new major players, have been a source of deep concern for policy-makers. This heightened level of concern has led most notably to the initiation of the Lisbon process and its efforts to encourage governments to launch employment- and productivity-enhancing reforms.

Economic performance is determined by a variety of macroeconomic policies and structural conditions, and thus differs significantly across regions and countries. Stability-oriented macroeconomic policies (*e.g.* inflation, fiscal policy), trade policy, financial market conditions and labour market institutions impact heavily on the framework conditions that nurture higher growth regimes in a sustainable manner.

In the long run, however, the economic performance of countries is also strongly determined by knowledge-related factors (*e.g.*

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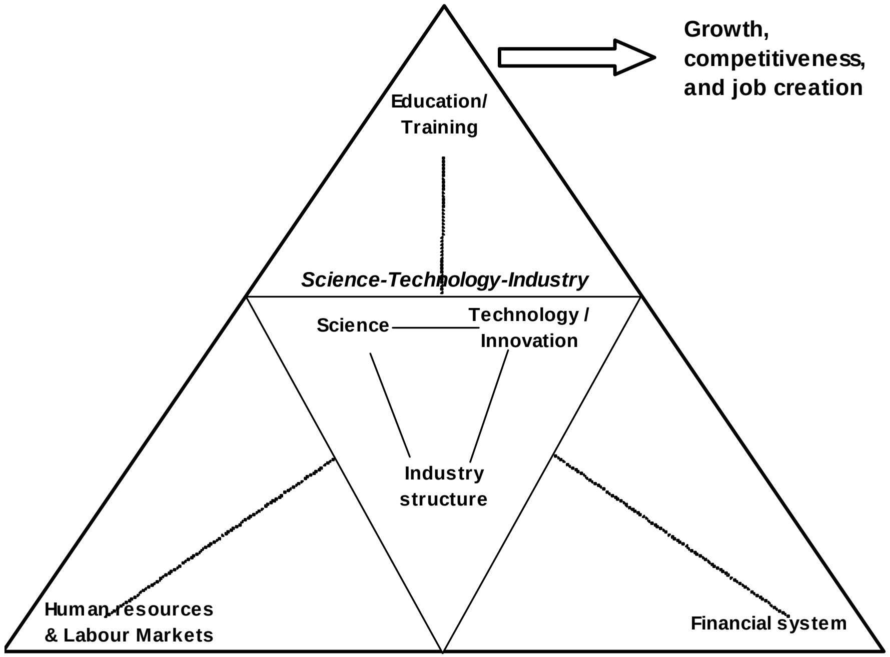
1 The so-called 'total factor productivity' (TFP). It is estimated that the reduced TFP growth accounts for the largest share of the decline in productivity growth (60%) (the remaining 40% being attributed to a weakening growth of the capital-labour ratio, or 'capital deepening') (Denis, C., Havik, K. and Mc Morrow, K (2006), *"EU Growth Trends at the Economy-Wide and Industry Levels"*, (DG Ecfin paper submitted to the EPC meeting of April 2006), Brussels, 2006).

technical change and human capital). In particular, R&D and technological innovation have contributed substantially to the strong US economic performance over recent years. More generally, the contribution of knowledge investments and activities to employment, productivity and economic growth has been emphasised in many studies[2].

'Activating' knowledge for more growth: the need for a systemic approach

However, the relationship between investment in knowledge and performance is complex and non-linear. What factors can explain the differences in innovative performance across countries with rather similar levels of knowledge investment? An important source of diversity between industrialised economies relates to the respective roles of the main actors (*i.e.* firms, universities, and government and other public research institutions) in the process of knowledge production, diffusion and utilisation, as well as to the forms, quality, and intensity of their interactions. These actors are influenced by a variety of factors that exhibit some degree of country specificity: industry structure, the education and training system, the human resources and labour market, the financial system, etc.

Figure 1 The Science, Technology and Innovation system and its constituting building blocks



Source: DG Research Key Figures 2007
Data: Adapted from Amable B., Barré R. and Boyer R., "Les systèmes d'innovation à l'ère de la globalisation", Economica, Paris, 1997, p. 127.

Competition policy, public intervention and the further integration of the internal market should also be emphasised, as they play an across-the-board role with regard to the influence of the other institutions involved in the Science, Technology and Innovation system (STI system). From this perspective, the STI system covers infrastructure, the education system, legislation (*e.g.* IPRs, anti-trust

2 For instance, according to the EU Economy Review 2004, a substantial increase in knowledge investment (R&D and education) could boost potential EU growth rates by between one half and three quarters of a percentage point annually over a 5-10 years horizon. Regarding the US, the knowledge-based economy appears to be more fully entrenched, with studies suggesting that investments in R&D and education can explain almost as much as 75% of the US productivity growth rate over the period 1950-2003. The differences in EU-US productivity patterns are fundamentally driven by the superiority of the US in terms of its capacity to produce and absorb new technologies, in particular Information and Communication Technologies (European Commission (2004), EU Economy Review 2004, Brussels).

policy, labour market) and, broadly speaking, corrective measures for market and system failures, as well as policies aimed at ensuring macroeconomic stability.

By examining all the different institutions in a country that individually and jointly contribute to the production, diffusion and utilisation of knowledge, it is possible to identify the main building blocks of an STI system (see Figure 1). In this system, science, technology/innovation and industry are central but not sufficient to ensure economic growth, competitiveness and job creation. The education and training system, human resources and the labour market, and the financial system – all have a substantial impact on the performance of 'Science-Technology-Industry'. From this perspective, the performance of an economy depends not only on how the individual institutions perform in isolation, but also on how they interact with each other as elements of a collective system of knowledge creation, diffusion and use, and on their interplay with other institutions.

Moreover, because national systems have developed at different times and under different conditions, the characteristics of the STI system of a country are often rather specific. These disparities between STI systems are, in part, a product of history and a legitimate expression of national preferences. However, it is crucial that unnecessary disparities do not hamper the development of integrated markets for research, technology and high-tech products towards a true 'European Area of Knowledge'. Business investment decisions are primarily determined by the size and dynamism of these markets, which are thus becoming a crucial factor of attractiveness in the global economy.

Such interactions between policies and, above all, the need for better coherence between them, both at the Member State and European levels, have been stressed since the re-launch of the Lisbon Strategy in the "Integrated Guidelines for Growth and Jobs (2005-2008)" dealing with macroeconomic, microeconomic and employment issues as proposed by the European Commission in the framework of the revised Lisbon Strategy adopted by the Council of Ministers (see Box)[3].

Box: the Integrated Guidelines for Growth and Jobs (2005-2008)

On March 22-23 2005, the Heads of State and Government of the EU endorsed the revision of the Lisbon Strategy as proposed by the Commission. The Spring European Council approved the simplified governance arrangement with one set of Integrated Guidelines dealing with macroeconomic, microeconomic and employment issues. Taking stock of the unsatisfactory results half way to the 2010 target, the Commission proposed a fundamental revision of the original strategy. To overcome the rather limited implementation of reform in Member States so far, the Commission has proposed focusing partnership with Member States on growth and jobs, and has introduced a Lisbon Action Plan that outlines actions to be taken at the EU and national levels in three policy areas:

Making Europe a more attractive place to invest and work

(1) Extend and deepen the internal market
(2) Ensure open and competitive markets inside and outside Europe
(3) Improve European and national regulation
(4) Expand and improve European infrastructure

Knowledge and innovation for growth

(5) Increase and improve investment in Research and Development
(6) Facilitate innovation, the uptake of ICT and the sustainable use of resources

3 "Council recommendation of 12 July 2005 on the broad guidelines for the economic policies of the Member States and the Community (2005 to 2008)" (2005/601/EC), in: *Official Journal of the European Union*, L205/28-37.

(7) Contribute to a strong European industrial base

Creating more and better jobs

(8) Attract more people into employment, increase labour supply and modernise social protection systems

(9) Improve the adaptability of workers and enterprises

(10) Invest more in human capital through better education and skills.

The Commission proposal for the integrated guidelines package is mainly based on the priority action areas as identified in its Lisbon mid-term review. While the macroeconomic guidelines (covering for instance budgetary policy, reduction of public debts and EMU issues) have no counterpart in the Lisbon Action Programme, the microeconomic guidelines build on Lisbon action areas (1) to (7), and the employment guidelines build on Lisbon action areas (8) to (10).

This integrated approach is intended to leverage the guidelines, which are the cornerstones of EU economic policy, and make them a driving force of the Lisbon Strategy. Modernising economic and employment coordination in the EU will help deliver on the new Lisbon objectives to create growth and jobs. The proposed integrated guidelines constitute the beginning of a new governance cycle. On the basis of the guidelines, Member States have in the course of 2005 drawn up three-year national reform programmes, and report on the implementation of these on a yearly basis in a single national Lisbon progress report.

The Commission publishes its assessment of progress on implementation in its Annual Progress Report, indicating at the same time where it deems further action is necessary at Member State or Community level. On the basis of the Progress Report, the Commission can propose amendments to the integrated guidelines, if necessary. This integrated approach stimulates a policy-learning cycle at both the Member State level and the Community level that will enhance the quality of decision-making and implementation.

Intensifying the pace of reforms

The recent productivity growth performance of the EU in comparison with that of the US, together with the increasing presence of major new players, show that the 2005 relaunching of the Lisbon agenda was indeed appropriate. Many countries now accept that the solution to the EU's growth problem requires a longer-term policy perspective, and that a sustainable long-term recovery process needs to be built upon a Lisbon-inspired structural reform agenda aimed at effectively addressing the fundamental growth challenges posed by the accelerating pace of technological change, globalisation and ageing populations.

In particular, it is essential that the transition of the EU economies towards a knowledge-driven economy – within which education and training, R&D and innovation, and ICTs play a critical role – is speeded up. Therefore, it is necessary to increase the efficiency of R&D, improve the transformation of new ideas into new products, processes, services and solutions, and make the overall environment more supportive of firms wanting to increase investment in R&D.

While the policy challenge of implementing Lisbon-driven reforms remains a serious one for a large number of EU Member States, it should be clear that the expected gains are considerable. For instance, a recent CBS study estimates that the introduction of five key measures of the Lisbon Strategy (i.e. the Services Directive, reduction of the administrative burden, improving human capital, 3% R&D target, increase in the employment rate) can boost the EU's economic and employment growth rates by at least 0.8% per year for more than a decade[4].

[4] Gelauff, G.M.M. and Lejour, A.M. (2006), "The new Lisbon Strategy. An estimation of the economic impact of reaching five Lisbon Targets", (*Industrial Policy and Economic Reforms Papers nr. 1*), CPB

The rest of this report takes a detailed look at the most important aspects of EU investment and performance in the knowledge-based economy, and in this regard benchmarks the EU and its Member States against their main competitors. The set of benchmarking indicators used consists of five broad categories – R&D expenditure, human resources, scientific performance, technological performance, and the impacts of S&T performance on competitiveness (e.g. high-tech trade performance) – and is organised in two main chapters. The first chapter compares the European Union with the other main world regions. Here, the scope has been broadened as much as possible to include 'non-triadic' economies such as China and South Korea. The second chapter examines intra-European differences and similarities, convergences and divergences by analysing the performances of the Member States in relation to each other and to the EU average.

Netherlands Bureau for Economic Policy Analysis, The Hague, January 2006.

Part I Europe's place in the changing world of Science and Technology

Introduction

Part I compares the Scientific, Technological and Innovation performance of the European Union as a whole with that of the other main world regions. The geographical scope has been broadened as much as possible to include new major world players such as China, South Korea and the Russian Federation. An intra-European analysis is the subject of Part II of the report.

This part is structured as follows. Sections I.1 and I.2 examine the R&D financing and expenditure patterns of the EU and the world, with the main emphasis on business sector R&D. In particular, the first two sections seek to identify the reasons for the EU's relatively low R&D intensity. Section I.3 focuses on human resources for Science and Technology and assesses the implications for Europe of the changes in international mobility patterns. Section I.4 presents indicators on research performance including publication counts and citation scores. Section I.5 explores the quality of linkages between the scientific base and technological innovations, using citations in patents to the scientific literature as a proxy. Section 1.6 elaborates on the emergence of new, high-tech industries by looking at the case of nanotechnology. Finally, Section I.7 compares the EU's performance in high-tech patents and high-tech trade with that of the rest of the world.

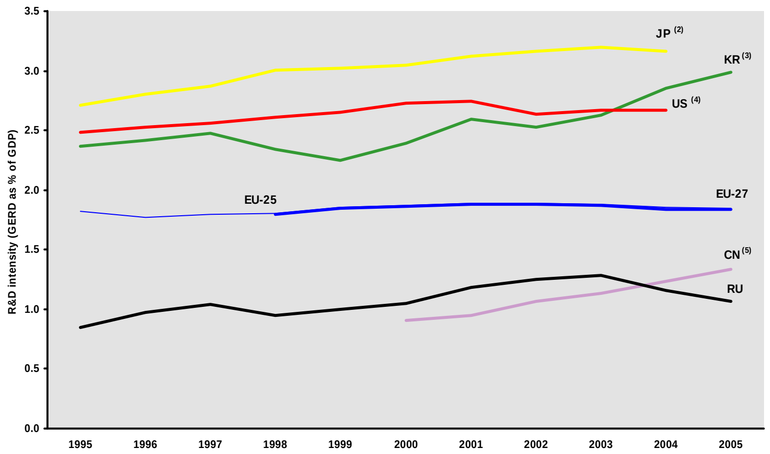
I.1 Overall investment in Research and Development

Europe's investment in R&D is low and stagnating

Europe's R&D intensity remains at a lower level than the R&D intensities of most of the other major world economies such as the US, Japan and South Korea. After a period of slow but continued growth between the mid-nineties and 2001, the Union's R&D intensity stagnated in 2001-2002 and even decreased slightly after that. In 2005, only 1.84% of GDP was spent on R&D in EU-27. In Japan, the US and South Korea, and in spite of some minor, short-term fluctuations, the trend over the past decade has been much more positive, outpacing Europe's performance in R&D intensity growth. As a result, the R&D intensity gap with our main competitors has not been reduced at all. On the contrary, if the current trends as observed over the past five years continue, by 2010 Europe's R&D intensity will have declined to its mid-nineties level of under the 1.80% of GDP.

Moreover, new emerging economies such as China are rapidly catching-up. If current trends persist, it is expected that China will have caught up with EU-27 by 2009 in terms of R&D intensity. The Russian Federation also increased substantially its allocation of resources to R&D between 1995 and 2003. However, since 2003, Russian R&D intensity has fallen back to its pre-2001 level.

Figure I.1.1 R&D intensity (GERD as % of GDP) in the major world regions, 1995-2005 [1]



Source: DG Research — Key Figures 2007

Data: Eurostat, OECD

Notes: (1) US : Break in series between 1998 and previous years; JP : Break in series between 1996 and previous years.
(2) JP : GERD was adjusted by OECD for the years 1991 to 1995 inclusive.
(3) KR : GERD does not include R&D in the social sciences and humanities.
(4) US : GERD does not include most or all capital expenditure.
(5) CN : Hong Kong is not included.

The weight of advanced economies in global R&D is shrinking

Advanced economies such as the European Union, the US and Japan represent a shrinking share of global R&D expenditure worldwide. According to OECD data, the EU-27 share declined from 29% in 1995 to 25% in 2005. Similarly the US and Japan have lost 4 and 3 percentage points respectively of their shares over the same period.

Conversely, all emerging economies account for an increasing share of global R&D activity, mirroring the rapid expansion of their S&T systems. This is particularly true for China and, to a lesser extent, for South Korea and other Asian economies such as Singapore and Taiwan. These countries have more than compensated for the declining share of Japan and allowed Asia to take over Europe's position as the second biggest region worldwide in terms of R&D activity.

Table I.1.1 Total R&D expenditure (GERD) for the major world regions, 1995 and 2005

	1995		2005	
	PPP$ mio (current)	%	PPP$ mio (current)	%
Europe	**147588**	**30.8**	**242102**	**26.7**
EU-27 [1]	139438	29.1	227543	25.0
EFTA [2]	6845	1.4	10905	1.2
Turkey	1306	0.3	3654	0.4
North America	**195390**	**40.8**	**334309**	**36.8**
US	184077	38.4	312535	34.4
Canada	11313	2.4	21774	2.4
Asia	**114025**	**23.8**	**282522**	**31.1**
Japan	76182	15.9	118026	13.0
China	17399	3.6	115197	12.7
South Korea	13681	2.9	31632	3.5
Other Asia [3]	6763	1.4	17668	1.9
Oceania	**6248**	**1.3**	**12678**	**1.4**
Australia	5639	1.2	11590	1.3
New Zealand	609	0.1	1089	0.1
Russian Federation	7373	1.5	16669	1.8
Israel	2977	0.6	8774	1.0
Others [4]	5400	1.1	11340	1.2
Total	**479002**	**100**	**908394**	**100**

Source : DG Research — Key Figures 2007

Data: OECD

Notes: (1) EU-27 does not include BG.
(2) EFTA does not include Liechtenstein.
(3) Taiwan and Singapore.
(4) Argentina, South Africa and Mexico.

Moreover, the growing share of emerging countries in global R&D is not only due to their increasing weight in world GDP, but is also accounted for by the fact that their R&D expenditure is growing at a much faster rate than overall economic activity (Figure I.1.1).

The gap in R&D intensity between the EU and its main competitors stems mainly from the lower contribution of the private sector to the financing of R&D

As R&D is a main driver of innovation, the EU's relatively low R&D intensity is a source of concern for policy-makers. As shown on Table I-1.2, the business sector accounts for the largest part of the overall R&D intensity gap between the EU and its main competitors. The deficit in business-funded R&D explains almost 85% of the gap between the EU and the US, and an even larger share of the gap between the EU and the two Asian countries.

Table I.1.2 Contribution of the main funding sectors (business, government) [(1)] to the overall R&D intensity gap, 2005 [(2)]

	R&D intensity (GERD as % of GDP)	Privately financed R&D intensity (GERD financed by business) as % of GDP)	Publicly financed R&D intensity (GERD financed by government) as % of GDP)
EU-27 [(1)]	1.84	1.00	0.64
US	2.67	1.70	0.83
Japan	3.17	2.37	0.57
South Korea	2.99	2.13	0.69
US - EU gap	0.83	0.70	0.19
Japan - EU gap	1.33	1.37	-0.07
South Korea - EU gap	1.15	1.13	0.05

Source: DG Research — Key Figures 2007
Data: Eurostat, OECD
Notes: (1) Funding from abroad and from other national sources is not shown on the Table.
(2) US, JP :2004.

Box . Institutional classification of R&D

Research and experimental development (R&D) comprise 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.

R&D data are compiled in accordance with the guidelines laid down in the Proposed standard practice for surveys of research and experimental development — *Frascati Manual*, OECD, 2002. R&D expenditure is broken down by the following sectors of performance: business enterprise (BES), government (GOV), higher education (HES) and private non-profit (PNP). It is further broken down into five sources of funds: BES, GOV, HES, PNP and abroad. In this publication, R&D expenditure funded from HES and PNP have been re-grouped under 'other national sources'.

The **business enterprise sector** (BES) includes all firms, organisations and institutions whose primary activity is the market production of goods or services (other than higher education) for sale to the general public at an economically significant price.

The **government sector** is composed of all departments, offices and other bodies which furnish, but normally do not sell to the community, those common services, other than higher education, which cannot otherwise be conveniently and economically provided, as well as those that administer the state and the economic and social policy of the community. (Public enterprises are included in the business enterprise sector.)

The **private non-profit sector** includes non-market, private non-profit institutions serving households (*i.e.* the general public), private individuals or households.

The **higher education sector** consists of all universities, colleges of technology and other institutions of post-secondary education, whatever their source of finance or legal status. It also includes all research institutes, experimental stations and clinics operating under the direct control of or administered by or associated with higher education institutions.

The **abroad sector** includes all institutions and individuals located outside the political borders of a country, except vehicles, ships, aircraft and space satellites operated by domestic entities and testing grounds acquired by such entities. It includes also all international organisations (except business enterprises), including facilities and operations within the country's borders.

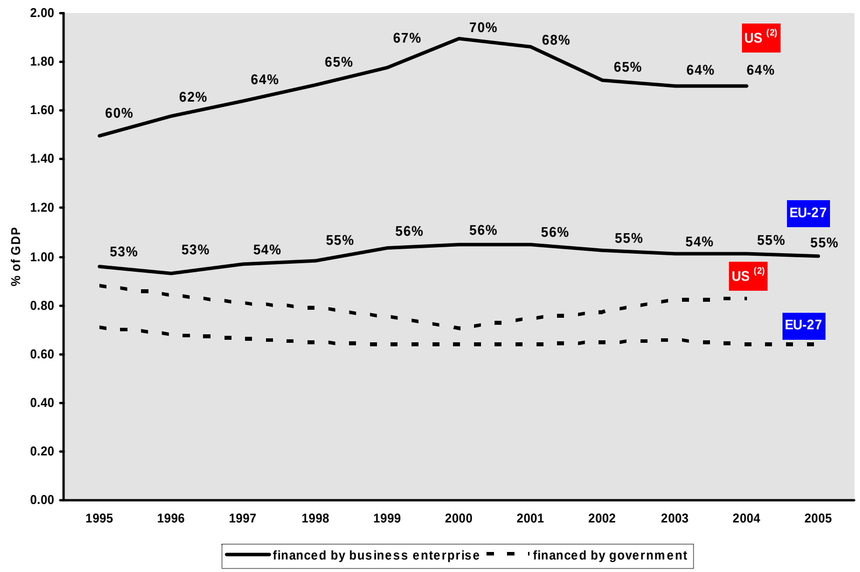
Despite increased attention from policy makers, the business funding of R&D remains low and has even decreased since 2000

European Heads of State decided at the Barcelona Summit of March 2002 not only to increase R&D intensity, but also to improve the private sector contribution to the financing of R&D. In particular they set a target of increasing the share of R&D expenditure funded by the business enterprise sector to two-thirds of the total by 2010.

As shown on Figure I.1.2, the private sector contribution to the financing of R&D in the EU has not progressed substantially over the past 10 years. R&D financed by the business sector remained at around 1% of GDP in the EU, without any noticeable variation over the decade. In 2004, the private sector financed 64% of total R&D in the US, 67% in China and 75% in both Japan and South Korea compared to only 55% in the EU. In the US, the trend over the past decade is clearly positive (despite a trend reversal in 2001-2002). In China too (and to a lesser extent in Japan), the financing of R&D by the private sector has increased at a much faster pace than in the EU. Moreover, since 2000, the private sector contribution to the financing of R&D has even been decreasing in the EU. As a result, the gap between Europe and the US and Japan has widened significantly over the past decade.

R&D funded by government has in general remained very stable (although slightly less stable in the US) and at rather similar levels (between 0.6% and 0.8% of GDP). This shows that the business sector is the funding sector which is mainly responsible for the increasing R&D intensity gap between the EU and the US over the past decade.

Figure I.1.2 GERD financed by business enterprise and by government as % of GDP, 1995-2005 (1)



Source : DG Research — Key Figures 2007
Data: Eurostat, OECD
Notes: (1) The %'s on the graph refer to the share of GERD financed by business enterprise.
(2) US : GERD does not include most or all capital expenditure.

When considering these figures, it is worth mentioning that the level of domestic R&D financed from private sources is slightly under-estimated in the EU, due to the unavailability of a breakdown in the category 'funded from abroad' between private and public sources. However, since total R&D expenditure funded from abroad represents only 0.16% of GDP in EU-27 in 2005, this margin of error does not invalidate the observation that the bulk of the R&D intensity gap is caused by the low and stagnating business sector contribution to the funding of R&D.

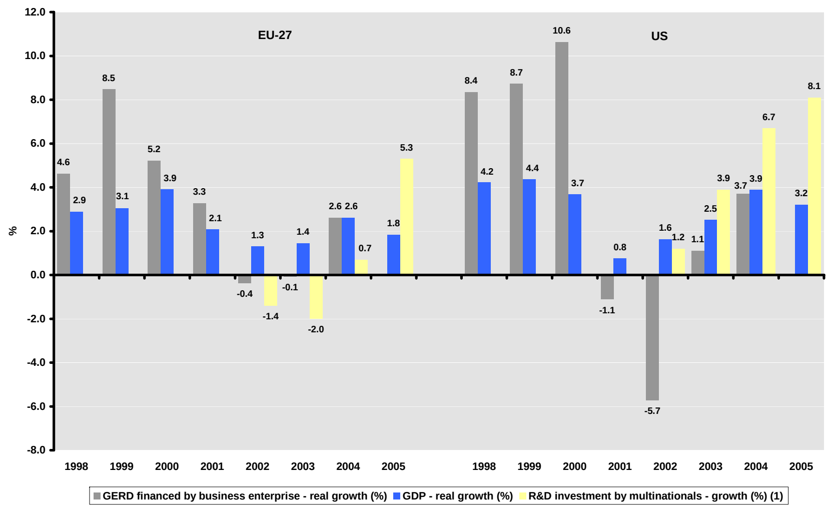
Private financing of R&D is more pro-cyclical in the US than in the EU

Not surprisingly, there is a positive correlation between the overall business cycle and the involvement of the private sector in the funding of R&D, as witnessed by, for instance, the increasing level of privately funded R&D during the second half of the Nineties in both the EU and the US which was followed by a decline after 2000 (Figure I.1.2). There are also some interesting differences between the EU and the US regarding the cyclical evolution of private investment (Figure I.1.3).

Up until 2000 business-funded R&D in the EU grew at a very high rate which even outpaced the rate of GDP growth. This trend continued in 2001, even though growth weakened on both fronts. After 2001, the economic slowdown translated into a sharp reduction in the growth of business funded R&D: which in 2002 and 2003 was negative and well below the rate of GDP growth.

A similar pattern was observed in the US, albeit with two noticeable differences. Firstly, growth of privately financed R&D is much more pro-cyclical in the US: its growth rates were two to three times higher than overall GDP growth until 2000, dropped more sharply than in the EU in 2001-2002 and experienced subsequently a stronger recovery from 2003 onwards. Secondly, there seems to be one year time-lag between the EU and the US. The big decline in private investment growth occurred in 2001-2002 in the US whereas in the EU it took place mainly in 2002-2003. Conversely, the recovery of both economic growth and the level of business-funded R&D started in 2003 in the US, but only from 2004 onwards in the EU.

Figure I.1.3 GDP and GERD financed by business enterprise and R&D investment by multinationals - growth against previous year (%), 1998-2005



Source: DG Research — Key Figures 2007
Data: Eurostat, OECD, DG Research, JRC
Note: (1) The data on R&D investment by multinationals come from the 2006 Industrial R&D Investment Scoreboard. [1]

Given the stronger 'pro-cyclical behaviour' of private R&D investment in the US, one can expect US business funded R&D expenditure to pull further ahead of the EU after 2005. Although not fully comparable, data from the 'Industrial Scoreboard' on global R&D investment by large companies tend to confirm this cyclical evolution (Figure I.1.3). They also tend to show a recovery of worldwide private R&D investment since 2005.However, private R&D investment continues to grow less strongly in the EU than in the US.

I.2 R&D in the business sector

Two-thirds to three quarters of all R&D activities worldwide are carried out in the business enterprise sector[5]. Therefore, the business sector is not only the principal financing sector of R&D, it is also by far the main performer of R&D. Moreover, within the 'research fabrics', the business sector is the closest to consumers and therefore best positioned to develop products based on new knowledge (or new combinations of existing knowledge) and to exploit them commercially. The involvement of the business sector in research-driven activities is therefore crucial for Europe's future economic growth and competitiveness.

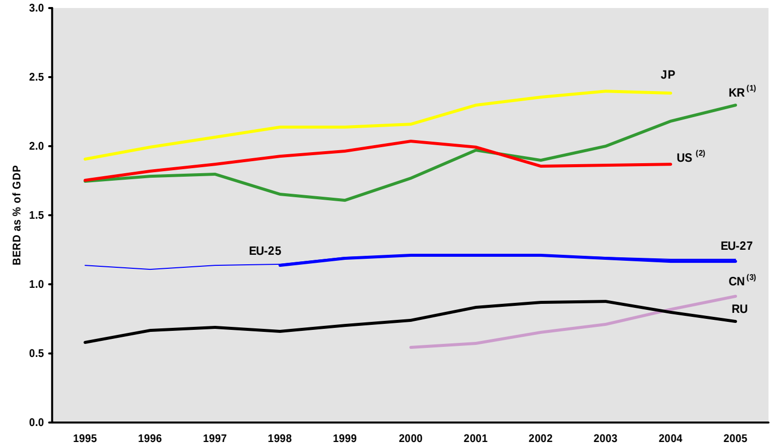
Business R&D expenditure remains low and is stagnating

As is the case with the overall R&D investment position of the EU, R&D expenditure in the business sector (as % of GDP) remains at a lower level than in most of the other main world regions at around 1.20% of GDP. Whereas business expenditure on R&D (as % of GDP) increased in the second half of the Nineties, since 2001, the trend has been negative.

Conversely, business R&D is increasing at a fast pace in Asia (even though Japan's rate of growth is diminishing), while in the US the downward trend of 2001-2002 has come to an end and turned back into positive growth. If these trends are maintained, private R&D investment in China will have reached the same level as in the EU by 2008.

5 Part of them are financed from public sources.

Figure I.2.1 Business enterprise expenditure on R&D (BERD) as % of GDP in the major world regions, 1995-2005 (1)



Source: DG Research Key Figures 2007
Data: Eurostat, OECD
Notes: (1) KR : BERD does not include R&D in the social sciences and humanities.
(2) US : BERD does not include most or all capital expenditure.
(3) CN : Hong Kong is not included.

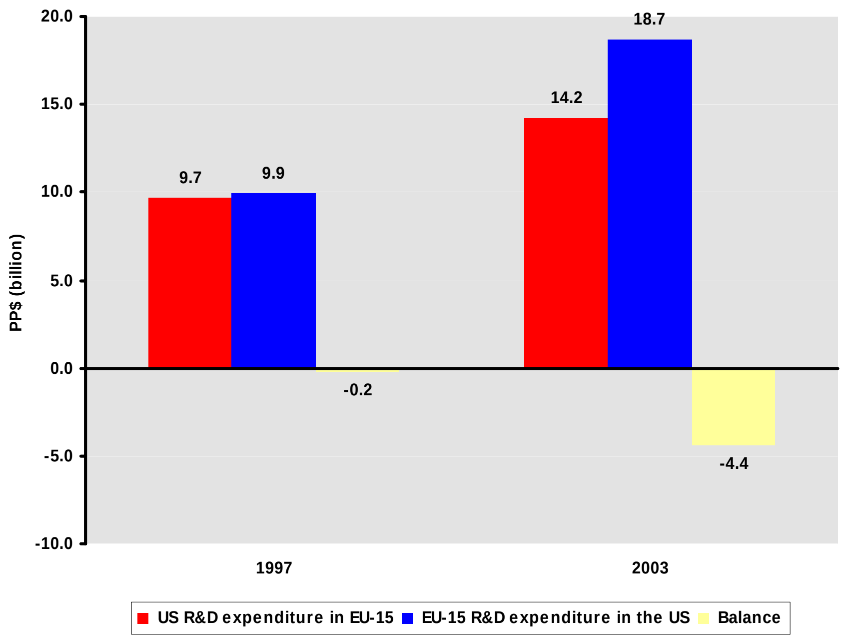
Europe is losing its attractiveness for international R&D investments

In tandem with the overall process of globalisation, the 'R&D fabric' is becoming increasingly internationalised. While there has been no drastic variation in overall R&D intensities (with the exception of China), there has been a significant shift in the level of internationally controlled business R&D. According to the OECD, the share of domestic business R&D controlled by foreign affiliates increased from less than 12% in 1993 to 16.5% in 2001 in the OECD area[6], an increase of almost 40%. This growth shows that the

6 OECD (2005), "Measuring Globalisation: the OECD Economic Globalisation Indicators 2005", Paris, 2005, p. 121.

progressive international relocation of R&D facilities is fast becoming a key element in the overall process of economic globalisation.

Figure I.2.2 R&D expenditure flows between EU-15 and the US (billion PPP$), 1997 and 2003



Source: DG Research — Key Figures 2007

Data: OECD (Activities of Foreign Affiliates database).

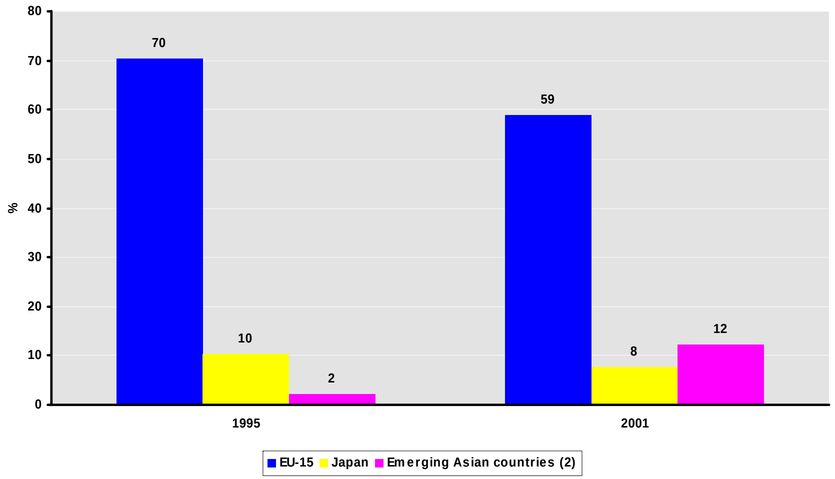
Traditionally, R&D internationalisation has been an intra-Triad phenomenon, with the EU, but especially the US, being major locations for R&D. One of the reasons for the EU's low R&D intensity compared to the US is that the decision of large European companies to carry out R&D activities in the US rather than in the EU. These companies probably have good reasons for doing so: their principal market may be in the US or they may want to benefit from american technical expertise available in the US. Nevertheless, this phenomenon should normally be reciprocal with US companies deciding to do research in the EU in order to benefit from local expertise or market openings. However, there is evidence showing that this is not the case. EU companies tend to invest more in R&D in the US than do their US counterparts in the EU. Between 1997 and 2003, US R&D spending in EU-15 increased from 9.7 to 14.2 billion PPP$, while EU-15 R&D spending in the US increased from 9.9 to 18.7 billion PPP$, turning a net outflow of 0.2 billion into one of 4.4 billion PPP$ (Figure I.2.2).

Although there is evidence to show that EU companies might benefit from this "technology-sourcing" by means of knowledge spillovers to the parent company resulting in increased marginal productivity at company level in the region of origin[7], such a net, increasing outflow reflects the stronger attractiveness of the US research and innovation systems compared to those of the EU.

Moreover, internationalisation of R&D is no longer limited to the intra-Triad flows. More recently, this phenomenon has become more truly global, with many emerging economies becoming important locations for internationally mobile R&D facilities. A 2004 survey by the Economist Intelligence Unit , for instance, has shown that the favourite locations for planned R&D investments by large European and US companies are China, followed by the US and India.

[7] See for instance Griffith, R., Harrison, R. and Van Reenen, J. (2006), "How special is the special relationship? Using the impact of US R&D spillovers on UK firms as a test of technology sourcing", in: *American Economic Review*, vol. 96-5 (Dec 2006), pp. 1859-1875.

Figure I.2.3 Destination of US outward R&D spending (1) in 1995 and 2001 (% share of host region in total US outward R&D spending worldwide)



Source: DG Research Key Figures 2007

Data: US Bureau of Economic Analysis : US Direct Investment Abroad - Operations of US Parent Companies and Their Foreign Affilates (Washington DC, annual series)

Notes: (1) US outward R&D spending refers to R&D expenditure performed by majority-owned (more than 50% ownership) non-bank foreign affiliates of non-bank US parent companies. Data include R&D expenditures conducted by affiliates, whether for themselves or for others under contract; exclude R&D expenditures conducted by others for affiliates under contract.

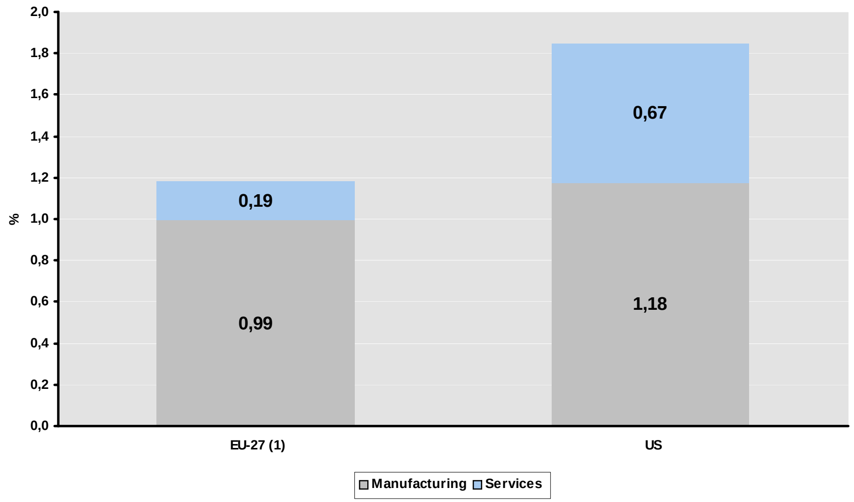
(2) China, Hong Kong, India, Indonesia, South Korea, Malaysia, Philippines, Singapore, Taiwan and Thailand.

This more global focus for R&D spending can be seen in the increasing diversification of the US's own outward R&D investment. US firms are targeting all major regions of the world and especially Asia, with the result that the EU's share in US outward R&D spending has been decreasing significantly since the mid-nineties (Figure I.2.3). This trend is expected to continue as the new, emerging market players continue to build up their science and technology systems and open up their markets to foreign entrants.

The role of services industries in the business R&D gap

As previously mentioned, EU business sector expenditure on R&D (as % of GDP) remains at a significantly low level compared to its main competitors. Figure I.2.4 shows business R&D expenditure performed in the services sector and in manufacturing industry (expressed as a percentage of GDP) in the EU and in the US.

Figure I.2.4 BERD performed in the services and manufacturing sectors as % of GDP, 2003



Source: DG Research Key Figures 2007

Data: OECD, Eurostat

Note: (1) EU-27 was estimated by DG Research and does not include MT.

Compared to the US, the EU has a much lower level of R&D performed in the services sector. At a first sight, this could lead us to conclude that the EU R&D investment deficit with the US is almost exclusively located in the services sector. Recent studies, however, have revealed comparability problems with industry-level data on R&D expenditure[8]. In particular they tend to show that services

8 For a recent overview of these studies and of the comparability problems in industry-level statistics, see OECD (2005), *Business*

R&D expenditure is significantly over-estimated in the US compared to the EU.

One of the main factors that limit comparability across countries is differences in the methods used to classify R&D by industrial activity. Although the Frascati Manual provides some guidelines, it appears that countries follow different practices in their national surveys when it comes to classifying large, multi-activity enterprises or firms with R&D as their main activity.

As regards the classification of multi-activity companies, the Frascati Manual recommends using the principal activity of the firm as the classification criterion, but to subdivide its R&D when the activities are heterogeneous, therefore using product field information (i.e. nature or use of the product for which the R&D is conducted) to re-distribute the R&D activities to the served manufacturing industry. However, not all countries use product field data to the same extent to re-classify R&D, which, according to the OECD, *'may result in similar R&D expenditure being categorised in different industries across countries, thus partially explaining the wide range of values for the shares of services in BERD across countries'*[9]. While in the US, firms are classified by principal activity only, the majority of EU Member States use product field information to re-allocate R&D expenditure[10].

This may explain a large part of the difference between the EU and the US in the share of services in total R&D expenditure. For instance, according to the NSF, the classification of much of the R&D expenditure allocated to the 'Wholesale and retail trade' services industry (ISIC Rev3 50-52) in the US is a statistical artefact due to the US classification of companies according to their principal activity. Because the sale and marketing of goods and services is a trade activity, a large pharmaceutical firm or electronics manufacturer (including its R&D expenditure) would be classified in the trade services industry if the payroll associated with its sales and marketing efforts outweighed that of any other industrial activity in the company. The NSF estimates that 93% of the R&D expenditure recorded under the 'Wholesale and retail trade' industry (i.e. 33.5% of total services R&D expenditure in the US) should be re-allocated to the manufacturing industry[11]. In 2003, the R&D expenditure recorded for the 'Wholesale and retail trade' services industry represented 36% of total services BERD in the US compared to less than 4% in France, Germany, Italy, the United Kingdom and Sweden.

The methodological differences between the classification of R&D expenditure in the EU and the US may also apply to other services industries such as ‘Computer and related services’ (ISIC Rev3 72)[12]. ‘Computer and related services’ in the US represented 27% of total

enterprise R&D data by industry – A review of Anberd and other issues, (DSTI/EAS/STP/NESTI(2005)12), May 2005, 22 p.

9 Ibidem, p. 5.

10 Among the 13 EU-27 Member States covered in the OECD’s Anberd statistics, 8 use product field information to re-allocate industry-level R&D expenditure (BE, DK, DE, FI, FR, NL, SE, UK) and 5 use the principal activity criterion (CZ, ES, IE, IT, PO) (Ibidem, p. 5 and 14-16).

11 National Science Foundation, Division of Science Resources Statistics (2005), *National Patterns of Research and Development Resources: 2003*, NSF 05-308, Brandon Shackelford (Arlington, VA 2005, 111 p) (see mainly pages 25-30).

12 The case of IBM is well-known. Because of the increasing weight of its services activities, the company switched in 1992 from being a manufacturing company to being a services company, which caused a significant -artificial- increase in services R&D expenditure in the US.

services BERD, twice as much as in the EU countries for which comparable data are available.

Finally, firms with R&D as their main activity ('scientific R&D services industry', ISIC Rev3 73) are also treated differently across countries. The scientific R&D services industry comprises companies that specialize in conducting R&D for other organisations, such as biotechnology companies. Although these companies and their R&D activities are classified as non-manufacturing because they provide business services, many of the industries they serve are manufacturing industries. This implies that the R&D activities of a research firm that services a manufacturer would have been classified as R&D in manufacturing if the same research firm were a subsidiary of the manufacturer. Part of the services R&D recorded under this industry may therefore reflect a more general pattern of manufacturing's reliance on outsourcing and contract R&D.

In most of the EU Member States such as France, the United Kingdom, Germany, Belgium and Denmark, the R&D performed by these services companies is at least partially re-distributed to the manufacturing sector for which the R&D has been conducted. In the US, the R&D expenditure of these companies is largely included under the services sector 'scientific R&D services' (ISIC Rev3 73). In 2003, this sector represented 6% of total BERD in the US compared with 2.5% in the EU countries for which comparable data are available. According to the OECD, redistributing the R&D of this sector could significantly alter the overall manufacturing / services distribution in total BERD[13].

[13] OECD (2005), *Business enterprise R&D data by industry – A review of Anberd and other issues*, (DSTI/EAS/STP/NESTI(2005)12), May 2005, p 6.

For these reasons and although it is at this stage impossible to quantify the exact extent of the over-estimation of services BERD in the US, it would be unsafe to conclude from Figure I.2.4 that the EU / US R&D deficit mainly emanates from the business services sector.

In the EU, a smaller share of business R&D is taking place in high-tech sectors compared to the US

Despite comparability problems, one can estimate that at least three quarters of total business R&D is concentrated in manufacturing industries in both the EU and the US[14]. A comparison of the distribution of manufacturing R&D across industrial sectors according to their level of technology intensity shows that in the US, manufacturing R&D is more concentrated in high-tech sectors than in the EU (see Table I.2.4). In 2003, 55% of total EU manufacturing R&D occurred in high-tech sectors compared with 70% in the US. European industrial R&D is more likely to be concentrated in medium-high-tech and, to a lesser extent, medium-low-tech manufacturing.

[14] If one considers that at least 33% of services BERD in the US is misallocated and should be redistributed to the manufacturing industry (see above NSF estimation of re-allocating 'trade R&D' to manufacturing industries), the share of services in total BERD would be less than 25% in the US. In the EU, business services account for 16% of total BERD.

Table I.2.1 Manufacturing BERD and value added by type of industry, 2003 [(1)]

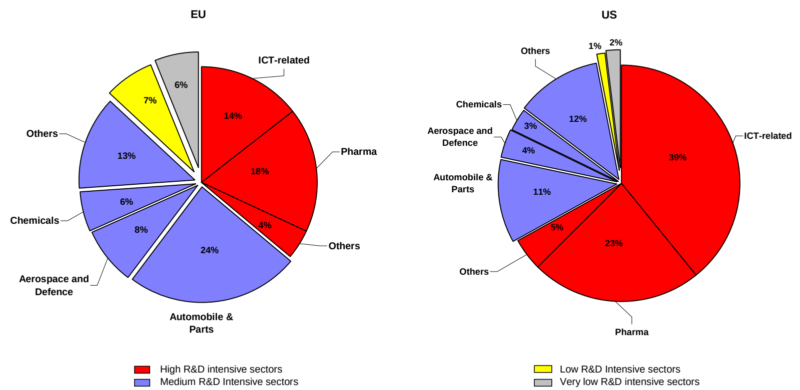
	Total manufacturing	of which :			
		High-Tech	Medium-High-Tech	Medium-Low-Tech	Low-Tech
Manufacturing BERD as % of total GDP					
EU-27 [(2)]	1.02	0.56	0.35	0.07	0.04
US	1.18	0.81	0.25	0.05	0.07
Ratio US / EU-27 [(2)]	115%	146%	70%	74%	154%
Value Added as % of total GDP					
EU-27 [(2)]	15.9	3.1	3.8	3.8	5.2
US	13.4	3.7	2.6	2.8	4.3
Ratio US / EU-27 [(2)]	84%	121%	68%	73%	83%
Manufacturing BERD as % of Value Added					
EU-27 [(2)]	6.4	18.1	9.3	1.8	0.9
US	8.8	21.9	9.5	1.8	1.6

Source : DG Research Key Figures 2007
Data : Eurostat, OECD, Groningen Growth and Development Centre
Notes: (1) In the absence of a breakdown for value added between pharmaceuticals (high-tech) and other chemical products (medium-high-tech), total chemicals (i.e. pharmaceuticals + other chemical products) has been included in high-tech.
(2) EU-27 does not include : BG, EE, LV, LT, LU, CY, MT, AT, PT, RO, SI, SK.

As shown in Table I.2.1, high-tech industries show a slightly higher R&D intensity in the US than in the EU. This, however, may be due to the inclusion of the sector 'total chemicals' in the high-tech category (see note (1) under Table I.2.1). 'Total chemicals' is larger in the EU than in the US but in both the EU and the US it is also less R&D intensive than high-tech. Medium-tech industries have rather similar levels of R&D intensity in both the EU and the US. In conclusion, it appears that, R&D intensity by type of industry is very similar in the EU and the US[15].

Therefore, the higher concentration of business R&D in high-tech industries in the US largely emanates from differences in industrial structure between the EU and the US. As shown in Table I.2.1, in the US, high-tech industries account for a much larger share of both industrial value added and GDP than in the EU. In the EU, the industrial texture is more concentrated on medium-high-tech and low-tech activities.

Figure I.2.5 Sectoral composition of R&D investment by EU and US companies, 2005



Source: DG Research Key Figures 2007
Data: The 2006 EU Industrial R&D investment Scoreboard

Although not fully comparable with the ANBERD data used here to analyse the distribution of business R&D across sectors, data from the ‘2006 Industrial R&D Investment Scoreboard’ on the composition of corporate investment made by the largest R&D spending companies worldwide confirm the differences between the EU and the US. According to the Scoreboard, EU companies considered sector-by-sector appear to be as R&D intensive as their US counterparts[16]. The deficit in private R&D spending is mostly due to difference in industry structure and the smaller size of the

15 Even though low-tech industries represent only less than 5% of manufacturing BERD in both the EU and the US and therefore do not play any important role in explaining EU-US differences in business R&D intensity, it is interesting to note that in the US low-tech industries are much more R&D intensive than in the EU. They also represent a lower share of GDP in the US.

16 European Commission (2007), "Monitoring Industrial Research: Analysis of the 2006 EU industrial R&D investment scoreboard", (EUR LF-NA-22694-EN-C), Brussels, 2007, p. 9-10.

high-tech sectors. As illustrated in Figure I.2.5, 67% of US corporate R&D investment is made by companies belonging to high R&D intensity sectors, compared to just 36% for EU companies. Figure I.2.5 also illustrates how the ICT sector accounts for a large part of the difference in the sectoral composition of R&D investment by US and EU companies[17].

Which sectors account for most of the EU-US R&D funding gap?

Since the EU R&D deficit with the US appears to be primarily located in the high-tech manufacturing industry, it is worth examining EU-US differences in the composition of the high-tech industry and the relative importance of each sector in the R&D funding gap (Figures I.2.6 and I.2.7). The heavier reliance of the EU on medium-high-tech industries justifies a deeper analysis of the composition of this sector.

Figure I.2.6 shows both the R&D expenditure and the value added (as percentage of GDP) for each sub-sector of the high-tech and medium-high-tech industries. Figure I.2.7 shows the R&D intensity of each individual sub-sector. The following observations can be made.

The sector ‘chemicals’ doesn’t play any significant role in explaining differences between the EU and the US and the higher concentration of R&D in high-tech sectors in the US. This sector is equally large in both economies (somewhat bigger in the EU) and it is equally R&D intensive in the EU as in the US (even slightly more R&D intensive in the EU).

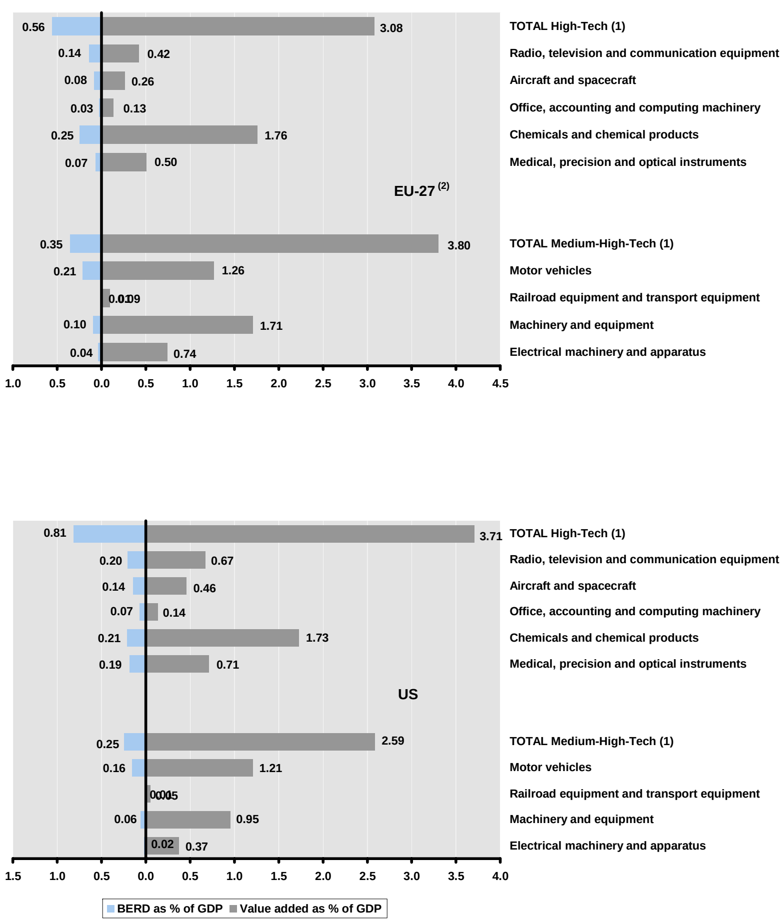
‘Aircraft and spacecraft’ industries have equal R&D intensities on both sides of the Atlantic, but in the US this sector is almost twice as large as in the EU. It therefore contributes to the higher concentration of R&D in the high-tech sector in the US, but only because of its larger size.

The ‘ICT manufacturing industries’[18] largely explain the higher concentration of R&D in the high-tech sectors in the US, by virtue both of their high R&D intensity and their larger size. ‘Office, accounting and computing machinery’ is much more R&D intensive in the US than in the EU, but is equally small in both economies. ‘Radio, television and communication equipment’ is slightly less R&D intensive in the US, but this industrial sector is 60% bigger than in the EU. Finally, ‘medical, precision and optical instruments’ is twice as R&D intensive and almost 50% bigger in the US than in the EU.

17 R&D investment made by these European (US) companies are not necessarily located in Europe (the US).

18 ‘ICT manufacturing industries’ refer to the following three sectors: radio, television and communication equipment; office, accounting and computing machinery; medical, precision and optical instruments.

Figure I.2.6 High-tech and medium-high-tech industries [1] - BERD as % of GDP and value added as % of GDP, EU-27 [2] and the US, 2003

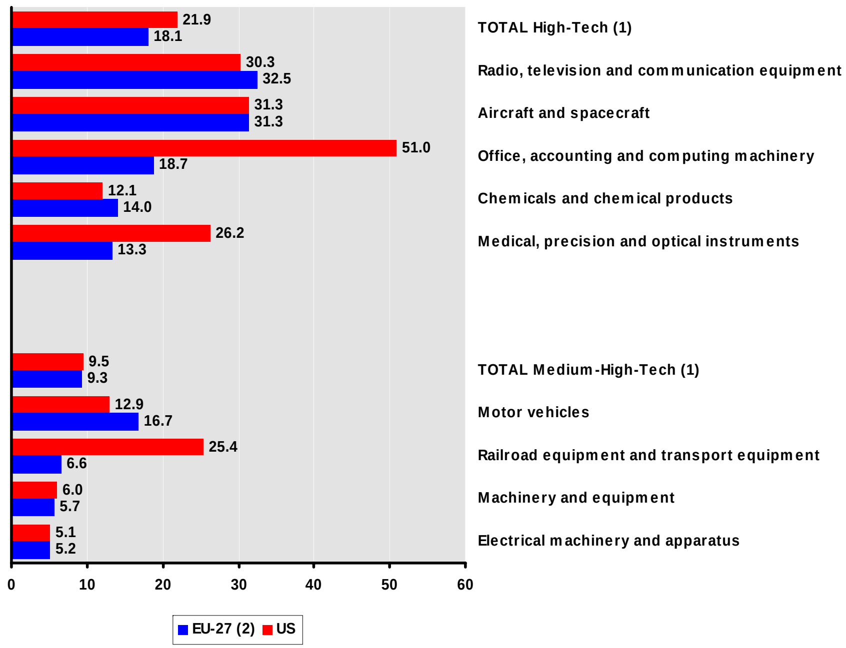


Source: DG Research Key Figures 2007

Data: Eurostat, OECD, Groningen Growth and Development Centre

Notes: (1) In the absence of a breakdown for value added between pharmaceuticals (high-tech) and other chemical products (medium-high-tech), total chemicals (i.e. pharmaceuticals + other chemical products) has been included in high-tech.
(2) EU-27 does not include : BG, EE, LV, LT, LU, CY, MT, AT, PT, RO, SI, SK.

Figure I.2.7 High-tech and medium-high-tech industries [1] - BERD as % of value added, EU-27 [2] and the US, 2003



Source: DG Research Key Figures 2007

Data: Eurostat, OECD, Groningen Growth and Development Centre

Notes: (1) In the absence of a breakdown for value added between pharmaceuticals (high-tech) and other chemical products (medium-high-tech), total chemicals (i.e. pharmaceuticals + other chemical products) has been included in high-tech.
(2) EU-27 does not include : BG, EE, LV, LT, LU, CY, MT, AT, PT, RO, SI, SK.

Two main conclusions can be drawn. First, it is clear that ICT manufacturing industries play a crucial role in explaining the R&D funding gap between the EU and the US, not only because they tend to be more R&D intensive in the US, but also because of their larger size. To a much smaller extent, 'aircraft and spacecraft' industries also contribute to the EU R&D deficit. Second, structural differences between the two economies (i.e. the larger share of both the ICT manufacturing industries and the 'aircraft and spacecraft' industries in the industrial texture of the US) seem to be at least as important as the 'intrinsic effect' (i.e. sector-specific R&D intensities).

Similarly, one can examine which sectors are responsible for the higher concentration of R&D expenditure in medium-high-tech sectors in the EU.

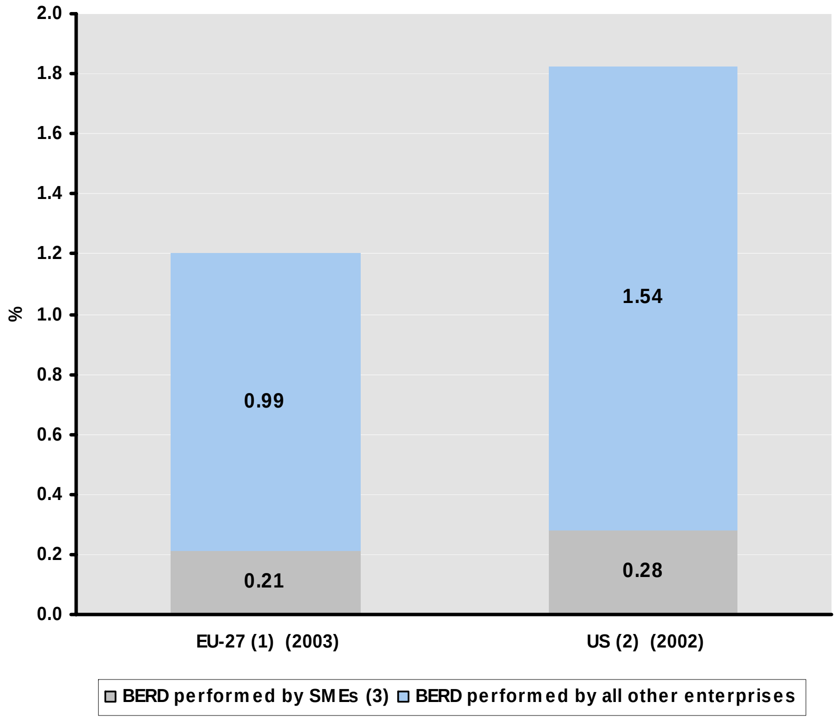
The sector 'railroad and transport equipment' does not play any significant role in the explanation of the differences: this sector is much more R&D intensive in the US than in the EU, but it is equally very small in both economies. 'Motor vehicles' also plays a rather limited role: it is only slightly bigger and more R&D intensive in the EU. The major differences come from 'machinery and equipment' and, to a lesser extent, 'electrical machinery and apparatus'. These two sectors have similar R&D intensities in the EU and the US but are twice as big in the EU as in the US.

Here again, structural differences and the larger size of sectors seem to account for the largest part of the differences between the EU and the US.

The role of SME's in the EU-US R&D deficit

Figure I.2.8 shows the business R&D expenditure (BERD) performed by SMEs[19] and larger firms in the EU and in the US as % of GDP. BERD carried out by SMEs is only slightly lower in the EU than in the US.

Figure I.2.8 Business enterprise expenditure on R&D (BERD) by type of enterprise as % of GDP



Source: DG Research Key Figures 2007
Data: OECD, Eurostat
Notes: (1) EU-27 does not include MT and AT.
(2) US : BERD does not include federally funded research and development centres.
(3) For the purposes of this graph SMEs are defined as enterprises with less than 250 employees.

It should be borne in mind, however, that SMEs represent a higher share of total output in the EU than in the US. Due to this structural difference between the two economies, the best way to compare the level of R&D efforts of the SMEs in the EU and in the US is to calculate their average R&D intensities (share of total SME R&D

19 SMEs are here defined as firms with less than 250 employees.

expenditure in total SME value-added). Correcting for differences in the industrial structure between the EU and the US, and based on estimations of the shares of SMEs in total output of 61% in the EU and 41% in the US[20], the average R&D intensity of SMEs would be (0.21% / 61% =) 0.34% in the EU compared with (0.28% / 41%=) 0.68% in the US.

This estimated 'SME-specific' R&D intensity reveals a clear deficit between European SMEs and their US counterparts. This deficit, however, is not significantly different from the overall BERD deficit. As shown in the Table I.2.2 the ratio between the SME R&D intensities for the EU and the US is similar to the ratio between the overall BERD intensities for the EU and the US.

Table I.2.2 R&D intensity of SMEs

	EU	US	Ratio EU / US
R&D intensity of SMEs (estimated)	0.34	0.68	51%
BERD intensity	1.17	1.87	63%

Source: DG Research — Key Figures 2007
Data: European Commission

This seems to indicate that the situation of European SMEs vis-à-vis their American counterparts regarding R&D intensity does not significantly differ from the situation of larger companies. In other words, there is no *SME-specific* R&D intensity deficit.

SME's, however, can grow and become major, critical players in their sector. As previously mentioned, EU companies are, sector-by-sector, as R&D intensive as their US counterparts, but they tend to be less involved in some very R&D intensive sectors/sub-sectors (especially the ICT sector). In other words, the EU/US BERD deficit cannot be attributed to the fact that individual European companies perform less R&D than their US counterparts in the same sectors: the main reason for the deficit is linked to differences between the European and the American industrial structures.

This difference in industrial structure involves an important time dimension. 22% of the US companies which are now in the world top 1000 in terms of market capitalization were created[21] after 1980, compared with only 5% of their European counterparts[22]. Of those US companies which were created after 1980 and are now in the world top 1000, 70% are IT companies.

These figures reflect the fact that, in the US more than in the EU, many new, R&D-intensive firms, active in high-tech sectors (often labelled "New Technology-based firms" or NTBFs) were able to develop, grow rapidly and become key economic players.

This difference between the EU and the US economies is not limited to the IT sectors: similar trends can be seen in other emerging high-tech sectors. For instance in the biotech sector, although the number of companies created is similar in the EU and in the US, the average turnover and number of employees of these companies are much higher in the US than in the EU[23]. It seems that the US economy has

20 European Commission (2002), "SMEs in Europe. Competitiveness, Innovation and the Knowledge-driven society", (KS-CJ-02-001-EN-N), Brussels, 2002, p. 13.

21 This figure does not include creations of companies through mergers and acquisitions, but only *ex nihilo* creations

22 Cohen, E. and Lorenzi, J.-H. (2000), *Politiques industrielles pour l'Europe*, Paris: Conseil d'Analyse Économique, p. 122-126.

23 Cohen and Lorenzi note that, in 1997, there were 1.274 biotechnology companies in the US compared with 1.036 in the EU, but they generated revenue of $15,9 billion and employed 140.000 people in the US compared to $2,7 billion and 39.045 people respectively for

the flexibility to re-orient itself towards new promising sectors, especially through the rapid growth of new, R&D intensive firms.

In conclusion, the role of SMEs in the overall EU/US BERD deficit has to be assessed from a double perspective. From a *static* point of view, the re-estimated R&D intensity of SMEs is lower in the EU than in the US but not significantly lower than in the case of large companies. The total EU/US BERD deficit lies mainly with large firms; SMEs play a very marginal role in it. However, from a *dynamic* point of view, it is important to note that some of the large US companies which are now key contributors to US BERD were in fact SMEs 20 years ago and that the lack of a similar dynamic in the EU plays a significant role in the EU/US deficit.

In order to allow Europe to achieve its R&D potential, the creation and expansion of new firms in high-technology sectors is essential. It is therefore of the utmost importance to ensure that the right conditions exist to enable "New Technology-based firms" to flourish in the same way in the EU as they do in the US. There is, however, some evidence that shows less will on the part of the EU financial markets to fund new sectors and new firms than is the case in the US.

Fewer opportunities for high-tech Venture Capital

Large firms tend to finance most of their R&D effort from profits. In their case, public policy tends to stimulate activities at the margin only. For smaller firms, however, access to venture capital is often a decisive factor in R&D investment decisions. In other words, venture capital can play a critical role in the creation and expansion of R&D-intensive SMEs because the anticipated research effort is likely to be beyond their financial capacity. Venture Capital (VC) investment can finance the seed, start-up and expansion phases of a firm's life cycle. It provides equity capital and managerial skills for high risk, promising new companies, which frequently are found in high-tech and knowledge intensive sectors.

their European counterparts (Cohen, E. and Lorenzi, J.-H. (2000), ibid, p. 126).

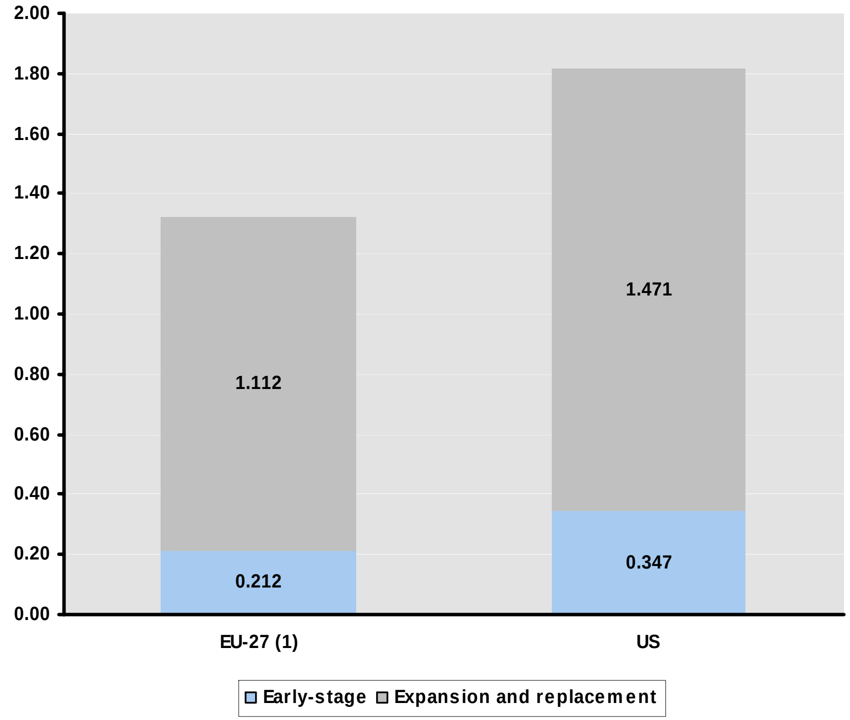
In terms of Venture Capital investment in relation to GDP, the EU is still lagging behind the US. In 2005, the US's total Venture Capital investment was 1.8 euro per thousand GDP, almost 40% higher than the amount invested in the EU. EU-US differences are even more marked when only early-stage investment is considered: early- stage Venture Capital investment equals 0.35 euro per thousand GDP in the US compared with 0.21 in the EU, a difference in level of 64%.

A recent study by the European Commission, based on comparable data but focusing on Venture Capital investment in high-tech sectors only points to three major differences between the EU and the US[24]:

1) The number of high-tech companies benefiting from early-stage venture capital investment is much higher in Europe (twice as much as in the US in 2003).

24 European Commission (2005), "The shifting structure of private equity funding in Europe. What role for early stage investment?", (ECFIN/L/6(2005)REP/51515-EN).

Figure I.2.9 Venture Capital by stage per 1000 GDP, 2005



Source: DG Research

Key Figures 2007

Data: Eurostat

Note: (1) EU-27 does not include BG, EE, CY, LV, LT, LU, MT and SI.

2) The average investment in a technology company is much larger in the US (in 2003, the average deal size in a high-tech company was about 9 times higher than in the EU).

3) There is a significant disparity between the US and the EU in the profitability of early-stage Venture Capital investment: in 2003, average internal rates of return were about 30 to 50 times higher in the US.

This study concluded that the main problem for Europe consists less of an underperforming Venture Capital industry (supply side) than of the level of development of projects prior to early-stage financing (demand side). In other words, the financing of the commercialisation of technological innovation cannot be solved solely through actions aimed at strengthening Venture Capital funds specialised in early stage investment. It needs to be assessed in a more systemic way, improving the links between universities and industry and the quality of mechanisms for technology transfer.

I.3. Human Resources for Science and Technology: towards new mobility patterns?

The international mobility of human resources for Science and Technology comprises the mobility of both students at the tertiary level of education and of graduates employed in S&T occupations.

International mobility to and from Europe is marginal

The international mobility of human resources for S&T to the EU, albeit increasing continuously in absolute numbers, is rather marginal. In the EU, foreign students enrolled in tertiary education (all fields) represent only between 3% and 4% of the total number of tertiary students in 2004[25] (this percentage increases to 7.6% if intra-EU27 migration is included). The share is even lower when one considers S&T employees: less than 2% of the persons employed in S&T occupations in the EU were of non-EU origin in 2000[26]. International mobility of both graduates and tertiary students in Europe is in fact primarily an intra-European phenomenon with almost half of foreign students and foreign S&T employees coming from another EU Member State.

International mobility from Europe is mainly directed towards the US. The scarce statistical evidence shows however that it is very limited. The number of S&E PhDs awarded in the US to EU-born PhD recipients between 1991 and 2000 represented only 2-3% of all S&E PhDs awarded in the EU (Reist2003: 226-227; Estat/NC2006). Given that almost 60% of these graduate scientists stay in the US after completing their PhD and assuming that they include the EU's best PhD-students, these figures nevertheless show that the size and impact of the so-called 'brain drain' should not be over-estimated.

Looking beyond PhD graduates it is also estimated that about 400.000 S&T graduates living in the US come from the EU. This figure represents only 3.5% of the total European stock of S&T educated people[27]

Conversely, the US is highly dependent on large inflows of foreign S&T human resources

During the Nineties, employment in S&E occupations in the US grew at 3 to 4 times the rate of growth of other jobs. This sustained growth of the US S&E workforce was made possible by three factors: 1) increases in the numbers of S&E degrees earned by both native and foreign-born students; 2) both temporary and permanent migration to the US of foreign S&E graduates and 3) the relatively small numbers of scientists and engineers old enough to retire[28].

However, as the number of S&E graduates in the US was not sufficient to meet the demand for S&E employees, the contribution of incoming foreign human resources was crucial to sustain the rapid growth of S&E jobs. The number of foreign students enrolled in US S&E tertiary education more than doubled between 1983 and 2003, rising from 19% to 27% of all S&E tertiary students over that period[29]. As a result, the share of foreign-born individuals holding US S&E jobs in the total number of US S&E jobs increased between 1990 and 2000 from 14% to 22%. At the doctorate level the US is even more dependent on foreign talent: no less than 24% of PhD-

25 Eurostat, Statistics in Focus, 2005/6.

26 This percentage amounts up to 4% if mobility between Member States is taken into account (EC (2003), Third European Report on S&T Indicators, p. 224).

27 EC (2003), Third European Report on S&T Indicators, p. 226.

28 US National Science Foundation (2006), Science and Engineering Indicators 2006, p. 3-5.

29 Ibidem, p. 2-5.

degree holders employed in US S&E occupations in 1991 were foreign born and this share rose dramatically in the subsequent years up to 40% in 2003[30]. Most of these foreign human resources working in the US had graduated in computer sciences (60% in the case of the foreign PhD holders) and therefore they made a crucial contribution to the recent ICT-induced economic success of the US.

But the US's success at importing foreign talent has significantly weakened since 2001, which, together with trends in retirement and degree production, may point to a slowdown in the growth of the US's S&E workforce

The US reaction to the events of September 11, 2001 continues to affect the inflow of foreign-born highly-skilled S&T personnel into the US. The data on temporary visas issued by the US Immigration administration to students, exchange visitors and other highly-skilled individuals dropped sharply after 2001 (by 30% in the case of student visas between 2001 and 2003). Even though the number of visas recovered somewhat after 2003, it is still significantly below the pre-2001 level[31].

Moreover, another leading indicator suggests declining foreign enrolments in advanced S&E studies in the US since 2001. The number of foreign S&E graduates enrolled in advanced S&E studies declined in 2002 by 5% and in 2003 by 8%. The decline was most pronounced in computer sciences (-28% between 2001 and 2003) and engineering (-17% between 2001 and 2003), two fields of education for which the US traditionally has recourse to foreign graduates[32].

Barring major trend reversals, many individuals in the US S&E work force will retire between now and 2020: in 2003, 28% of S&E doctorate holders were 55 years of age or older. It is estimated that the number of individuals in the US with S&E degrees will triple between 2012 and 2020. Furthermore, projected changes in the composition of successive US college-age cohorts means that increasing the number of S&E degrees earned by US citizens will be a challenge. The share of whites in the total population, for instance, is projected to decline from 71% in 1990 to 58% in 2020, while historically that group has been more likely than other groups to earn S&E degrees[33].

The convergence of these three factors (reduced immigration, higher retirement, lower degree production) may hamper the sustained growth in R&D employment and spending in the US from 2012 onwards, affecting both the technological progress and economic growth of the country.

At the same time, Asia is to an increasing extent retaining its own stock of human resources for S&T

Asian countries that have been a major source of mobile human resources in S&T for both Europe and the US are developing their own S&T infrastructures. During the past two decades, two-thirds of foreign students earning a US S&E PhD were from Asia: about 20% from China and 10–11% each from Taiwan, India, and South Korea (compared with a meagre 13% from the EU). In 2002, 25% of all

30 Ibidem, p. 0-14, 3-4 ; US National Science Foundation (2002), S&E Indicators report 2002, p. 3-4.

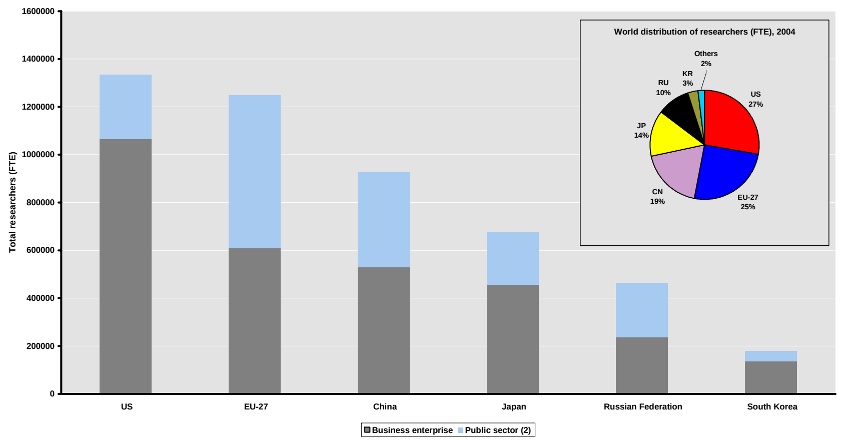
31 US National Science Foundation (2006), Science and Engineering Indicators 2006, p. 0-16.

32 Ibidem, p. 0-17, 2-5.

33 Ibidem, p. 0-18, 3-39.

foreign students enrolled in tertiary education in the EU were of Asian origin.

Figure I.3.1 Number of researchers (FTE) by world region, 2004 [1]



Source: DG Research
Data: Eurostat, OECD
Notes: (1) US : 2002; RU, KR : 2005.
(2) The private non-profit sector is included in public sector.

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However, Asia is investing heavily in the development of knowledge-based economies and higher education systems: S&E degree production in China doubled and engineering degrees tripled over the past two decades. Increasingly, graduates in China can depend on more and better career opportunities due to the impressive development of both the business enterprise and S&T system. Many indicators suggest that countries such as China are already very close to EU and US levels in this regard. For instance, China will have caught up with the EU by 2010 in terms of R&D intensity. Total R&D expenditure in China, after correction for purchasing power disparities, is equal to around. 40% of EU total, but the total number of business enterprise researchers (FTE) in China already represents about 80% of the equivalent numbers in the EU, with an annual growth since 2000 that is about three times higher than that of the EU (Figure I.3.1). Moreover, developed Asian countries such as Japan are starting to import large numbers of Asian scientists and engineers (in 2003, 92% of foreign students enrolled in Japanese tertiary education were from another Asian country).

There is therefore no assurance of a continued influx of Asian S&T personnel onto the world market.

South-East Asia: the new major player for tertiary education

When it comes to the domestic production of talented people (in particular in the S&T fields), both the EU and the US find themselves increasingly outperformed by countries in East Asia. Indeed, in many Asian countries, the combined effect of growing populations and rising access to education has resulted in a dramatic increase in student numbers and will potentially result in increased attainment rates. Between 1995 and 2004 the number of students attending university more than doubled in China and Malaysia, and expanded by 83% in Thailand and 51% in India. This translates into a vast graduate output in absolute terms: in 2005, China already surpassed the EU with 4.4 million graduates from tertiary education compared with 2.5 million in the EU [34](OECD 2006: 14-16). It is obvious that these diverging dynamics are drastically changing the distribution of human capital stocks around the world. According to most recent estimates, Asian countries such as China, India, South Korea, the Philippines and Thailand today account for more than one-fifth of World's tertiary educated population[35].

34 OECD (2006), "Education trends in perspective. Analysis of the World Education Indicators". Paris, 2006.

35 US National Science Foundation (2006), S&E Indicators report 2006, p. 3-33.

Furthermore, even though some challenges remain, some indicators suggest that Asian education systems have comparable quality outputs to the EU and the US. According to the latest PISA assessment in 2003, 15-year-olds in the US and in most of the EU's large economies only performed at around or below the OECD average. In contrast, the six East Asian education systems which took part in PISA 2003 were among the top ten performers.

The logical consequence: increased international demand for EU-born human resources for Science and Technology

It is expected that the US will remain highly dependent on the inflow of large numbers of foreign-born, highly-skilled immigrants. Domestic problems (as already mentioned: ageing, reduced immigration, lower degree production) may even increase the need for the US to attract talented people from abroad. On the other hand, the tremendous economic growth of the emerging economies and the concurrent expansion of their Science and Technology systems, has created a large and increasing pressure on their stock of human resources. Therefore, and in spite of the expanding education system in the emerging countries, there is no guarantee of a continued influx of talented people from Asia onto the international markets. All of this will affect the international production and mobility patterns of human resources and may cause increased international demand for EU-born human resources for Science and Technology.

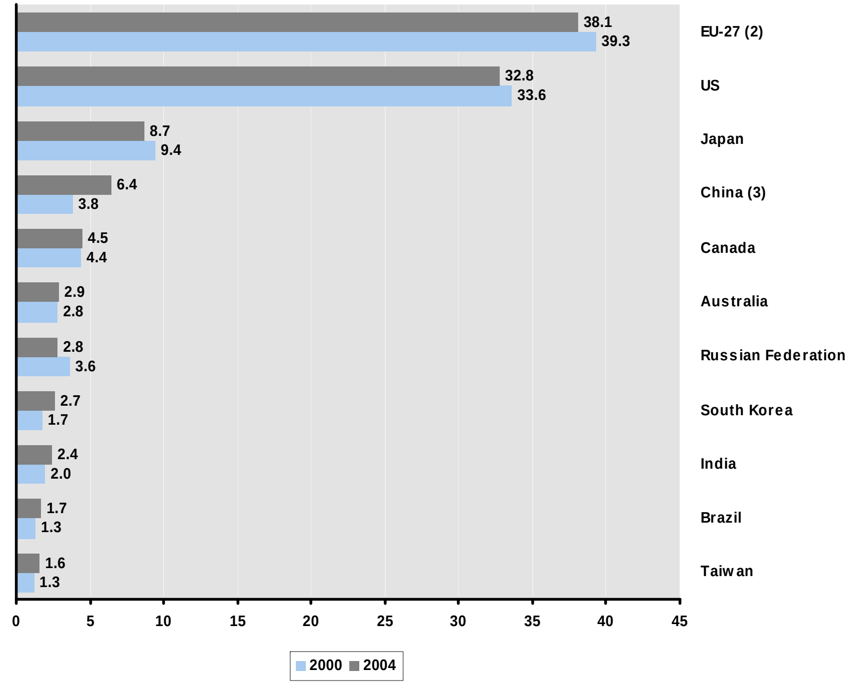
I.4. Research excellence[36]

The EU is the world's largest producer of scientific output, as measured by its share in the world total of peer reviewed scientific articles: in 2004, the Union represented 38% of world scientific output, compared with 33% for the US and 9% for Japan. China is ranked fourth, representing 6% of the world's scientific output (Figure I.4.1).

However, the shares of both the EU and the US have been declining in recent years, because of the rise of new global actors such as China and India. The total number of scientific publications produced each year grew by less than 10% in the advanced economies between 1997 and 2004 (by 6 to 7% in both the EU and the US), while in the emerging countries it rose by more than 40%. Chinese annual scientific output almost doubled between 1997 and 2004, mirroring the rapid expansion and internationalisation of the Chinese S&T system.

[36] This section summarises some trends on the quality of Europe's scientific output based on bibliometric evidence ('quality' being primarily measured here by the citation impact scores of scientific publications). The analyses are based on data extracted from the Science Citation Index (SCI) and related Citation Indexes on CD-Rom, produced by Thomson Scientific (formerly Institute for Scientific Information) and covering some 7,000 international journals in all domains of scholarship, with a good to excellent coverage especially in basic science. For more details on the SCI and its fields' coverage, see MOED, H. F. (2005), 'Citation Analysis and Research Evaluation', (Information Science and Knowledge Management 9), Springer, Dordrecht, 2005, p. 119-136.

Figure I.4.1 World shares of scientific publications (%) (1), 2000 and 2004



Source: DG Research Key Figures 2007

Data: Thomson Scientific / CWTS, Leiden University

Notes: (1) Full counting method was used at country level. At the aggregate level, double countings were avoided.
(2) EU-27 does not include BG and RO.
(3) CN : Hong Kong is included in the data for 2000.

Moreover, the leadership of the EU in terms of total scientific output disappears when one adjusts for size and input: while the US and the EUhave similar levels of public R&D expenditure (in 2004, the EU spent 0.66% of its GDP on public R&D, compared with 0.69% for the US), the US produces significantly more scientific publications per million population (in 2004, 894 publications compared with 662 for the EU) and per university researcher[37].

Finally, being the world's largest producer of scientific output does not necessarily mean that the EU also ranks first as regards the impact of its scientific output.

The EU lags behind the US in terms of the citation impact of its scientific output

One of the most widely used proxies to assess the impact of scientific work is citations. Citations of scientific articles give an indication of the extent to which the scientific work of a research unit / university / country has influence and impact on the world scientific community. The more citations a scientific oeuvre achieves, the bigger its impact and relevance.

In this section, the so-called 'Field-Normalised Citation Impact Score' per scientific discipline is used as an impact indicator. This indicator is considered as one of the most suitable measures for international comparisons. It is the ratio of the actual number of citations received per publication (excluding self-citations) published in a scientific sub-field on the ‘expected’ (average) number of citations received by all papers published worldwide in the same sub-field. If the ratio is above 1.0, this means that the scientific oeuvre is cited more frequently than the world average. The denominator (average number of citations per sub-field) is a weighted average taking into account differences in impact between

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[37] DOSI, G., LLERENA, P. and LABINI, M.S., "The relationships between science, technologies and their industrial exploitation: An illustration through the myths and realities of the so-called 'European Paradox' ", *Research Policy* 35 (2006), p. 1454.

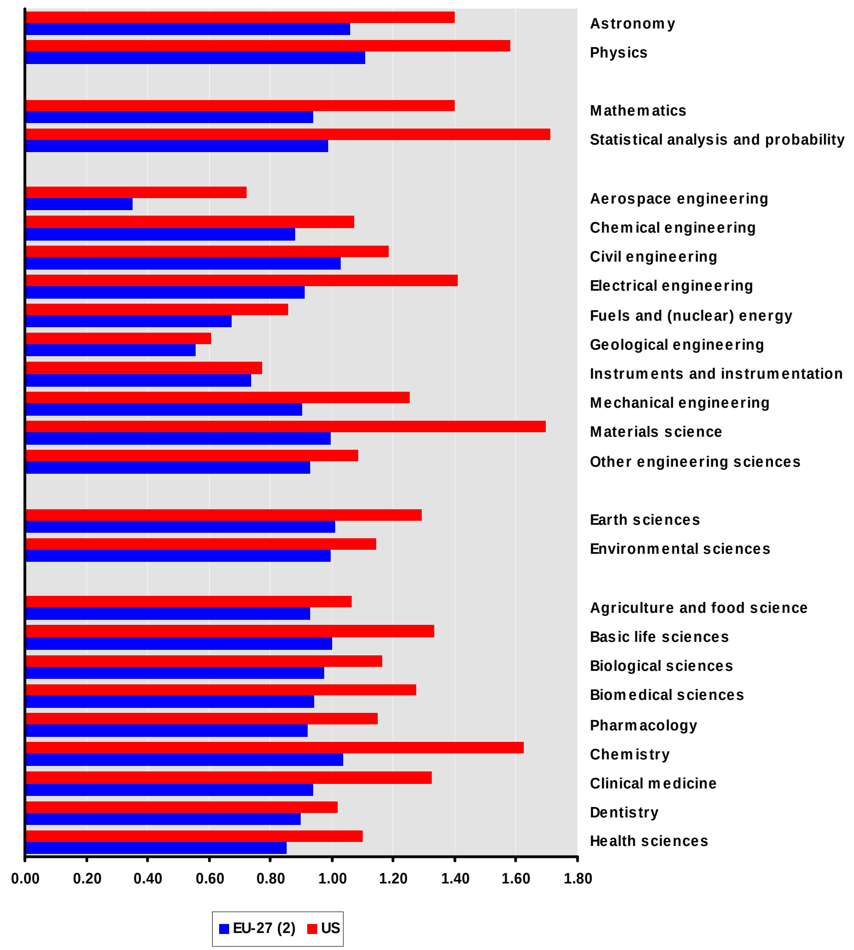
the journals related to the sub-field in question (thus high-impact journals receive a higher weighting than low-impact journals).

The citation impact indicator normalised per scientific sub-field has been preferred over an indicator normalised *per journal*. When normalising by journal, one does not take into account (differences in) the quality or impact of the journals in which a country publishes. In other words, the factor 'quality of the journal' is 'cancelled out', because it is the journal's mean average citation score that constitutes the benchmark, appearing in the ratio's denominator. As a result, a country publishing low impact publications in low impact journals may get a similar score as a country publishing high impact publications in high impact journals. The impact or quality of the journals in which a country publishes should not be cancelled out, but taken into account as is the case here, where a field-normalisation, which is obtained by calculating a weighted average of the citation rates of the journals appearing in the scientific sub-field in question, is used.

Figure I.4.2 presents recent data on the 'Field-normalised Citation Impact Score' per scientific discipline for both the EU and the US. It shows that the EU's scientific impact is around or below world average in almost all scientific disciplines.

Compared to the US, the EU has lower impact scores in all of the scientific disciplines examined. The gap with the US is particularly striking (i.e. difference in citation impact >0.5) in disciplines such as chemistry, computer sciences and material sciences (in terms of number of publications the most important sub-field of the engineering sciences). In all of the ‘largest publishing’ sub-fields (i.e. basic life sciences, biomedical sciences, chemistry, clinical medicine and physics which together account for almost two thirds of the total number of scientific articles published worldwide), the

Figure I.4.2 Field-normalised citation impact score per scientific discipline, 2002-2004 (1)



Source: DG Research
Data: Thomson Scientific, processed by CWTS / Leiden University
Notes: (1) The data refer to scientific articles published in 2002 and citations which occurred in 2002, 2003 and 2004. Social Sciences and multidisciplinary sciences are not included. See also the methodological annex.
(2) EU-27 does not include BG and RO.

EU scores significantly lower than the US[38].

The EU-US gap in citation impact scores has remained unchanged in 14 out of the 25 scientific disciplines since the second half of the 1990s. The gap increased even further in 7 disciplines, such as material sciences, computer sciences, and mathematics, while in 4 disciplines (including basic life sciences and chemical engineering), the EU has been catching-up with the US.

38 Although the possibility of a 'US bias' in citation practices (US authors over-citing US papers as compared to other countries) is often presented as a potential cause of US superiority in citation impact scores, it is still a heavily debated question in scientometric literature and no consensus seems to emerge with regard to either the existence of such a bias or the extent of its impact (see for instance VAN RAAN, A.F.J., "Fatal Attraction: Conceptual and methodological problems in the ranking of universities by bibliometric methods", *Scientometrics*, Vol. 62, nr. 1 (2005), 133-143 (especially p. 138-139)). According to Moed, '[…] *detailed analysis* […] *found no empirical* evidence *supporting the claim that US scientists overcite papers from their own country more than scientists from Western-European countries overcite papers from their countries. All countries overcite themselves, relative to what one would expect on the basis of their shares of citable papers in the database'* (MOED, H. F. (2005), 'Citation Analysis and Research Evaluation', (Information Science and Knowledge Management 9), Springer, Dordrecht, 2005, p 80, 291-300). A recent report by an EC High-Level Expert Group which came to similar conclusions with regard to the EU deficit in citation impact scores against the US stated that *'while this […] may be influenced to a certain extent by a bias in favour of the USA and other English-language countries in the original data source (SCI), this is by no means sufficient to explain away the difference between the USA and Europe*' (European Commission (2005), "Frontier research: the European challenge", (Final report of the High-Level Expert Group on 'Maximising the wider benefits of competitive basic research funding at European level, EUR 21619), Brussels, Feb. 2005, p. 26).

But compared to the world, the EU excels in the traditional disciplines

The EU scores particularly well (i.e. field-normalised citation impact score above 1.0) in 'traditional' scientific fields, such as chemistry, astronomy, physics and engineering sciences (i.e. civil engineering and materials sciences).

These results are consistent with other recent analyses. The French 'Observatoire des Sciences et des Techniques (OST)', for instance, published recently 'Field normalised citation impact scores' for the EU- and the US. Even though the classification of scientific fields used by OST is not entirely comparable with the classification used here, the results (e.g. citation impact scores above world average for the EU in chemistry and in physics, but impact scores significantly below the US in all fields) are consistent with the findings mentioned above[39]. King (2004) computed a 'field-normalised citation impact score' at country level (across all disciplines) for 16 EU Member States, the US, Japan and a few other countries[40]. Even though the results are not fully comparable (i.e. the period studied, 1993-2002, is longer and no EU-aggregate is presented), the overall conclusion is consistent with the findings presented above[41]. The

39 OST, Key Figures on Science and Technology 2006, Paris, p.47.

40 KING, D. A., 'The scientific impact of nations. What different countries get for their research spending', *Nature* (vol. 430), July 2004, 311-316.

41 According to King's calculations, the citation impact scores increased in almost all countries. It increased faster than in the US in 8 out of the 16 EU Member States (in Denmark, the UK, Germany, Austria, Ireland, Luxembourg, Spain and Poland) and slower than in the US in the other 8 EU Member States (in the Netherlands, Belgium, Sweden, France, Italy, Finland, Portugal and Greece). Both groups of countries represent about half of EU-16's scientific output. One cannot thus derive from these figures any improvement of the EU's position relative to the US (KING (2004), 311-312).

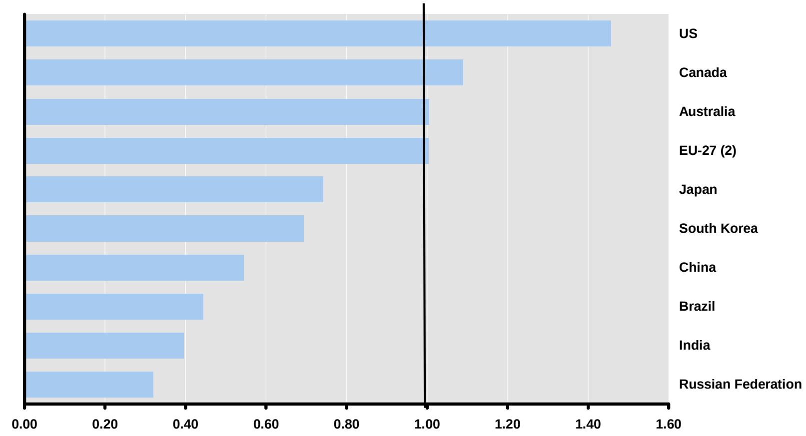
2005 EC report on 'Frontier Research' also examined citation impact scores per discipline and came to very similar conclusions[42].

Using a citation impact indicator normalised *by journal* tends to show better results for the EU as compared to the US[43]. As already stated, a normalisation by scientific sub-field (where differences in impact between journals have been taken into account) has been preferred here over the normalisation by journal. However, it is interesting to consider this difference between the two types of indicators, since it demonstrates that US scientists on average publish more frequently in high-impact journals than EU scientists.

The EU generates relatively less high-impact scientific publications than the US

An additional impact indicator reflects the contribution of a region to the most frequently cited papers worldwide. Figure I.4.3 ranks the world's most important regions / countries according to this indicator.

Figure I.4.3 Contribution to the 10% most cited scientific publications, 2001-2004 - major world regions (1)



Source: DG Research Key Figures 2006
Data: Thomson Scientific / CWTS, Leiden University
Notes: (1) The 'contribution to the 10% most cited scientific publications' indicator is the ratio of the share in the total number of the 10% most frequently cited scientific publications worldwide to the share in the total number of scientific publications worldwide. The numerator is calculated from the total number of citations per publication for the publications published in 2001 and cited between 2001 and 2004. A ratio above 1.0 means that the country contributes more to highly-cited, high-impact publications than would be expected from it's share in total scientific publications worldwide.
(2) EU-27 does not include BG, CY, LU, MT and RO.

In spite of a contribution to the (top 10%) high-impact publications that corresponds more or less to what can be expected given its publication output (i.e. around 1.0), the EU lags significantly behind the US. The US has, compared with the EU, a disproportionate number of highly-cited publications. A look at the top 1% of the most cited publications confirms this result[44].

42 '[…] *the USA, although producing a broadly similar number of scientific publications to Europe, leads both in terms of total number of citations (reflecting the total impact of research) and in terms of the average number of citations per paper (reflecting the average impact per paper)'* (European Commission (2005) p. 26).

43 For instance the 2002 report of the Expert Group on 'Benchmarking S&T Productivity' provided an assessment of the citation impact performance of EU Member States as compared to the US (see European Commission (2002), 'Final report of the Expert group on *Benchmarking S&T Productivity*', June 2002, p. 16-19). For various Member States the report demonstrates an improvement of the citation impact compared with the US between the late eighties and 1996. Some Member States such as Germany and the United Kingdom even show higher citation impact scores than the US.

44 *'Analysis of the top 1% of publications in terms of citations reveals even more discouraging evidence for Europe* [than when looking at citation impacts scores]. *In almost all fields, the US dominates in terms of high-impact papers. Its share of highly-cited publications is*

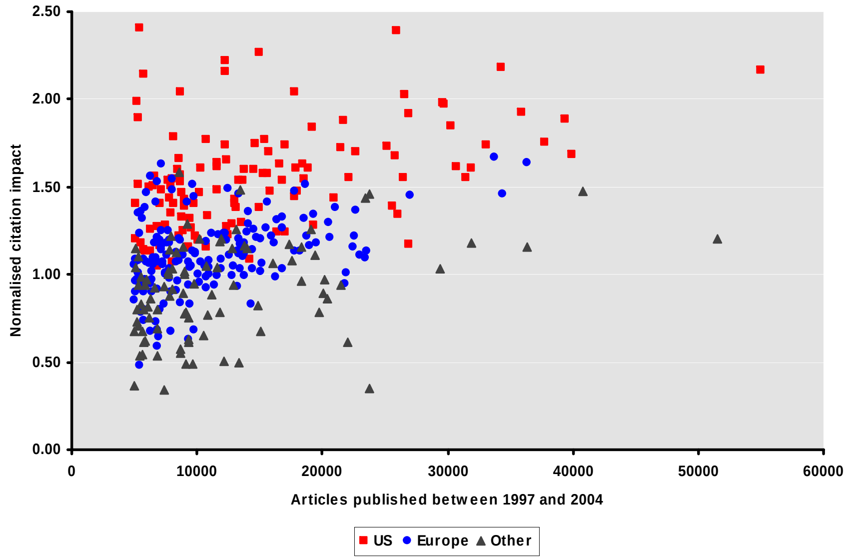
The US dominates rankings of world's biggest research universities

Figure I.4.4 shows the citation impact scores of the world's largest universities (in terms of publication output). The 386 universities selected include 182 EU-25 universities and 122 US universities. The universities plotted represent respectively 72% (EU) and 83% (US) of all university scientific articles.

As shown on figure I.4.4, US universities are highly over represented both at the top of the ranking based on normalised citation impact, and to a lesser extent, at the top the ranking of the number of published articles per year. In the group of 25 universities with the highest citation impact, all universities are from the US and in the group of 76 universities with a citation impact above 1.5, 67 (88%) are located in the US and 8 (11%) in the EU.

disproportionately much larger than its share of total publications' (European Commission (2005) p. 26).

Figure I.4.4 Number of published articles and normalised citation impact for 386 world universities with at least 5000 articles published during 1997-2004



Source: DG Research — Key Figures 2007
Data: Thomson Scientific, processsed by CWTS / Leiden University
Note: (1) This ranking is based in large part on the work carried out for a project funded by the European Commission, DG Research-C (Assist project).

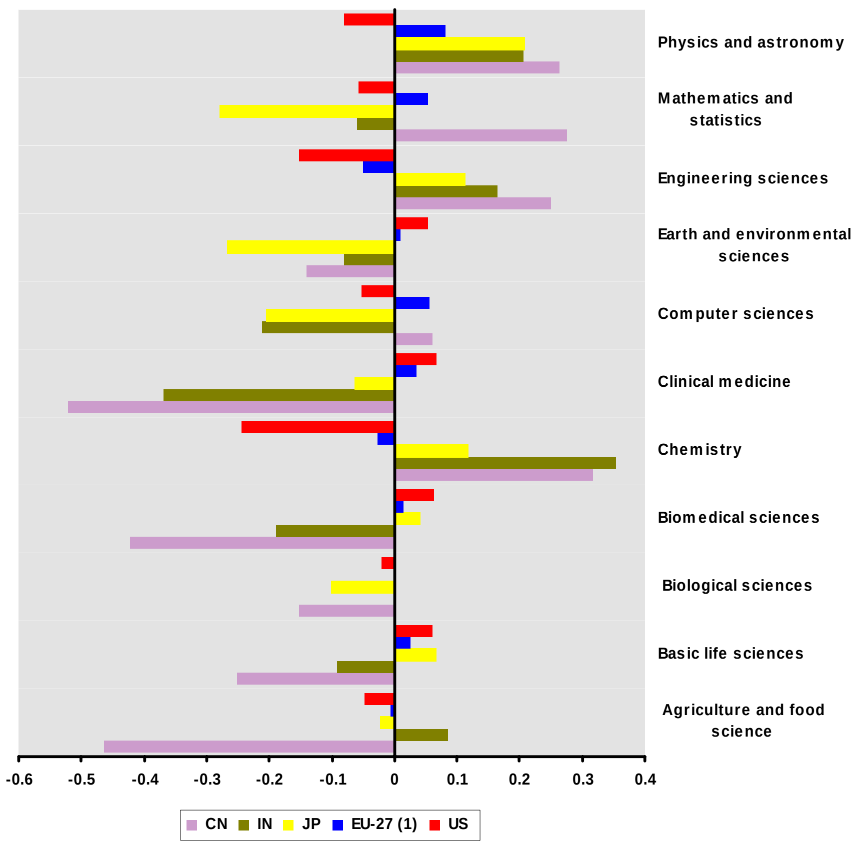
Scientific output is more dispersed across scientific disciplines in the EU than in the US

In order to assess the relative scientific strengths of regions and countries, it is useful to examine their scientific specialisations. A country's level of specialisation in a given field of science is measured by comparing the world share of the country's publications for the particular field with the world share of the country's publications for all fields combined. Multidisciplinary sciences and social sciences have been left out. Moreover, it should be borne in mind that, as the relative activity index is calculated on the basis of the shares of each country in the world total (per discipline and across all disciplines), large countries/regions (in terms of publication output) influence the average more than small countries, and will thus tend to be less 'specialised' than the small countries (as they deviate less from the average).

However, even though the EU and the US are of comparable sizes (and therefore influence the average to the same extent), the EU's scientific output appears to be more evenly distributed across all fields of science than that of the US. Although this is a potentially rich resource in the medium and long term, additional efforts are required to ensure that activities are not too fragmented.

The EU shows no strong specialisation or under-specialisation in any particular field. Conversely, the US is under-specialised in chemistry and engineering sciences; Japan specialises in physics and astronomy but is less active in biological sciences, computer sciences, earth and environmental sciences, and mathematics and statistics. China is specialised in chemistry, engineering sciences, mathematics and statistics, and physics and astronomy. It is under-specialised in clinical medicine, biomedical sciences and agriculture and food science.

Figure I.4.5 Scientific publications - relative activity index, 2001-2004



Source : DG Research

Key Figures 2007

Data: Thomson Scientific, processed by CWTS / Leiden University

Note: (1) EU-27 does not include BG and RO.

I.5. Knowledge flows from Science to 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, a number which grew substantially in the 1990s, at both the EPO and the USPTO. Comparing the EU with the US in this regard however shows that in EU countries the linkage between patented inventions and the science base is much weaker than in the US[45]. A recent study conducted on behalf of the European Commission and based on data for the period 1990-2003 confirms this for the most science-intensive technological fields[46]. The main findings can be summarised as follows.

High quality scientific publications find their way into a large number of technological developments.

Publications that are (highly) cited in patents are not only cited in the realm of technology, but are also heavily cited by other scientific publications. Besides validating the methodological choice of using patent citations to scientific publications as proxy of knowledge flows from science to technology, this finding suggests that there is not necessarily a conflicting logic between scientific and industrial communities. In this respect, however, it should be also noted that European scientific publications cited in patents receive a lower

45 European Commission (2003), Third European Report on Science and Technology Indicators, Brussels, p. 414-418.

46 Breschi, S. e.a., *Highly-cited patents, highly-cited publications and research networks*, (Research contract carried out by CESPRI-University Bocconi on behalf of the European Commission (research contract PP-CT-M2-2004-005), final report delivered in December 2006), 2006.

Box 'Knowledge flows from Science to Technology': What can scientific references in patents tell us?

This section 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, allowing one to touch upon the degree of diffusion of science into technology.

However, in interpreting the data, it is important to bear in mind a number of factors:

1) 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;

2) The mere presence of science citations in patent documents does not necessarily imply a *direct* contribution to the invention, or a transfer of tacit knowledge;

3) Patent examiners tend to restrict their reading to a narrow range of specialties, and to be relatively unfamiliar with the wider literature;

4) 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;

5) Citations in EPO patents are primarily examiner citations (however, examiner sometimes takes 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.;

6) A high level of citations to publications primarily indicates a strong relationship of a technology to basic research. However, in some areas (e.g. mechanical engineering), the level of citations to publications is low, as research primarily relates to applied issues in respect of which the output is already documented in patents.

average number of citations in scientific literature than the corresponding articles published by US authors. This evidence seems to suggest that high quality European publications face more obstacles in translating into technological applications than comparable scientific output in the US.

But European science is relatively under-represented among publications that provide key contributions to technological developments.

Table I.5.1 shows the shares of cited and highly cited publications in patents held by both the EU-25 and the US in five science-intensive technological fields, and respectively for the European (EPO) and American (USPTO) patent offices. For both EPO and USPTO patents in the field, the table is divided into three panels. The top panel reports the share of *all* citations to publications cited in patents; the central panel reports the share of *highly* cited publications (i.e. very frequently cited in patents). Finally, the bottom panel simply reports the ratio between the latter and the former shares. A ratio greater than 1 just means that a certain area holds a share of *highly cited* publications which is higher than its share of citations to *all* publications.

An inspection of the tables reveals a number of interesting results. If we look at EPO data, out of 5 technology fields, Europe shows a relative strength only in two sectors (transmission of digital information and speech analysis), whereas in semiconductors, lasers and biotechnology its share of highly cited publications is systematically lower than its overall share of cited publications. The European shares of cited and highly cited publications at the USPTO are lower than the corresponding shares at the EPO. In addition to this, we also observe that its share of highly cited publications at the USPTO is lower than its share of all cited publications for all technology fields considered here.

Table I.5.1. Share of the EU-25 and the US in the total number of scientific publications cited in patents, for five science-intensive technological fields, 1990-2003

	Transmission	*Speech analysis*	*Semiconductors*	*Laser*	*Biotechnology*
	1. EPO Patents - all cited publications				
EU-25	26,9	32,1	19,6	23,9	29,8
US	45,9	39,7	46,1	45,5	53,4
	2. EPO Patents - Highly-cited publications				
EU-25	28,3	55,7	10,1	11,4	24,9
US	52,1	26,4	49,6	61,3	63,6
	3. EPO Patents - Ratio (2/1)				
EU-25	1,1	1,7	0,5	0,5	0,8
US	1,1	0,7	1,1	1,3	1,2
	1. USPTO Patents - all cited publications				
EU-25	15,8	19,9	12,7	20,7	22,3
US	60,1	61,2	60,7	53,6	64,2
	2. USPTO Patents - Highly-cited publications				
EU-25	11,0	18,7	9,7	14,7	19,7
US	76,9	68,3	64,5	55,7	68,9
	3. USPTO Patents - Ratio (2/1)				
EU-25	0,7	0,9	0,8	0,7	0,9
US	1,3	1,1	1,1	1,0	1,1

Source: DG Research *Key Figures 2007*
Data: DG Research, research contract PP-CT-M2-2004-005, final report (Dec 2006), p. 57.

As far as the other areas are concerned, the US leadership is quite evident, especially in the fields of biotechnology, lasers and TDI. With reference to EPO data, the share of citations to *highly cited* publications is, respectively, 64%, 50% and 52%, compared to a share of citations to *all* cited publications of, respectively, 53%, 45% and 46%. Not surprisingly, the US share of citations is higher, both for all cited and for highly cited publications, if one looks at USPTO data.

Broadly speaking, the empirical evidence seems to show that European science is relatively under-represented in publications that provide key contributions to technological developments. A key issue in this respect is to what extent the fact that Europe does not feature prominently among highly cited publications is due to the underlying quality of its scientific production or, conversely, it has to be ascribed to weak transfer mechanisms from science to technology, or to a combination of both.

Private companies account for a large share of scientific publications highly cited in patents

The role played by different types of institutions in the production of scientific publications highly cited in patents varies across technology fields, with universities accounting for a large share particularly in biotechnology. However, private companies account for a quite large fraction of highly cited publications in all technology fields. In particular, the share of highly cited publications held by private companies is remarkably larger than their share of all scientific publications. This result suggests that corporate labs contribute to a large extent to the scientific research that is incorporated into technological applications.

But the contribution of European private companies to the production of scientific publications highly cited in patents is significantly lower than the contribution of private companies located in the US

A major feature of the European systems of research, as compared to other geographical areas, especially the US, is the low degree of involvement of private companies in the conduct of research leading to scientific publications cited in patents. Whereas the contribution of the public system of scientific research, i.e. universities and public research organisations, is generally comparable to the contribution of the corresponding system in the US, the fraction of scientific publications accounted for by the private system of research is considerably lower. To the extent that the ability of private companies to profit from scientific output generated in the sphere of science depends on the possession of absorptive capabilities and especially on the existence of boundary-spanning individuals, this characteristic represents a major obstacle to the effective diffusion of knowledge from the realm of science to that of technology.

The propensity of European technology to build upon US scientific publications is generally higher than the propensity of US technology to rely upon European science.

An analysis of the knowledge flows across geographical areas by origin of citing patents and origin of cited publications reveals that European patents tend to cite US scientific publications to a larger extent than US patents tend to cite European scientific papers (see also Table I.5.1). In other terms, the empirical evidence shows the existence of an asymmetry in knowledge flows between Europe and the US, with a larger amount of knowledge flowing from the US to Europe than vice versa. Likewise, the propensity of US inventors to rely upon the domestic science base is significantly greater than the propensity of European inventors to exploit their domestic science base.

I.6. From Science to Industry: the case of nanotechnology

Nanotechnology will have a major impact on the world economy, because nanotechnological applications can be used in virtually all sectors. Like ICT, it is a highly pervasive technology that will lead to the improvement of many existing products and will allow the production of completely new ones. The impressive surge, in the mid-nineties, in the creation of new nanotech companies worldwide may be a sign that nanotechnology, in combination with biotechnology, might be a new technological wave comparable to the ICT wave that has already profoundly transformed the world. This section focuses on the R&D performance of Europe in this emerging sector, in comparison with its main competitors.

Public support for European nanotech R&D is large and competitive at world level …

The level of public funding of nanotechnology in Europe is high and is competitive at world level. Public expenditure on nanotechnology R&D by EU Member States along with the European Commission's funding of nanotechnology research amounted to around 1.7 billion euro in 2006 (about 2.2 billion US$, Figure I.6.1), an amount which places the EU ahead of the US (1.8 billion US$), and far ahead of Japan and the other competitors. The European Commission itself, with 532 million euro (665 billion US$) in 2006 and 1.3 billion euro between 2004 and 2006 is the largest funding organisation of nanotechnology research in the world[47].

47 *The economic development of nanotechnology – An indicators based analysis*, Hullmann A., European Commission, DG Research, November 2006, p14.

Figure I.6.1 Public and private funding of nanotechnology R&D, 2006

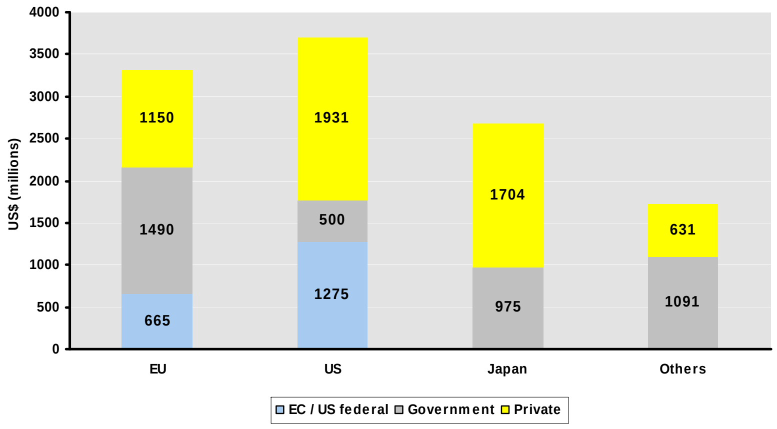
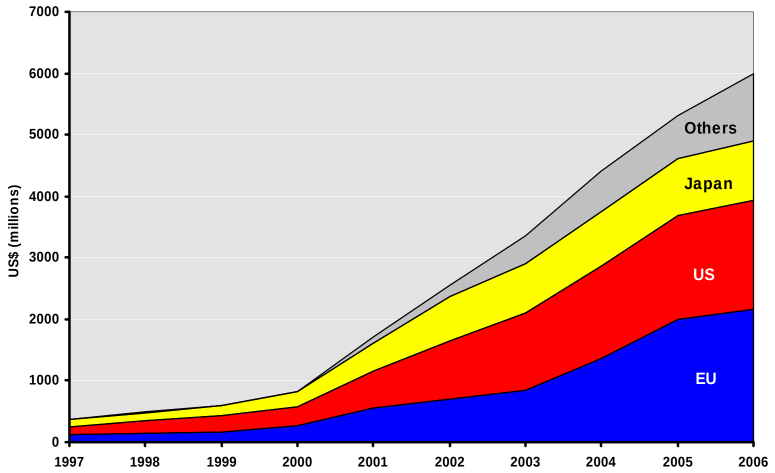


Figure I.6.2 Evolution of public funding of nanotechnology R&D, 1997-2006



Source: DG Research
Data: European Commision and Lux Research

Figure 1.6.2 shows the considerable increase in public funding of nanotechnology R&D in every world region, and particularly in the EU, since 1997. It shows that EU research policy reacted early to the new opportunities offered by nanotechnology and has been actively participating in the "nano race" since the beginning.

In fact, the number of universities and research institutes active in nanotechnology in 2003 was substantially higher in Europe than in North America (US and Canada combined)[48]. As for scientific output, over the years 1998-2001, Europe had the largest world share of scientific publications in nanotechnology (41%), followed by North America (24%)[49]. In terms of impact of publications, as measured by the number of citations *per* paper over the period 1991-2000, however, the EU is clearly lagging behind the US (even though one Member State, the Netherlands, is ahead of the US).

… but the industrial take-off has not yet occurred

Notwithstanding the large public support for European nanotechnology, private investment in nanotechnology R&D remains very low compared to Europe's main competitors. Only one third of the total funding for nanotechnology research in Europe stems from private sources (Figure I.6.1); in the US, private sources account for 52% and in Japan for almost two thirds. In volume, private funding for nanotechnology R&D in Europe is equal to about half of private funding for nanotechnology R&D in the US.

In fact, the number of new nanotech companies created over the last 25 years (and in particular since the mid eighties which saw the nanotech boom[43]) and still active in 2005 is significantly lower in Europe than in North America (US and Canada combined).

48 Ibidem, p 20.
49 Ibidem, p 26.

Consequently, the number of nanotech firms is now much larger in America than in Europe. In particular, the number of nanotech start-ups is several times higher in America than in Europe[50]. Moreover, the majority of European nanotech companies (mainly located in Germany and the United Kingdom) are much smaller in terms of turnover than their counterparts in the US[51]. With less and smaller nanotech companies, research efforts in the private sector are bound to be smaller in Europe than in America. It is not surprising therefore to find that America is by far the most active region in the world for registering patents in nanotechnology. In 2003, American applicants registered about 1200 nanotech patents, compared to slightly more than 400 from European applicants[52]. Altogether, the European nanotech industry is clearly lagging behind.

Moreover, other countries such as Japan, China, India and the Russian Federation in particular, are emerging in the field of nanotechnology. Although they may still lag behind for most indicators, they are in a position to develop and expand and bridge the gap with Europe. They will very probably become serious competitors on the world market and attractive locations for research activities.

Europe has missed the ICT wave and may now be about to miss the nanotechnology wave, in spite of a strong commitment from public authorities to finance and develop nanotech research in Europe. European industry has not yet been able to build upon the strong and competitive European science base in nanotech and to substantially

50 Ibidem, p20.
51 Ibidem, p 19. This observation is based on a sample of 357 companies all over the world, from a survey by Fecht et al., *Nanotechnology Market and Company Report – Finding HiddenPearls*, WMtech Center of Excellence Micro and Nanomaterials, Ulm, 2003.
52 Ibidem, p 23.

increase its research efforts. The nanotechnology field is undoubtedly a very good example of Europe's difficulty in translating science into innovation and in creating innovative products and commercial activities from scientific results. This difficulty is revealed by the massive gap in Europe between the development of the science base and that of the nanotech industry.

I.7. S&T performance and competitiveness

EU, US and Japan account for most of the most important (triadic) patents

Europe, the US and Japan are the most important producers of triadic patents. These relate to those inventions for which patent protection is sought simultaneously at the three main patent offices of the triad.[53]

However, a number of emerging countries, mainly in Asia, have seen rapid growth in such patent applications, most notably China in respect of which triadic patents rose ninefold between 1995 and 2003 (Table I.7.1). Indeed, China has now joined the top ten countries filing international patents according to the World Intellectual Property Organization (WIPO), with filings for 2005 having increased by 47 per cent compared to 2004.[54] South Korea, India and Singapore have also expanded their patenting activities very significantly since the early 1990s.

Table I.7.1 Triadic patents by priority year and residence of inventor

	1990	1995	2000	2003
US	11062	11999	17440	19701
EU-27 (1)	9903	11328	16057	16108
Japan	9904	9389	13086	13557
South Korea	67	325	644	839
China	12	19	90	184
Taiwan	10	23	77	108
India	12	12	58	87
Singapore	4	24	79	84
Russian Federation	21	51	66	59
Hong Kong	11	20	33	40
South Africa	14	24	37	36
Brazil	11	13	27	35

Source : DG Research

Key Figures 2007

Data : OECD

Note: (1) EU-27 does not include BG.

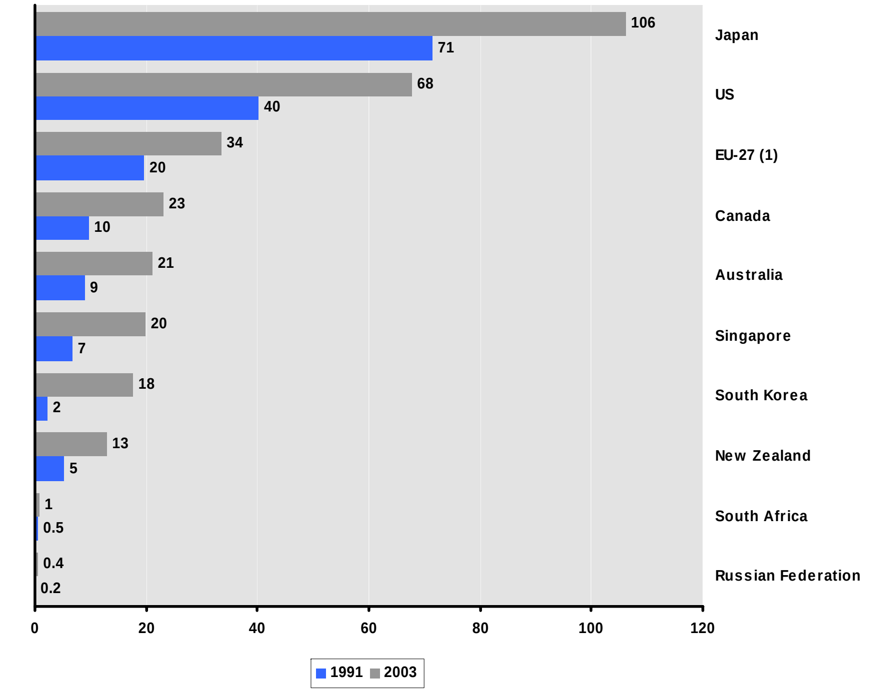
Europe lags behind the US and Japan in terms of patent intensity

Of course it is important to relate the volume of patenting to the size of the country. In terms of triadic patents per capita, Europe lags behind the US and Japan, with 34 triadic patents per million population in 2003, compared to 68 for the US and 106 for Japan (Figure I.7.1).

53 The European Patent Office, the US Patent and Trademark Office and the Japanese Patent Office. Because it is expensive to apply for patents in several offices, such patents generally relate to inventions which promise a high economic return.

54 PCT international applications – see http://www.wipo.int/ipstats/en/statistics/patents/

Figure I.7.1 Triadic patents per million population by priority year and residence of inventor



Source: DG Research Key Figures 2007
Data: OECD, Eurostat
Note: (1) EU-27 does not include BG.

The US patents more than Europe in high-tech areas

While, overall, EU inventors apply for more patents at the European Patent Office than their US counterparts, they are less prolific when it comes to patenting in high tech areas. The EU's share of total EPO patents stood at 38% in 2003, compared with 30% for the US, however, its share of high tech patents was only 29% compared with 37% for the US (Table I.7.2). A more detailed analysis of these data (Table I.7.2) confirms that the US is ahead of the EU in four out of six high-tech areas: (1) computers and automated business equipment, (2) micro-organisms and genetic engineering, (3) lasers, and (4) semi-conductors. On the other hand, the EU leads in aviation, and in communication technology.

Once again one sees the emergence of the Asian economies (such as China, India, South.Korea and Singapore) in various fields of patenting, as well as other new players such as Brazil, South Africa and the Russian Federation. While these economies still have rather modest numbers of patents in absolute terms, their patent applications have grown at a very rapid rate.

Table I.7.2 Patent applications at the European Patent Office (EPO) by priority year

	Total patent applications				High-tech patent applications			
	Total		% share		Total		% share	
	1995	2003	1995	2003	1995	2003	1995	2003
World - total	83817	163011	100.0	100.0	14826	37644	100.0	100.0
EU-27	35335	62250	42.2	38.2	4405	10840	29.7	28.8
US	28293	48786	33.8	29.9	6453	13845	43.5	36.8
Japan	13301	27987	15.9	17.2	3055	6834	20.6	18.2
South Korea	551	5400	0.7	3.3	135	1924	0.9	5.1
Switzerland	1872	3113	2.2	1.9	115	331	0.8	0.9
Canada	1217	2736	1.5	1.7	263	793	1.8	2.1
Australia	905	1958	1.1	1.2	134	396	0.9	1.1
China (1)	120	1898	0.1	1.2	12	703	0.1	1.9
Israel	502	1587	0.6	1.0	92	490	0.6	1.3
India	41	1003	0.05	0.6	2	164	0.02	0.4
Russian Federation	309	641	0.4	0.4	38	108	0.3	0.3
Taiwan	107	572	0.1	0.4	15	119	0.1	0.3
Norway	358	533	0.4	0.3	24	90	0.2	0.2
Singapore	61	416	0.1	0.3	17	196	0.1	0.5
South Africa	125	415	0.1	0.3	10	54	0.1	0.1
New Zealand	158	376	0.2	0.2	8	59	0.1	0.2
Brazil	87	348	0.1	0.2	6	36	0.04	0.1
Mexico	40	145	0.05	0.1	:	:	:	:

Source: DG Research Key Figures 2007
Data: Eurostat, OECD
Note: (1) CN : Hong Kong is not included.

Table I.7.3 Patent applications at the European Patent Office (EPO) by high technology field

Computer and automated business equipment

	Total		% share	
	1995	2003	1995	2003
World - total	4360	12584	100.0	100.0
US	2191	5479	50.3	43.5
EU-27	881	3242	20.2	25.8
Japan	1064	2088	24.4	16.6
South Korea	32	395	0.7	3.1
Canada	43	230	1.0	1.8
Australia	34	189	0.8	1.5
China (1)	5	131	0.1	1.0
India	1	84	0.01	0.7

Micro-organism and genetic engineering

	Total		% share	
	1995	2003	1995	2003
World - total	2679	4857	100.0	100.0
US	1331	2060	49.7	42.4
EU-27	831	1349	31.0	27.8
Japan	278	704	10.4	14.5
Canada	74	125	2.8	2.6
South Korea	10	102	0.4	2.1
Australia	63	99	2.3	2.0
China (1)	3	89	0.1	1.8
India	2	40	0.1	0.8

Aviation

	Total		% share	
	1995	2003	1995	2003
World - total	218	475	100.0	100.0
EU-27	77	256	35.3	54.0
US	106	153	48.4	32.3
Japan	8	18	3.7	3.8
Canada	10	11	4.4	2.3
Russian Federation	5	10	2.3	2.1
China (1)	1	5	0.5	1.1
South Korea	:	2	:	0.4

Communication technology

	Total		% share	
	1995	2003	1995	2003
World - total	5525	14991	100.0	100.0
EU-27	2048	4932	37.1	32.9
US	2047	4475	37.1	29.8
Japan	1081	2583	19.6	17.2
South Korea	79	1203	1.4	8.0
China (1)	3	449	0.0	3.0
Canada	122	395	2.2	2.6
Australia	29	86	0.5	0.6
Singapore	8	71	0.1	0.5

Semiconductors

	Total		% share	
	1995	2003	1995	2003
World - total	1764	4315	100.0	100.0
US	690	1520	39.1	35.2
Japan	559	1351	31.7	31.3
EU-27	451	943	25.6	21.9
South Korea	12	207	0.7	4.8
China (1)	:	28	:	0.6
Singapore	3	27	0.2	0.6
Taiwan	2	25	0.1	0.6
Canada	12	24	0.7	0.5

Laser

	Total		% share	
	1995	2003	1995	2003
World - total	280	422	100.0	100.0
US	88	158	31.3	37.4
EU-27	117	118	41.7	27.9
Japan	65	90	23.3	21.4
South Korea	1	15	0.4	3.6
Canada	3	8	1.1	1.9
Australia	1	4	0.4	0.9
Russian Federation	0	2	0.1	0.6
Singapore	:	1	:	0.2

Source: DG Research

Data: Eurostat, OECD

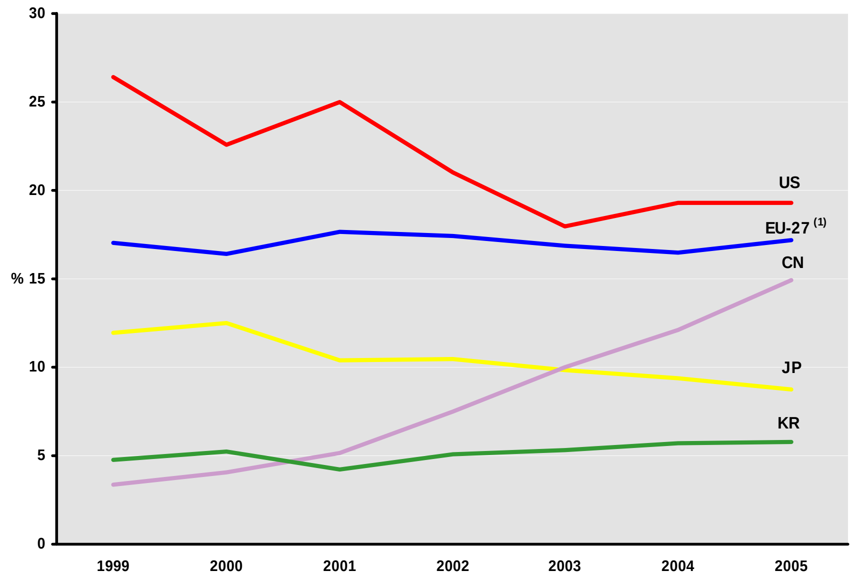
Notes: (1) CN : Hong Kong is not included.

Key Figures 2007

Europe's share of trade in high-tech products is stable, while China's market share has grown significantly

The EU's share of the global high-tech market has remained more or less stable since 1999, at around 17% (Figure I.7.2). The main feature of the last few years has been the rapid emergence of China, not just as a trading nation, but also as a major exporter of high technology goods. China's share of high-tech exports rose from 3% in 1999 to 15% in 2005, overtaking Japan in respect of which the share fell to 9% in 2005. Chinese high-tech exports have grown by nearly 30% annually since 1999. Over the same period, the US has seen its international sales of high-tech products fall significantly, from 26% to 19%. However, South Korea continues to be one of the important exporters of technology products, with a still rising share of the global market. India and Brazil have also registered increases in their high-tech trade, although their share of world exports is still very small.

Figure I.7.2 Exports of high-tech products - world market shares, 1999-2005



Source : DG Research, JRC-Ispra

Data: Eurostat (Comext), UN (Comtrade)

Note: (1) EU-27 does not include BG and RO.

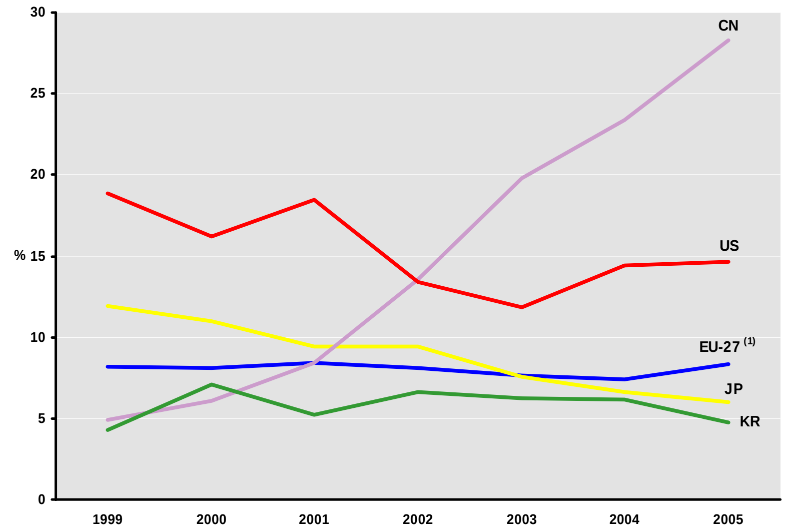
Key Figures 2007

China is now the top exporter of computers, and second to the US in electronics and telecoms

Looking in more detail, one sees that the growth in Chinese high-tech exports has been particularly significant in two key areas: computers, where it is now the world's number one exporter, and electronics and telecoms, where it is now second only to the US (Figures I.7.3 and I.7.4). In the latter area, South Korea is still a significant exporter, with nearly 5% of the global market in 2005. Although Europe's share of these two markets has remained fairly stable, but still significantly below the US and China, the shares of Japan and the US have declined markedly since 1999.

However, when it comes to exports of pharmaceuticals (Figure I.7.5), the EU ranks number one with a market share of 46% in 2005, which is double that of the US. This is a sector still dominated by the traditional players (notably the EU, US and Switzerland). Other countries have much lower shares of the global market, but some emerging countries such as China and India are gradually expanding their export sales.

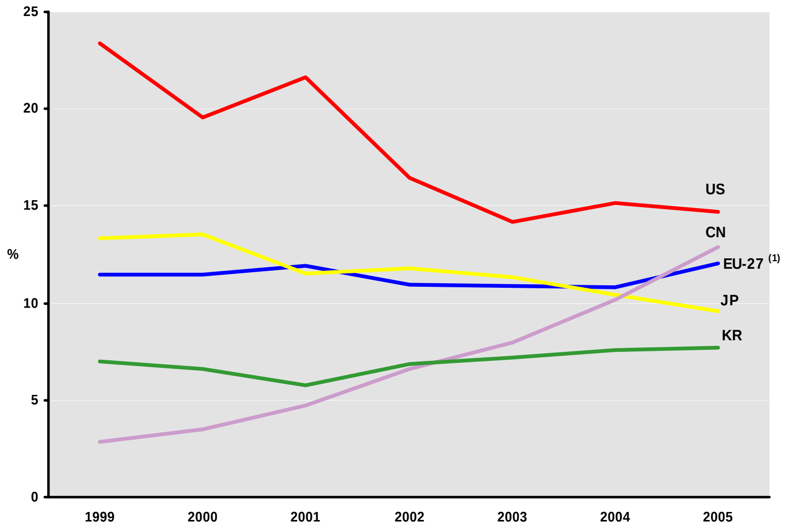
Figure I.7.3 World market shares - exports of computers and office machinery, 1999-2005



Source : DG Research, JRC-Ispra
Data: Eurostat (Comext), UN (Comtrade)
Note: (1) EU-27 does not include BG and RO.

Key Figures 2007

Figure I.7.4 World market shares - exports of electronics and telecoms, 1999-2005



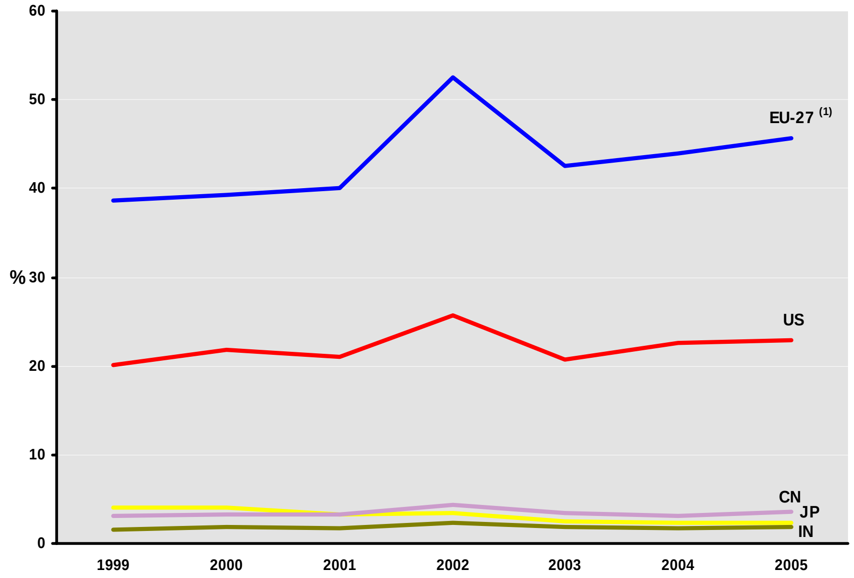
Source : DG Research, JRC-Ispra

Key Figures 2007

Data: Eurostat (Comext), UN (Comtrade)

Note: (1) EU-27 does not include BG and RO.

Figure I.7.5 World market shares - exports of pharmaceuticals, 1999-2005



Source : DG Research, JRC-Ispra

Key Figures 2007

Data: Eurostat (Comext), UN (Comtrade)

Note: (1) EU-27 does not include BG and RO.

Part II: The EU and the European Research Area

Part II examines intra-European differences, similarities, convergences and divergences within the European Research Area (ERA), by analysing the performances of the Member States in relation to each other and to the EU average. Other European countries including the EFTA countries of Iceland, Norway and Switzerland and the EU candidate countries of Turkey and Croatia, as well as countries associated with the European Commission's Framework Programmes such as Israel are included in the analysis in so far as is possible.

Part II is structured as follows. Section II.1 deals with patterns of R&D funding and performance within the EU. Section II.2 focuses on human resources for Science and Technology. Sections II.3 and II.4 regroup indicators on scientific and technological output; they include an analysis of scientific specialisation profiles within the ERA. Finally, Section II.5 explores the impacts of Science and Technology on the competitiveness of European countries, by looking at indicators such as high-tech trade, value added in high-tech industries and labour productivity.

II-1 Expenditure on R&D

II-1-1 Overall investment in R&D and its financing

Introduction

A common policy trend across EU Member States concerns the important place of R&D and R&D investment in the overall policy agendas. Under the influence of the Lisbon strategy (2000), the Barcelona '3%' objective (2002) for more investment in research in Europe (with increased private sector funding) and the renewed Lisbon strategy (2005), R&D is increasingly considered a key source for sustaining economic growth and welfare. Member States are developing commonly shared R&D policy objectives: recently, and consequent to the renewed Lisbon strategy in 2005, almost all Member States have set targets for R&D investment.

This section takes a look at the latest developments in R&D investment. The volume of financial resources allocated to R&D is an indicator of the level of commitment to the production and exploitation of new knowledge, as well as an indirect measure of a country's innovation capacity. Both the evolution of R&D intensity (i.e. total R&D expenditure as % of GDP) in the EU and its Member States, as well as the structure of the financing of R&D in the different national research systems, are examined.

R&D intensity in Europe: large disparities and limited convergence

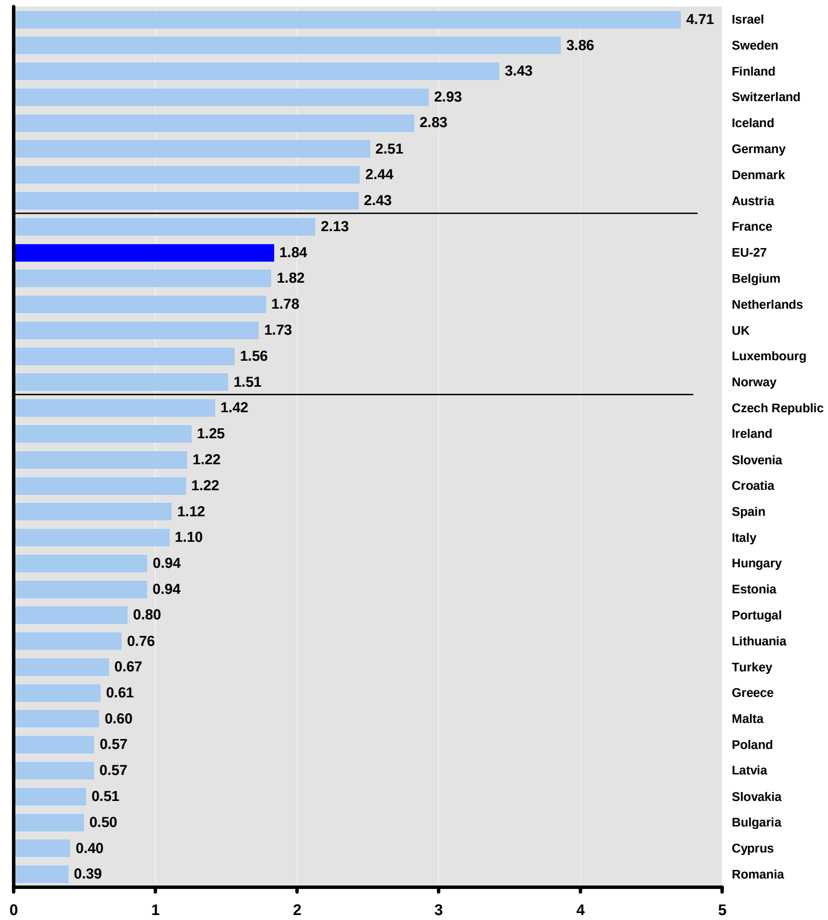
In 2005, EU R&D intensity amounted to 1.84%. Broadly speaking, one can distinguish three groups of countries according to the share of their GDP devoted to R&D (Figure II.1.1).

The three Nordic countries, Sweden, Finland and Denmark, as well as Germany and Austria, top the EU ranking with values above 2.4% of GDP and therefore form the group of high R&D-intensive Member States. In fact, Sweden and Finland spend significantly more than 3% of the national wealth on R&D. A second group consisting of five countries – France, Belgium, the Netherlands, the United Kingdom and Luxembourg – is close to the EU average with values between 1.5% and 2.2% of GDP. Among them, France is the only Member State scoring above average. A third large group, including the southern European countries and the new Member States, shows R&D intensities below 1.5%. Differences within that group are still large, with countries such as the Czech Republic and Slovenia showing intensities well above 1% and others such as Romania devoting less than 0.4% of GDP to R&D.

Figure II.1.2 compares the 2005 level of R&D intensity of each Member State with its recent growth performance (2000-2005). After a period of slow but continued growth from 1.80% in 1998 to 1.88% in 2001, EU-27 R&D intensity stagnated in 2001-2002 and decreased slightly after that to fall back to its pre-1999 level.

An examination of the individual Member States' pace of progress since 2000 reveals a distinction between four groups of EU countries. With the exception of Sweden, all high R&D-intensive Member States (Finland, Denmark, Austria and Germany) have been able to increase their already high R&D intensities between 2000 and 2005. These countries, among which Austria demonstrates the

Figure II.1.1 R&D intensity (GERD as % of GDP), 2005 (1)

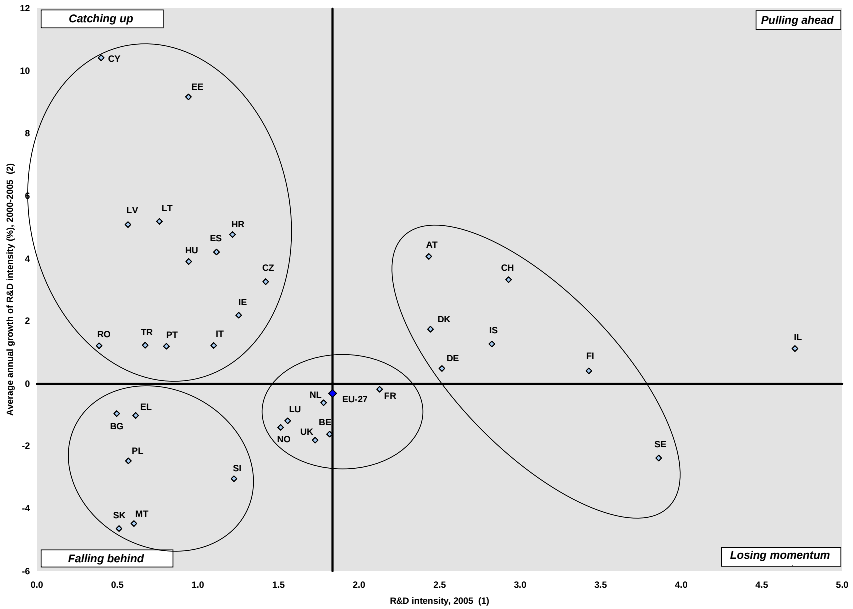


Source: DG Research
Data: Eurostat, OECD
Note: (1) IT, NL, RO, UK, HR, TR, IS, CH : 2004; AT, FI : 2006.

Key Figures 2007

most impressive rate of growth, are pulling further ahead of the EU average. For Sweden, a clear trend reversal occurred in 2001-2002: after having increased sharply from 3.59% in 1998 to 4.25% in 2001, Sweden's R&D intensity declined significantly after that and is now 3.86%.

Figure II.1.2 R&D intensity, 2005 and average annual growth, 2000-2005



Source: DG Research   Key Figures 2007
Data: Eurostat, OECD
Notes: (1) IT, NL, RO, UK, HR, TR, IS, CH : 2004; AT, FI : 2006.
(2) IT, NL, RO, UK, TR, IS, CH : 2000-2004; AT, FI : 2000-2006; EL, SE, NO : 2001-2005; HR : 2002-2004; MT : 2004-2005.

The group of Member States with average R&D intensities (France, the United Kingdom and the Benelux countries of Belgium, the Netherlands and Luxembourg) all experienced declining R&D intensities between 2000 and 2005. France, whose R&D intensity is still above average, is losing momentum. The majority of the low R&D-intensive Member States (i.e. R&D intensity below 1.5%) is catching up with the remainder of the Union, albeit at different speeds. Finally, a group of six low R&D-intensive Member States, including Greece, Bulgaria, Poland, Slovenia, Malta and Slovakia, has been falling further behind since 2000.

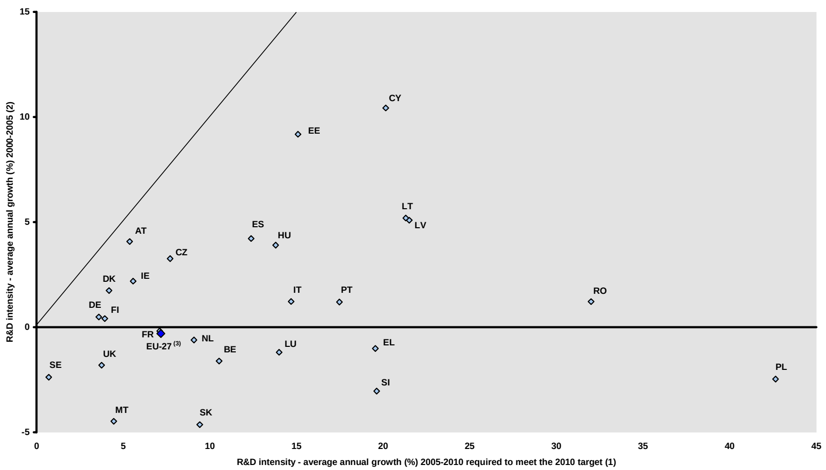
Member States' targets for increased R&D investment are often very ambitious

As a consequence of increased commitments to the renewed Lisbon strategy and the 3% objective, 26 Member States have set targets for their R&D intensities for 2010 or other years (the target is not necessarily 3%). Bulgaria is the only Member State which does not have a target. If the Member States reach their objectives, the overall EU-27 R&D intensity will have progressed substantially to about 2.6% by 2010.

By comparing the annual rate of growth in R&D intensity necessary to meet each Member State’s national target, under the revised Lisbon strategy, with the rate of growth experienced over recent years (2000-2005), we can assess the level of ambition of these targets (Figure II.1.3).

A number of countries close to the bisector (Austria, Denmark, Ireland, Germany and Finland) have experienced rates of growth which, if they are maintained, will be sufficient to advance significantly towards their targets. A larger group of countries has experienced a positive average rate of growth since 2000, but will need to step up its efforts significantly if it is to deliver on the level of ambition reflected in these targets. An equally large group of countries has experienced a negative average rate of growth over the past five years and will therefore need to reverse a declining trend if it is to start progressing towards these targets. For these countries, the targets set are extremely ambitious: delivering on the ambition reflected in them will require strong commitment and radical reform packages.

Figure II.1.3 R&D intensity - average annual growth (%), 2000-2005 and average annual growth (%) required to meet the 2010 target



Data: Eurostat, Member States — Key Figures 2007

Notes: (1) RO : 2004-2009; IT, NL, UK : 2004-2010; PL : 2005-2008; AT, FI : 2006-2010.
(2) IT, NL, RO, UK : 2000-2004; AT, FI : 2000-2006; EL, SE : 2001-2005; MT : 2004-2005.
(3) EU-27 does not include Bulgaria.
(4) IE, PL, RO, UK : R&D intensity targets for 2010 were estimated on the basis of data provided by these countries.

If, however, the current negative trend persists as observed since 2000, EU-27 R&D intensity will have further declined by 2010 to its mid-Nineties level of below 1.80% of GDP.

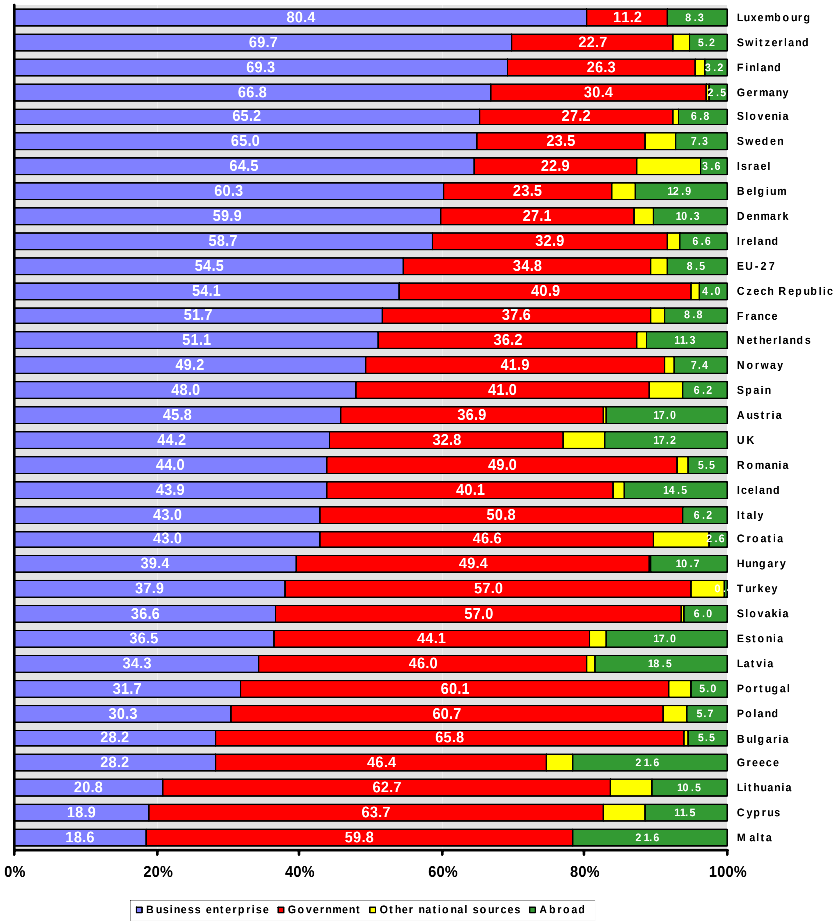
Contribution from the private sector to the financing of R&D: large disparities in the EU

The Barcelona objectives target an increase in both the overall expenditure on R&D (to approach 3% of GDP allocated to R&D by 2010) and the share of R&D expenditure funded by the private sector. According to the Barcelona objectives, two-thirds of total R&D expenditure should be funded by the business enterprise sector.

In 2005, the business enterprise sector financed 54.5% of total R&D expenditure in the EU-27. Government accounted for slightly more than one-third of the Union's R&D spending (34.5%), while 8.5% of total R&D expenditure was funded from abroad (both from private and public sources). High R&D-intensive Member States such as Germany and the Nordic countries of Finland, Sweden and Denmark are characterised by a high involvement of the private sector in the financing of domestic R&D activities. Conversely, the government sector accounts for a large share of R&D funding in most of the new Member States and in the southern European countries. In 2005, more than 60% of R&D in Poland, Bulgaria, Lithuania and Cyprus was funded by the government sector.

It should be borne in mind, however, that the shares of domestic R&D expenditure financed from private and public sources are subject to a certain margin of error, due to the non-availability of a breakdown between private and public sources in the category 'funded from abroad'. At EU-27 level, funding from abroad represents 8.5% of total R&D expenditure. Since it can be assumed that an important part thereof comes from private sources (from abroad), it is very likely that the share of the private sector in the financing of domestic R&D is in reality significantly higher than 54.5%.

Figure II.1.4 R&D expenditure by main sources of funds (%), 2005 (1)



Source: DG Research Key Figures 2007
Data: Eurostat, OECD
Notes: (1) IT : 1996; MT, IL : 2002; BE, DK, EL, LU, NL, PT, SE, IS, NO : 2003; BG, DE, EE, ES, FR, CY, RO, FI, UK, HR, TR : 2004; AT : 2006.

At country level, this margin of error is likely to be large for Member States where a substantial share of domestic R&D expenditure is funded from abroad, such as the United Kingdom, Austria, Estonia, Latvia, Greece and Malta. In these countries, around one-fifth of domestic R&D is funded from abroad. Unfortunately, an accurate monitoring of the total private sector contribution to the financing of R&D will not be possible until statistical data on the breakdown between private and public funding of R&D from abroad become available from all Member States.

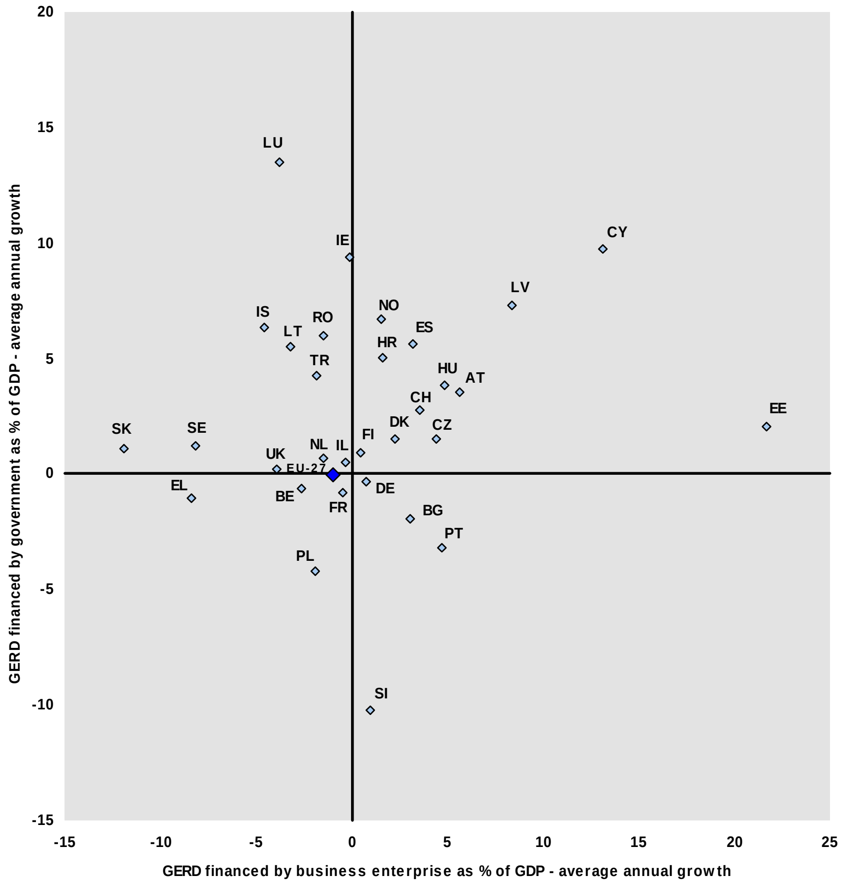
Changes in R&D intensity and the contribution of the funding sectors

How did the contributions of the business enterprise sector and the public sector to the financing of R&D activities evolve over recent years? At EU-27 level, the declining R&D intensity is exclusively due to the diminishing contribution from the private sector, while the amount of R&D expenditure funded by the government sector has remained extremely stable at 0.64% of GDP between 2000 and 2005.

For the countries with established high R&D intensities, the further growth of R&D intensity was mainly driven by the business sector in Austria and Germany, and by both the private and public sectors in Finland and Denmark. Sweden's declining R&D intensity after 2002 was exclusively caused by the sharply reduced contribution from the business enterprise sector.

Among the low R&D-intensive Member States that are catching up (i.e. those where the overall R&D intensity is increasing faster than the EU average), the catching-up process has been largely driven by the business sector in Hungary, the Czech Republic, Latvia, Cyprus, Estonia and Portugal, whereas in Spain, Ireland, Romania and Lithuania it largely reflects an increased contribution from the public sector.

Figure II.1.5 GERD financed by business enterprise and by government as % of GDP - average annual growth, 2000-2005 (1)



Source: DG Research Key Figures 2007
Data: Eurostat, OECD
Notes: (1) IL: 2000-2002; BE, LU, NL, PT: 2000-2003; BG, DE, EE, ES, FR, CY, RO, FI, UK, TR, CH: 2000-2004; AT: 2000-2006; DK, EL, SE, NO, IS: 2001-2003; HR : 2002-2004.
(2) IT and MT are not included due to unavailability of data.

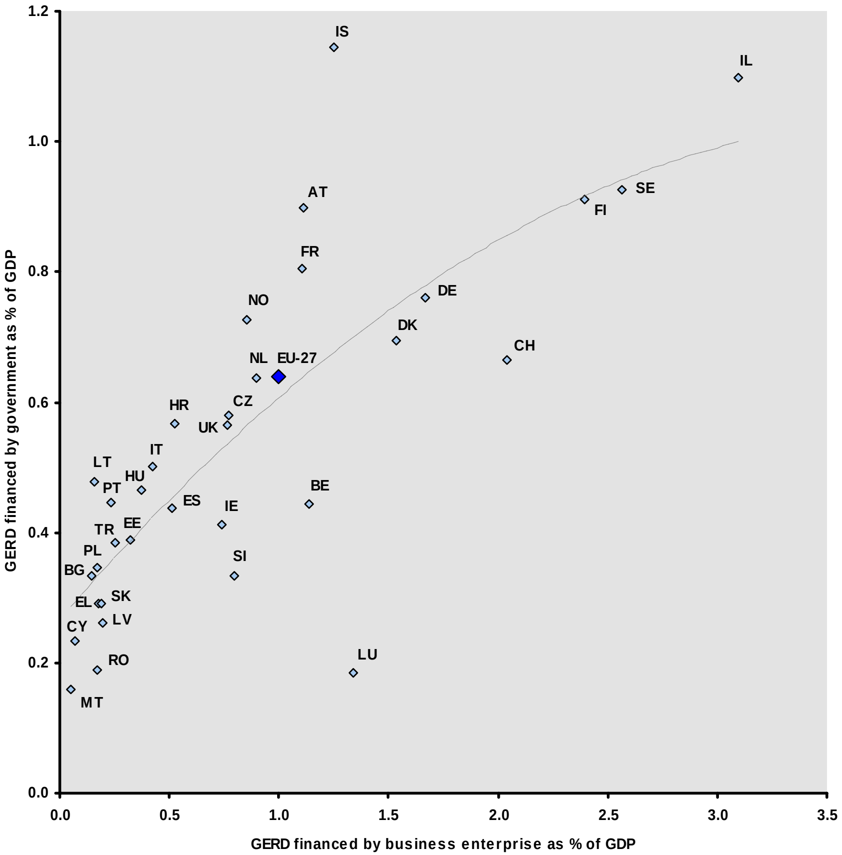
Among the low R&D-intensive Member States where overall R&D intensity has been falling further behind the EU average, this has been primarily caused by the weakened contribution from the private sector in Greece and Slovakia, whereas in Bulgaria, Slovenia and to a lesser extent Poland, it has been exclusively due to reduced funding from the government sector.

High R&D-intensive Member States maintain relatively high levels of government-funded R&D

Although domestic R&D efforts are largely financed by the business enterprise sector in the EU, the role of government in the financing of R&D should not be underestimated. As has already been said, the high R&D-intensive Member States of Finland, Sweden, Denmark, Austria and Germany are characterised by a high level of involvement by the private sector in funding these activities. In these countries, however, the level of government-funded R&D is still very substantial, showing that high private involvement in R&D financing does not preclude government funding (see Figure II.1.6). No substitution effect seems to occur; on the contrary, high contributions from the private sector go hand-in-hand with high levels of public funding.

Moreover, in low R&D-intensive countries, government-funded R&D is more important than business-funded R&D. Government funding of R&D is critical for creating and developing science and technology (S&T) capabilities – a prerequisite for catching up with countries at the technology frontier – and for supporting research projects with high expected social benefits, which the private sector may not find sufficiently attractive.

Figure II.1.6 GERD financed by business enterprise and by government as % of GDP, 2005 (1)



Source: DG Research — Key Figures 2007

Data: Eurostat, OECD

Note: (1) IT : 1996; MT, IL : 2002; BE, DK, EL, LU, NL, PT, SE, IS, NO : 2003; BG, DE, EE, ES, FR, CY, RO, FI, UK, HR, TR, CH : 2004; AT : 2006.

II-1-2 R&D in the business enterprise sector

Introduction

The level and intensity of overall expenditure on R&D are key determinants of the future competitiveness of an economy. In the short term, the business sector is probably the most important sector of the economy in this regard: it is closest to consumers and is best positioned to significantly improve or develop products based on new combinations of existing knowledge, or knowledge newly developed through research in-house or elsewhere, and to exploit them commercially. Business R&D expenditure is market-driven and accounts for an important share of innovation expenditure. In a direct way and also by stimulating other sectors, it contributes directly to employment and economic growth. Trends in the performance of business sector R&D are therefore a key concern for policy-makers. That is why the European Council of Ministers has stipulated that two-thirds of R&D expenditure should be financed by the business sector.

Trends in business R&D: business R&D intensity did not grow in 2005 …

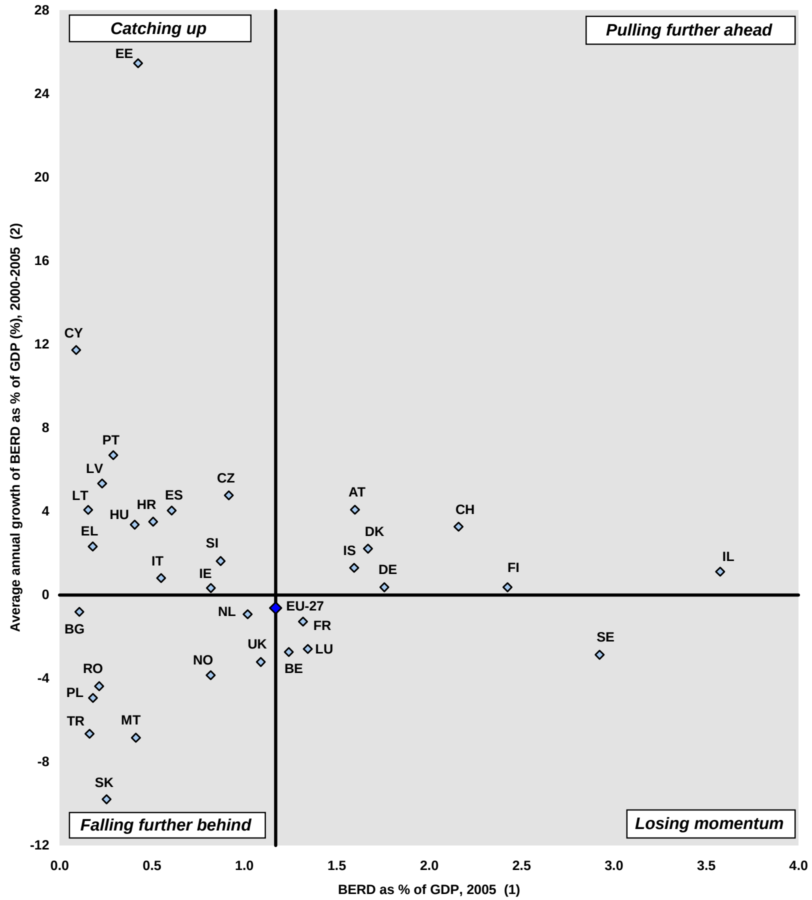
In 2005, the EU had a business R&D intensity of only 1.17% (Figure II.1.7), a value which was the same in 2004. Even more worrying is the fact that this value has decreased since 2000 (with an average annual growth of -0.6%), despite the acknowledged importance of business R&D for the future competitiveness of the European economy.

Four groups of countries may be distinguished in Figure II.1.7. Countries in the upper right panel of the graph have business R&D intensities above the EU average and are still experiencing a further growth in these intensities. Germany, Denmark, Austria and Finland, as well as Iceland, Switzerland and Israel, are pulling further ahead (see below for a more detailed analysis of the sectors driving these increases).

Another group of countries have business R&D intensities above the EU average in 2005 but have experienced decreases in these intensities since 2000 (lower right panel of Figure II.1.7). Belgium, France and Luxemburg are losing momentum; their business R&D intensities will fall below the EU average very soon if the current trend continues. Sweden also has experienced a comparable decrease since 2000 (see below for a sectoral analysis of this fall), but its current business R&D intensity of 2.92% is the highest in the EU and is far above that of France and Belgium..

A number of countries are falling further behind, with both decreasing business R&D intensities between 2000 and 2005, and below EU -average business R&D intensities in 2005 (lower left panel of Figure II.1.7). In the case of the United Kingdom, business R&D intensity was above the EU average in 1999, but has been declining since and is now significantly below the EU average[55]. The Netherlands, with a business R&D intensity of 1.02%, is still close to the EU average; with a decrease that is both small and similar to that of the EU, its relative position remains much the same. Norway is now clearly losing momentum.

Figure II.1.7 BERD as % of GDP, 2005 and average annual growth, 2000-2005



Source: DG Research Key Figures 2007
Data: Eurostat, OECD
Notes: (1) RO, UK, HR, TR, IS, CH : 2004; IT, FI : 2006.
(2) RO, TR, IS, CH : 2000-2004; IT, FI : 2000-2006; UK : 2001-2004; FR, SE, NO : 2001-2005; HR : 2002-2004; ES, AT : 2002-2005; MT : 2004-2005.

55 It must be noted, however, that the United Kingdom has experienced a relatively high GDP growth in recent years. The decrease in business R&D intensity since 1999 is due to the fact that business R&D expenditure grew more slowly than GDP.

More worrying is the persistent negative trend of five new Member States – Bulgaria, Malta, Poland, Romania and Slovakia – and Turkey, all of which already have extremely low business R&D intensities (less than 0.45% for all of them in 2005). The decrease is very marked in all of them except Bulgaria. The very weak business R&D activity in these countries is in the process of disappearing entirely.

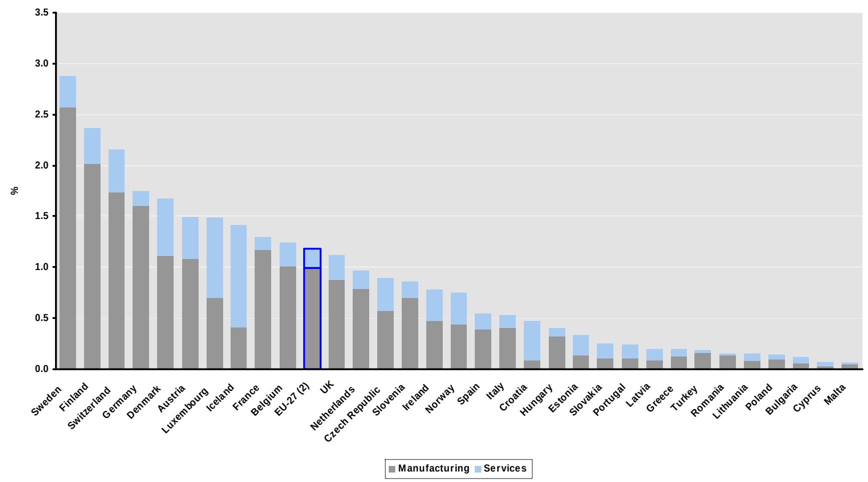
The situation is different for all of the other new Member States which have been catching up between 2000 and 2005 (upper left panel of Figure II.1.7), some of them like Cyprus and Estonia at a very fast pace (Estonia has an average annual growth of business R&D intensity of 25.5%). However, all of them still lag well behind the EU average. The Czech Republic was the top performer of this group in 2005, with a business R&D intensity of 0.92%.

Greece and Portugal, while increasing their business R&D efforts, have already been overtaken by several of the new Member States. Italy too has been caught up by some new Member States: it now has a lower business R&D intensity than the Czech Republic and Slovenia and a lower average annual growth of business R&D intensity than all of the countries in this group except Ireland. Spain is in the same situation regarding business R&D intensity as the bulk of the Member States that are currently catching up.

BERD in services: low but growing business R&D intensity in the services sector

Business enterprise expenditure on R&D (BERD) in the services sector in EU-27 amounts to 0.18% of GDP (Figure II.1.8), compared to 0.13% in 1998, i.e. a growth of almost 40% in less than 10 years. It remains low, however, compared to total EU-27 business R&D expenditure, which amounts to 1.17% of GDP. Only 15% of all EU-27 business R&D is thus performed in the services sector.

Figure II.1.8 BERD performed in the manufacturing sector and in the services sector as % of GDP, 2004 (1)



Source: DG Research — Key Figures 2007
Data: OECD, Eurostat
Notes: (1) MT, TR : 2002; EL, FR, LU, PT, SE, EU-27, IS, RU, US, JP, AU : 2003; CZ, LV, LT, NL, SI, SK : 2005.
(2) EU-27 was estimated by DG Research and does not include MT.

For most EU and EFTA countries, business R&D expenditure in the services sector expressed as a percentage of GDP has increased since 1998. The only exceptions are Latvia and Slovakia, which experienced a substantial decrease, and France and Norway where BERD performed in the services sector remained stable over the last 10 years (not shown).

The highest shares of the services sector in BERD are to be found in small and open economies with average-to-high R&D intensities: Iceland, Luxembourg, Denmark, Austria, Switzerland, the Czech Republic, Norway and Ireland. In Germany and France, in particular, BERD is almost totally performed in the manufacturing sector[56].

56 It must be borne in mind, however, that differences in the way R&D expenditure is allocated to industrial sectors (e.g. manufacturing versus

In a majority of low business R&D-intensive countries, the share of the services sector in BERD is relatively high, comparable to the share of the manufacturing sector (Latvia, Lithuania, Poland, Bulgaria) or higher (Croatia, Estonia, Slovakia, Portugal, Cyprus). In these countries, the level of business R&D expenditure in the services sector has rapidly reached the level of manufacturing business R&D over the last 10 years.

In view of the limited share of BERD performed in the services sector in the EU, it is relevant to focus on the sectors driving business R&D in the manufacturing sector.

Manufacturing BERD by technology intensity: the EU countries with the highest R&D intensities also have the highest shares of R&D performed by high-tech manufacturing industries

In 2003, the share of high-tech manufacturing industries in total manufacturing R&D expenditure in the EU was 46.7% with a wide distribution of shares across the Member States, ranging from 8.7% for Lithuania to 70.3% for Slovenia. European industrial expenditure on R&D is concentrated with almost equal force on medium-high-tech manufacturing, with a share of 42% at EU level and shares for individual Member States ranging from 18.9% for Slovenia to 66.6% for the Czech Republic.

There are therefore marked national differences within Europe in the distribution of manufacturing R&D in terms of technology intensity. The countries where the share of manufacturing R&D performed in high-tech industries is the highest are Slovenia, Finland, Ireland, the United Kingdom and Hungary with more than 60%, followed by Sweden, Denmark, France, Cyprus and the Netherlands with more than 50%[57]. In general, countries with the highest shares of R&D performed by high-tech manufacturing industries also have the highest business R&D intensities.

There are exceptions to this rule. Germany has one of the highest business R&D intensities in Europe (see Figure II.1.7), while spending only 33.5% of manufacturing R&D expenditure on high-tech manufacturing. In fact, Germany's business R&D is very much concentrated in medium-high-tech manufacturing (58.6%). On the other hand, there are countries with low to very low business R&D intensities, but with reasonable or even high shares of R&D expenditure on high-tech manufacturing. This is the case for Ireland, Greece[58], Cyprus[59], Hungary, and also for Slovenia. It must be noted however that, the low to very low business R&D intensities for these countries are all growing. The high-tech sector is therefore a driver of the business R&D intensity growth in these countries.

services industries) in the national surveys may limit the comparability of the data on services BERD between European countries (see for instance OECD (2005), *Business enterprise R&D data by industry – A review of Anberd and other issues*, (DSTI/EAS/STP/NESTI(2005)12), May 2005, 22 p).

[57] It must be noted that the manufacturing BERD in Cyprus is close to zero, so that the distribution among industry types is subject to great variations and therefore is not very relevant.

[58] The previous footnote also holds for Greece.

[59] Ibidem.

Table II.1.1 Manufacturing BERD by type of industry, 2004 [1]

	High-Tech	Medium-High-Tech	Medium-Low-Tech	Low-Tech
Lithuania	8.7	60.5	7.0	23.8
Czech Republic	18.8	66.6	10.8	3.9
Malta	28.5	42.8	14.3	14.3
Turkey	29.4	44.2	18.9	7.5
Poland	30.5	48.2	11.8	9.5
Norway	31.6	32.5	16.1	19.8
Germany	33.5	58.6	5.7	2.1
Spain	35.9	39.1	13.8	11.2
Croatia	37.7	19.5	20.8	22.1
Latvia	39.0	39.1	13.6	8.3
Iceland	45.1	29.8	6.2	18.9
Italy	46.5	41.0	6.7	5.8
EU-27 [2]	46.7	42.3	6.6	4.4
Greece	47.2	32.7	4.9	15.3
Belgium	49.5	29.9	14.1	6.5
Netherlands	50.9	36.9	4.2	8.0
Cyprus	51.0	23.3	2.4	23.3
France	51.8	34.8	8.8	4.6
Denmark	57.9	26.5	4.0	11.6
Sweden	58.5	34.1	3.9	3.5
Hungary	60.2	32.1	4.2	3.4
UK	62.5	28.2	5.6	3.6
Ireland	62.7	22.3	5.6	9.4
Finland	66.4	19.5	7.1	6.9
Slovenia	70.3	18.9	7.0	3.7

Source : DG Research Key Figures 2007
Data : Eurostat, OECD
Notes: (1) MT, TR : 2002; EL, FR, CY, LV, LT, HU, SE, EU-27, HR, IS : 2003.
(2) EU-27 does not include : BG, EE, LU, MT, AT, PT, RO, SK.
(3) There is an element of estimation involved in the data for DK, LV and LT.

It is interesting to compare the manufacturing BERD in the different types of industry in terms of share of GDP (these figures are not shown). Manufacturing BERD in the high-tech industry amounts to 0.47% of GDP for EU-27. In all countries except Sweden (1.5% of GDP) and Finland (1.34% of GDP) it is less than 0.65% of GDP. In the new Member States, manufacturing BERD in high-tech industry is less, often much less, than 0.16% of GDP, except for Slovenia which is comparable to the older Member States (0.55% of GDP).

Manufacturing BERD in medium-high-tech industry amounts to 0.43% of GDP for EU-27. All countries except Germany (0.94% of GDP) and Sweden (0.88% of GDP) are below the EU average.

Finally, manufacturing BERD as a percentage of GDP in the medium-low and low-tech sectors is less than 0.14% in all countries.

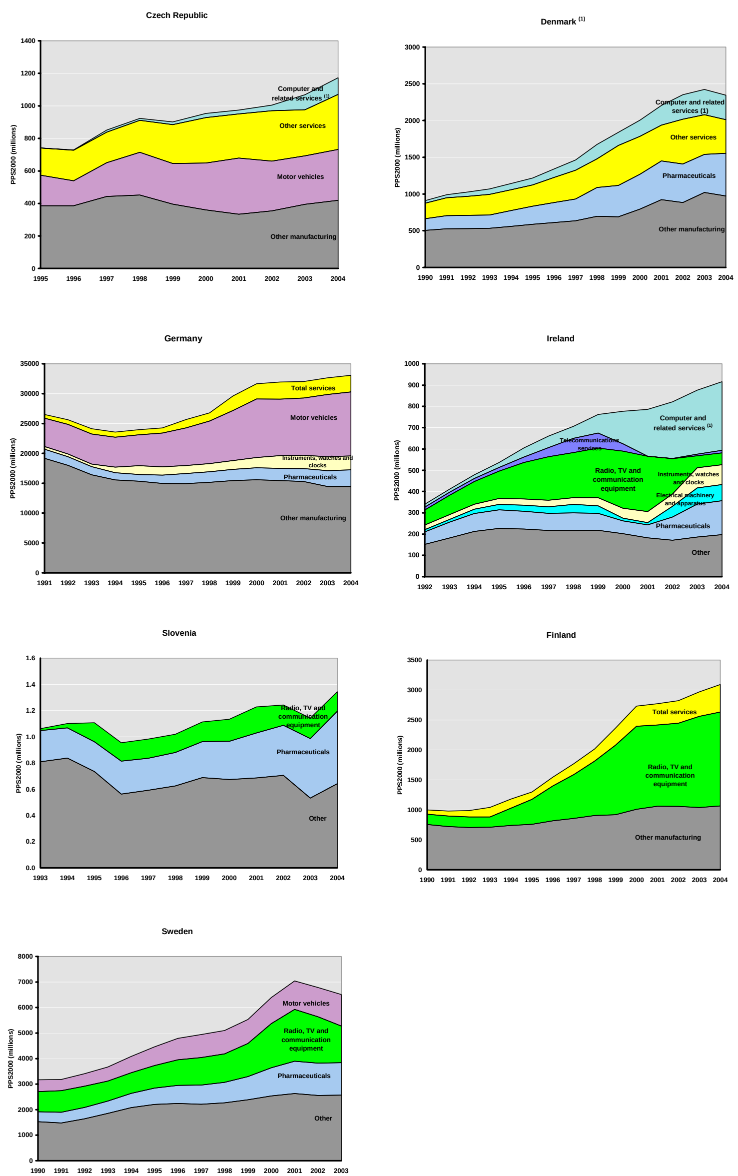
BERD growth is driven by a few key sectors

Business funding of R&D has stagnated in the EU for many years at around 1% of GDP, far below the 2010 target of 2% set by the European Council in Barcelona in 2002. However, the aggregate situation at EU level conceals a very different picture at the level of individual Member States. Some Member States have experienced strong growth in business-funded R&D.

The strongest growths are linked to the process of catching up by countries starting from an extremely low starting point: Cyprus, Estonia, Portugal, Latvia and Greece. However, other countries – Austria, Finland, Sweden, Denmark, Germany, Ireland, Slovenia and the Czech Republic – have been able to combine an existing level of business-funded R&D (as a percentage of GDP), above or not far below the EU average, with significant additional growth. This section explores the reason for the success of these countries by examining the contributions of the various economic sectors to the growth of their business R&D expenditures.

All the seven countries analysed below fulfil the two combined criteria of featuring (1) a level of business-funded R&D that corresponds to at least 0.6% of GDP for the latest available year and (2) an average annual real growth of business-funded R&D of more than 3% since 1995.

Figure II.I.9 Evolution of business enterprise expenditure on R&D by sector



Source: DG Research

Key Figures 2007

Data: OECD, Eurostat

Notes: (1) DK : The data for 2000 were estimated by DG Research.

(2) Computer and related services has been abbreviated from 'Total services - Computer and related activiies'.

Austria is the only Member State which fulfils both criteria but is not analysed below, due to the unavailability of historical data on business R&D expenditure by sector.

The graph presented for each of the seven countries shows the evolution of business R&D expenditure (BERD) in real terms (PPS2000) since the beginning of the Nineties. Each graph also shows a breakdown of BERD by economic sector. In order to simplify the graphs, only the sectors with the most interesting evolution are shown as distinct sectors for each country, while the others are aggregated in categories such as ‘other manufacturing’, ‘other services’ or ‘other’.

In Finland BERD has almost tripled in the last decade. As shown by the graph, this dramatic increase is explained by one sector: radio, TV and communication equipment. This sector alone accounts for 45% of BERD in 2004 (compared to 15% in 1990).

In Sweden, business expenditure on R&D more than doubled during the Nineties, thanks to three sectors: radio, TV and communication equipment, pharmaceuticals, and motor vehicles. The fall in the radio, TV and communication equipment sector since 2000 explains the decrease in total BERD since then.

In Denmark, pharmaceuticals and computer and related services were the main sectors behind the strong increase in business expenditure on R&D.

Without the strong growth that Germany experienced in the R&D expenditure of the motor vehicles sector in the second half of the Nineties, BERD in the manufacturing sector would be lower now than in 1991.

In Ireland there are two successive phenomena which explain the growth of BERD: (1) during the Nineties there was strong growth in the radio, TV and communication equipment sector and also in the telecommunications services sector; and (2) since 2000 these two sectors have experienced a downturn, but this downturn has been more than compensated for by the surge in computer and related services and the increases in various manufacturing sectors, notably pharmaceuticals and instruments, watches and clocks.

Without the strong growth that Slovenia experienced in the R&D expenditure of the pharmaceuticals sector, especially in recent years, its total BERD would be lower now than in 1991. The share of the pharmaceuticals sector in total BERD (41% in 2004) almost doubled in a decade.

The two sectors which successively played a key role in the growth of BERD in the Czech Republic are motor vehicles, in the second half of the Nineties, and computer and related services more recently. These two sectors represent 35% of total BERD in 2004 (compared to 25% in 1995).

Two main conclusions can be drawn from the analysis of these countries. First, in each of these countries, we find a very limited number of sectors which have played a key role in the growth of BERD. In other words, the growth of BERD has not been across the board, but is related to an increased concentration of BERD in specific sectors.

Second, although their contributions to the growth of BERD vary from country to country, these key sectors are generally the same four ones: 1) pharmaceuticals; 2) motor vehicles; 3) radio, TV and communication equipment; and 4) computer and related services. Clearly, there are technological and market trends which, at some point in time, create the conditions in specific sectors that can lead to a very significant increase in BERD.

The analysis performed above can be furthered by determining whether an increase in the BERD of a specific sector in a particular country is due mainly to an increase in the importance of that sector or to the R&D intensity of the sector. Doing this reveals that changes in the industrial structure of the country often play a predominant role in significantly increasing BERD. Two notable exceptions can be found, however, in the German and Czech car industries where the increase in R&D expenditure reflects an increase in the R&D intensity of that sector.

Such changes in the industrial structure can be the result of various kinds of development. Two opposing cases are those of Finland and Ireland. In Finland, the key development was the emergence of a domestic company as a global leader in a fast-growing market segment (Nokia in mobile communication equipment). In Ireland, the key development was the attraction of foreign direct investments (FDIs) into a number of high-tech growth sectors.

The main overall conclusion is that industrial structure and the evolution of this structure are key determinants of both the level and the trends of business-funded R&D for a given country.

From an analytical point of view, this means that the evolution of the level of business-funded R&D in a country cannot be correctly understood without paying attention to the sectoral breakdown of BERD. Sectoral analysis should be a key constituent of any analysis of a country's business R&D intensity.

From a policy point of view, it means that the Barcelona targets should be seen as an industrial policy objective as much as a research policy objective. It also means that the range of policy tools to be taken into account in reaching the Barcelona targets goes well beyond research policy.

II-1-3 Trends in the financing of business R&D

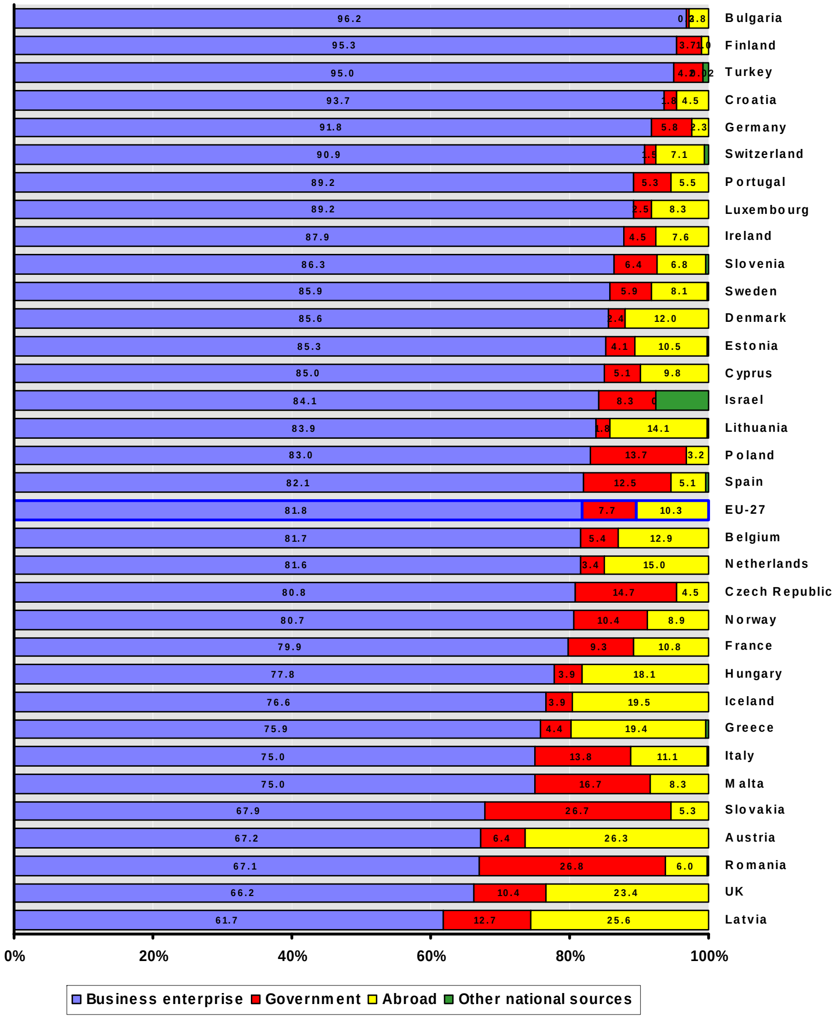
Business R&D remains largely funded by the private sector

R&D in the business enterprise sector is mainly funded by the sector itself: in 2005 it financed almost 82% of private-sector R&D activities in the EU.

High R&D-intensive Member States such as Germany and the Nordic countries of Sweden, Finland and Denmark demonstrate higher private-sector shares in the funding of business R&D but several low R&D-intensive countries, such as Bulgaria, Portugal and Slovenia, enjoy relatively high support from the business sector for their domestic private R&D.

It is, however, important to mention that these figures contain a margin of error due to the non-availability of a breakdown between public and private sources of funding within the category 'funded from abroad'. At EU level, this category accounts for about 10% of the financing of total domestic business R&D but, in some countries such as Austria, the United Kingdom and Latvia, around one-quarter of total business R&D is financed from abroad.

Figure II.1.10 BERD by main sources of funds, 2005 (1)



Source: DG Research — Key Figures 2007

Data: Eurostat, OECD

Notes: (1) MT, IL : 2002; BE, DK, EL, LU, NL, PT, SE, IS, NO : 2003; BG, DE, EE, ES, FR, IT, CY, AT, RO, FI, UK, HR, TR, CH : 2004.

Public support for business R&D is changing

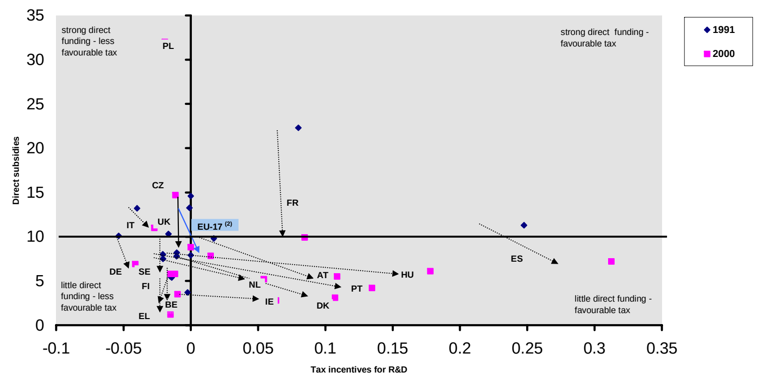
The government sector finances less than 8% of business R&D in EU-27. In low R&D-intensive countries such as Romania, Slovakia and Malta, it accounts for a much larger share of the funding than in higher R&D-intensive countries, where it represents a small share of business R&D funding. Moreover, the share of government funding has decreased significantly over recent years.

In the early-1990s, governments were financing about 12% of total domestic business R&D activities, compared to less than 8% in 2005. The gradual reduction of direct subsidies to private R&D, however, was accompanied by the increasing use of fiscal incentives to encourage R&D activities in the sector, allowing companies to reduce tax payments and the cost of research.

In general, fiscal incentives have evolved progressively in the EU Member States since the beginning of the 1990s, even though individual Member States choose very different combinations of the two policy tools (subsidies versus tax incentives) (see Figures II.1.11 and II.1.12). Moreover, the trend towards more fiscal stimuli has accelerated over the past five years.

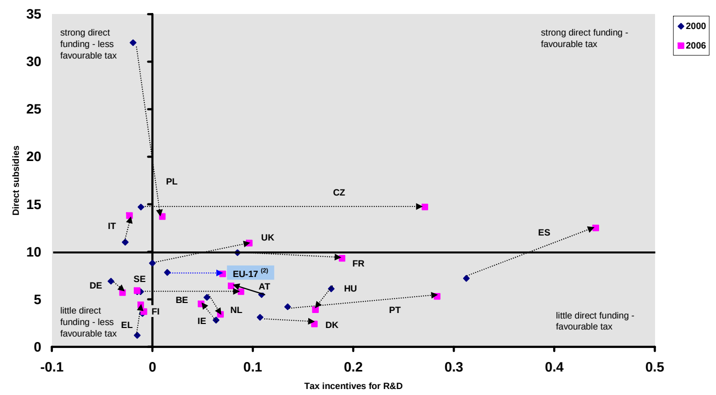
Interestingly, while in the Nineties the shift towards more favourable tax treatment of R&D went, without exception, hand-in-hand with a reduction in direct subsidies (the substitution effect) (Figure II.1.11), after 2000 the level of direct subsidies was in most cases no longer reduced but maintained, translating into a net reinforcement of the policy mix. Most Member States have chosen to focus on the strengthening of the whole portfolio by maintaining their level of direct funding while expanding their battery of R&D tax incentives. In some of them – mainly Spain and, to a lesser extent, Portugal and the United Kingdom – this expansion has even been combined with an increase in direct subsidies.

Figure II.1.11 Direct subsidies versus tax incentives, 1991 and 2000



Source: DG Research, Warda (2007) Key Figures 2007
Data: Eurostat, OECD
Notes: (1) See methodological annex for definition of the B-index.
(2) The tax subsidy for EU-27 was calculated as a weighted average, the weights being the share of a country's BERD in total BERD for EU-17 in a given year.

Figure II.1.12 Direct subsidies versus tax incentives, 2000 and 2006



Source: DG Research, Warda (2007) Key Figures 2007
Data: Eurostat, OECD
Notes: (1) See methodological annex for definition of the B-index.
(2) The tax subsidy for EU-27 was calculated as a weighted average, the weights being the share of a country's BERD in total BERD for EU-17 in a given year.

In conclusion, even though there is no convergence towards one 'optimum' level of tax treatment of R&D across EU countries, national governments increasingly recognise the importance of fiscal incentives for R&D as a complement to direct subsidies.

By examining a typology of policy mixes that distinguishes four different classes (as shown in Figures II.1.11 and II.1.12 and in Table II.1.2), one can further analyse the shift between direct and indirect fiscal incentives in the EU. Each graph is divided into four areas bounded by two thresholds: a direct subsidisation rate of 10% on the vertical axis and a tax subsidy rate of 0 on the horizontal axis[60].

First of all, there has been a movement from 'strong' direct funding towards 'favourable' fiscal incentives in the EU. While there were four countries located in that quadrant in 1991, only one (Italy) remains there in 2006. The weighted average of EU-17 was also located in this category in 1991.

In the category 'little direct funding and less favourable tax treatment' there was a significant drop in the number of EU countries (from eight in 1991 to six in 2000 and four in 2006); this is largely a reflection of the trend towards a greater use of tax incentives for R&D. Interestingly, the high R&D-intensive EU countries of Germany, Finland and Sweden have featured consistently in this quadrant since 1991.

Table II.1.2 Typology of policy-mixes with regard to direct funding and fiscal incentives for business R&D in the EU, 1991, 2000 and 2006

Analytical category	1991	2000	2006
Strong direct funding and unfavourable tax treatment	4 EU countries : DE, IT, SE, UK and EU-17	3 EU countries : CZ, IT, PL	1 EU country : IT
Little direct funding and unfavourable tax treatment	8 EU countries : BE, DK, IE, EL, HU, NL, PT, FI	6 EU countries : BE, DE, EL, FI, SE, UK	4 EU countries : DE, EL, FI, SE
Little direct funding and favourable tax treatment	1 EU country : AT	8 EU countries : DK, IE, ES, FR, HU, NL, AT, PT	8 EU countries : BE, DK, IE, FR, HU, NL, AT, PT and EU-17
Strong direct funding and favourable tax treatment	2 EU countries : ES, FR	No countries	4 EU countries : CZ, ES, PL, UK

Source: DG Research, Warda (2007) Key Figures 2007
Data: Eurostat, OECD

Eight EU countries, as well as the weighted average of EU-17, are now categorised as policy mixes with 'little direct funding and favourable tax treatment', supporting an overall policy-mix trend toward fiscal incentives. This quadrant has experienced a significant 'boom' since 1991, when Austria was the only country represented in this category.

Finally, the policy mix quadrant 'strong direct funding and favourable tax treatment' appears to be the least occupied, even though it is experiencing a relative comeback. Since 2000, this category has added four EU countries, of which the United Kingdom and Spain have increased their direct subsidies for R&D while keeping their fiscal incentives at a favourable level. Another two – the Czech Republic and Poland – are characterised by historically strong direct funding, and have added significant R&D tax incentives in recent years[61].

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60 For more details on the justification of these thresholds for categorising policy-mixes, see methodological note. See also Warda, J. (2001), *Measuring the Value of R&D Tax Treatments in OECD Countries*, STI Review, No. 27, OECD, Paris, 2001; Guellec, D. and van Pottelsberghe, B. (2000), *The Impact of Public R&D Expenditure on Business R&D*, STI Working Paper 2000/4, OECD, Paris, 2000.

61 The data used in this section on the evolution of fiscal incentives for private R&D were taken from Warda, J., (2007), An evolution of EU

II-1-4 Venture Capital investment for private R&D

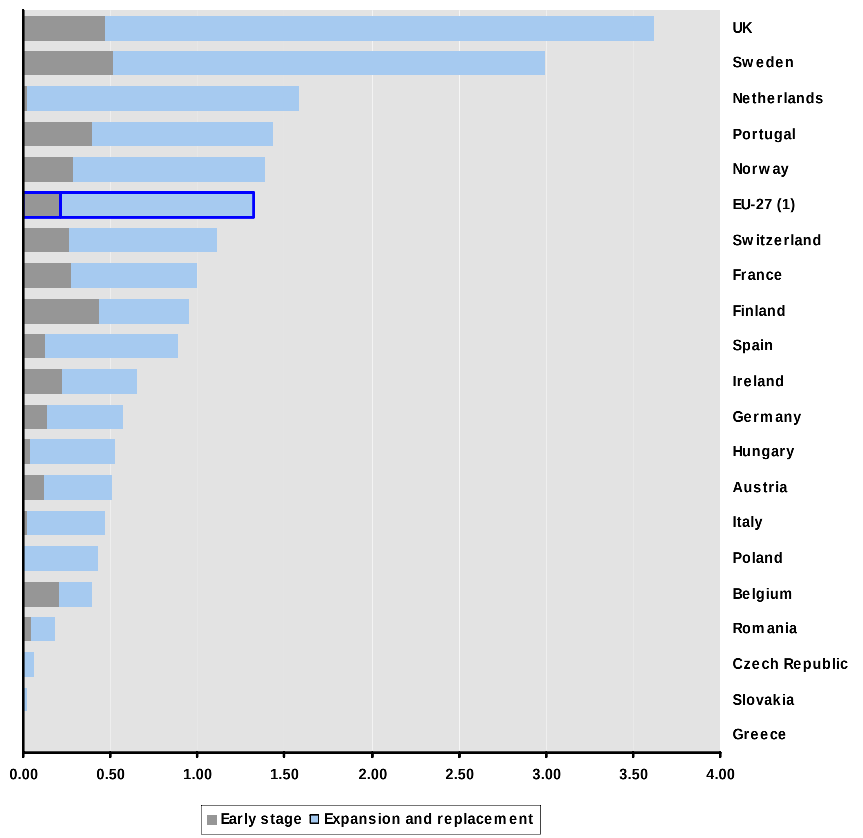
Introduction

Large firms are able to finance most of their R&D and innovation effort internally. On the contrary, entrepreneurs wanting to start new high-tech and knowledge-intensive activities need to have access to external financing. Such new business plans require high and risky investment, the hoped-for returns from which may never be realised or only in the long term. Venture Capital (VC) investment can finance the seed, start-up and expansion phases of a firm's life cycle, as well as replacement, management buy-outs and buy-ins. In other words, VC can play a critical role in the creation and expansion of R&D-intensive SMEs whose anticipated research effort is far beyond their financial capacity. By supporting the creation and expansion of new high-tech businesses, VC establishes new R&D performers, allows the commercialisation of research results, and thereby intensifies the exploitation of existing scientific and technological know-how. In this sense, VC is crucial for the creation and expansion of the knowledge-based economy.

Recourse to Venture Capital varies widely across Europe

The total investment in VC at national level varies in 2005 from 0 (Greece) to 0.52 (Sweden) per thousand GDP for seed and start-up ('early-stage') activities, with an EU-27 average of 0.21 (Figure II.1.13). For expansion and replacement activities, the total investment in VC at national level ranges from 0.006 (Greece) to 3.5 (Denmark) per thousand GDP, with an EU-27 average of 1.1. VC is therefore primarily used to finance expansion and replacement of already existing businesses.

Figure II.1.13 Venture capital by stage per 1000 GDP, 2005



Source: DG Research — Key Figures 2007
Data: Eurostat
Note: (1) EU-27 does not include BG, EE, CY, LV, LT, LU, MT and SI.

Recourse to VC varies widely across Europe. The United Kingdom and the Nordic countries, with the exception of Finland which is

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'Direct Subsidy – Fiscal Incentives' Policy Mix (1991-2006), (report prepared for EC, DG Research, January 2007) (A/125332).

below the EU-27 average, have the most developed VC industry. Portugal is the only low R&D-intensive country using VC more intensively than the EU-27 average. All of the new Member States for which data are available have weak VC investment rates. Germany and countries in southern Europe (with the exception of Portugal) have medium-to-low VC investment rates. Interestingly, in some countries (the Czech Republic, Greece, Italy, the Netherlands, Poland and Slovakia), VC does not finance early-stage activities, or only very marginally.

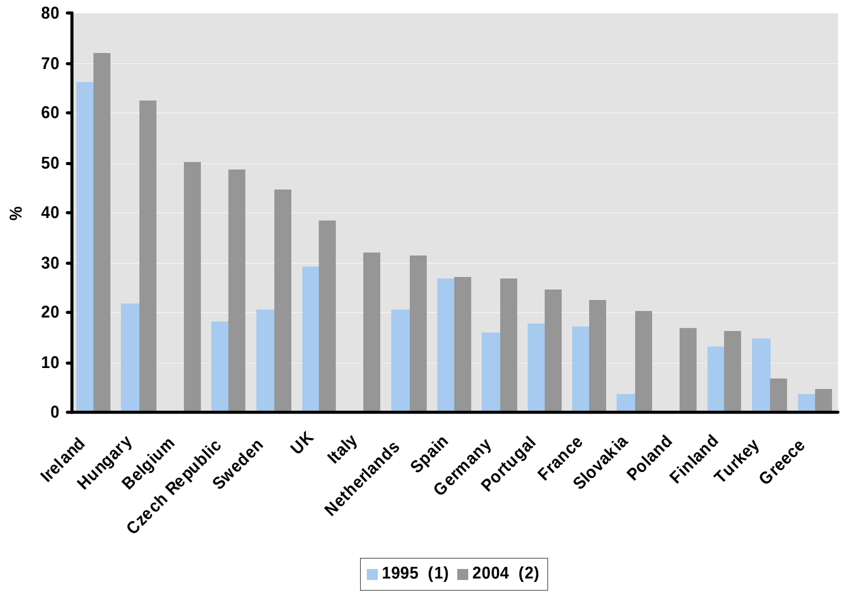
It should be noted that the VC industry for high-tech start-ups (supply side) can only develop if there is a reasonable level of project development prior to early-stage financing (demand side). Therefore, these figures not only reflect the performance of the VC industry in each country, but also the efficiency of their respective mechanisms for technology transfer.

II-1-5 Foreign R&D investment in the private sector

Increasing importance of foreign funding of domestic R&D

The globalisation of R&D has clearly been gathering strength for a number of years. R&D expenditure by affiliates of foreign companies is increasingly contributing to R&D spending in all EU Member States. Figure II.1.14 shows that the share of foreign affiliates in total R&D expenditure by enterprises has expanded considerably in a number of new Member States – the Czech Republic, Hungary, Poland and Slovakia – as well as in Sweden. In Germany, Ireland, Greece, Spain, France, the Netherlands, Portugal, Finland and the United Kingdom the increase has been less marked but still substantial. Only Turkey experienced a decrease.

Figure II.1.14 R&D expenditure by foreign affiliates, 1995 and 2004 as % of R&D expenditure by business enterprise



Source: DG Research | Key Figures 2007
Data: OECD (Activity of Foreign Affiliates database)
Notes: (1) CZ, SK : 1996; NL, FI, TR : 1997; PT : 1999.
(2) EL : 1999; NL, TR : 2002; DE, IE, IT, HU, PT, SE : 2003.

In other words, business R&D in EU Member States increasingly relies on foreign investment. In 2004, foreign affiliates accounted in the majority of the Member States for 20-50% of total domestic business R&D. This share was below 20% only in Greece, Poland, and Finland, and above 50% in Ireland and Hungary. In these two countries, business R&D is therefore extremely dependent on foreign sources of funding. It must be noted that intra-EU foreign spending also contributes to these high shares of foreign R&D investment.

These shifts in R&D spending by foreign affiliates from 1995 to 2004 may be largely explained by the more general process of globalisation. The share of foreign affiliates in domestic value added has (sometimes considerably) increased since 1995, and this tends to have a direct impact on the share of R&D spending by foreign affiliates. Mergers and acquisitions, in particular when national R&D-intensive firms pass into the control of foreign firms, also have a strong influence on this indicator. Therefore, the share of R&D spending by foreign affiliates does not alone reflect the attractiveness of a country for R&D. This is linked to a large extent to the industrial mix of foreign affiliates relative to domestic firms within a country (see below).

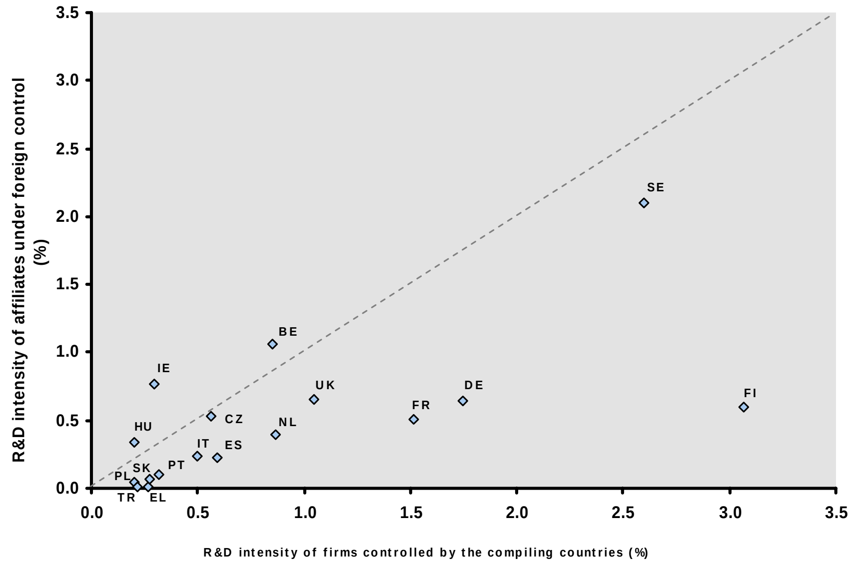
Finally, it is noticeable that the level of R&D intensity does not seem to be correlated to the share of R&D performed by foreign affiliates, as there are countries with high and low R&D intensities at each end of Figure II.1.14.

R&D intensity of foreign companies however remains below that of national firms in most countries…

Figure II.1.15 displays the 'R&D intensity' (R&D expenditure as a percentage of value added in industry) of national and foreign companies[62].

[62] 'R&D intensity' as defined here is *not* the average R&D intensity of foreign companies, but the share of their aggregate R&D expenditure in total industry value added. Therefore, the 'R&D intensity' of foreign companies as examined here can be influenced by both their specific R&D intensity and their overall weight in total value added.

Figure II.I.15 R&D intensity of foreign companies and of national firms (R&D expenditure as % of value added in industry), 2004 (1)



Source: DG Research
Data: OECD.
Notes: (1) EL : 1999; NL, TR : 2002; DE, IE, IT, HU, PT, SE : 2003.

Key Figures 2007

The R&D intensity of domestic companies varies greatly across Europe (Figure II.1.15): from 0.01% in Greece to 2.59% in Sweden and 3.06% in Finland. In Finland, the R&D intensity of national firms is almost twice as high as that of national firms in Germany and France and three times as high as that of national firms in the United Kingdom (1.05%). In all other countries, it is lower than 1%.

In most countries, national firms on average carry out more R&D than foreign affiliates. This is particularly true for Germany, France and Finland (far below the bisector), but it is also the case in Greece, Spain, Italy, Poland, Portugal and Slovakia, though for much smaller

R&D intensity values. The contrary holds true, however, for Belgium, Ireland and Hungary where the R&D intensity of foreign companies outpaces that of domestic firms (all three countries are above the bisector). As previously mentioned, these R&D intensities (of foreign versus national companies) are closely related to the respective shares of foreign affiliates and national firms in the value added of the country (see below for a comparison of these shares).

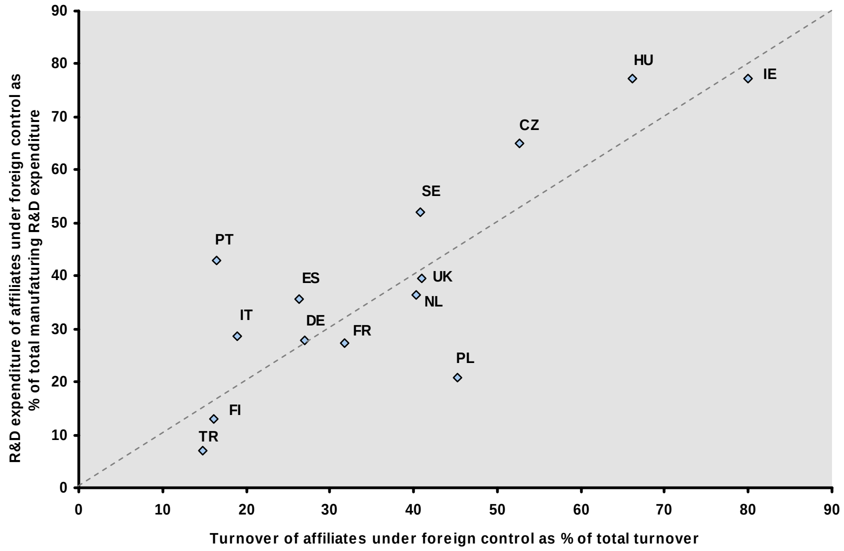
Finally, it is worth noting that some companies prefer to transfer technology directly to their affiliates. These intra-company transfers do not appear as R&D spending by foreign affiliates, but they do bring new technologies into the country concerned.

… thus reflecting the industrial mix of foreign affiliates relative to national firms in these countries

The attractiveness of a country for R&D can be gauged by comparing the share of R&D expenditure of foreign affiliates to their share of turnover in that country. This has been done for the manufacturing sector in Figure II.1.16. A country in which foreign companies contribute more to total R&D expenditure than to total turnover will be considered relatively attractive for R&D activities.

In Germany, Ireland and the United Kingdom, the share of foreign affiliates in total R&D is very similar to their share in overall turnover (these countries are located on or very close to the bisector): therefore these countries are attractive to the same degree for both R&D and production activities. The contribution of foreign companies to total manufacturing R&D perfectly reflects the weight of these foreign companies in the industrial structure of the country.

Figure II.1.16 Shares of R&D expenditure and turnover of affiliates under foreign control in total manufacturing R&D and total turnover, 2004 (1)



Source: DG Research — Key Figures 2007
Data: OECD
Note: (1) HU : 1997; FI, TR : 2001; IT, NL, PT : 2002; DE, IE, SE : 2003.

Countries where the share of foreign companies in total manufacturing R&D expenditure is significantly higher than the share of these companies in total manufacturing turnover may be more attractive for R&D than for production activities. This is primarily the case for Portugal and, to a lesser extent, the Czech Republic, Spain, Italy, Hungary and Sweden. However, for some of these countries, this observation could also be explained by the limited R&D efforts of national firms. It could also be due to the location of foreign affiliates in R&D-intensive sectors.

On the other hand, countries where the contribution of foreign firms to turnover significantly exceeds their contribution to manufacturing

R&D may be less attractive for R&D than for production activities. This is primarily the case for Poland and, to a much lesser extent, France, the Netherlands, Finland and Turkey. Foreign companies may prefer to transfer technology to these countries directly, rather than to set up local R&D activities.

However, on the whole, most countries do not deviate significantly from the bisector demonstrating that, with the exception of Poland and Portugal, the contribution of foreign and national companies to the domestic R&D effort largely mirrors their respective weights in the industrial structure of the country.

II-1-6 Public sector R&D and its relationship with the business sector

The rationale for government involvement in R&D has traditionally been to rectify market failures, such as its inability to fulfil the public health and defence-related needs of society. Public sector research provides scientific and technological knowledge that can be disseminated and utilised in the economy. It encourages exploration of new and challenging areas with long-term perspectives and unforeseeable economic returns. It provides new instruments and research infrastructures that can be used for industrial R&D activity. The higher education sector trains highly skilled graduates for industry. Public-private partnerships can boost innovation and help create new firms.

All of these factors create suitable conditions for investments by foreign-owned companies. In low R&D-intensive countries, government-funded R&D is of crucial importance for the development of the science and technology (S&T) capabilities necessary to catch up with countries at the technology frontier (see section I.2 of this chapter). Finally, governments are also responsible for promoting scientific education and culture in the population, fostering the dialogue between science and society to increase society's confidence in and demand for scientific research and technological development.

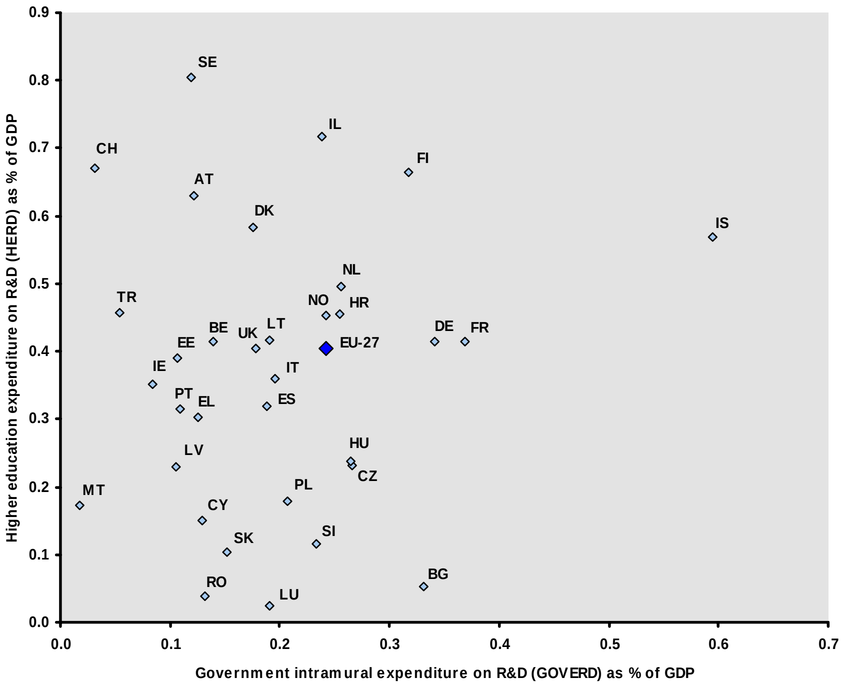
Public-sector R&D is largely university-oriented in the EU …

In EU-27, R&D expenditure in the higher education sector has been increasing only very slightly from 0.37% of GDP in 1998 to 0.41% in 2002 (Figure II.1.17). Since then, up to 2005, it has remained stable at 0.41%. The intensity of R&D performed in government institutions, measured as a percentage of GDP, has decreased in EU-27 from 0.27% in 1998 to 0.24% in 2004. In 2005, it remained at the same level as in 2004, i.e. at a much lower level than the intensity of R&D performed in the higher education sector. At EU level therefore, if the overall level of public R&D expenditure has remained very stable since 1998, its centre of gravity has been more and more directed towards the higher education sector over that period of time.

Within the EU, the relative positions of Member States have not fundamentally changed since the end of the Nineties. Three main groups of countries may be considered.

The three Nordic countries of Sweden, Finland and Denmark, as well as Austria, still stand out with the highest intensity of higher education R&D in 2005 (0.58% and above). The public R&D expenditure of these countries is largely university-oriented. This choice has been confirmed over the years: since 1998: Denmark and Finland clearly transferred part of public R&D expenditure from government R&D to higher education R&D while, in the period 1998-2005, Austria increased its higher education R&D share of GDP by one-third.

Figure II.1.17 Public R&D in relation to GDP, 2005 (1)



Source: DG Research
Data: Eurostat, OECD
Note: (1) IT, NL, RO, UK, HR, TR, IS, CH : 2004; FI : 2006.

Key Figures 2007

In a majority of European countries, expenditure on higher education R&D is at around the EU level, within the range of 0.3% to 0.5% of GDP, whereas expenditure on government R&D amounts to 0.1% to 0.4% of GDP. In this group of countries, old Member States have basically the same R&D intensity as in 1998, both in higher education and in government institutions (except for the Netherlands, where the percentage of GDP devoted to government and higher education R&D decreased). In 2005, as in 1998, France and Germany had the highest government R&D intensities in the EU, almost at the same level as their higher education R&D intensities. Government R&D maintains a remarkably strong position in these two countries, whereas in the two other largest Member States, the United Kingdom and Italy, university R&D prevails.

... except for most new Member States where public research is mainly conducted in the government sector

The third group of countries is composed of Luxembourg and most of the new Member States. Unlike the situation at EU level, public R&D in these countries is mainly conducted in the government sector. However, a modest shift has taken place since 2003 in all of these Member States, with a slow convergence towards a more widespread breakdown of public R&D. This shift is primarily due to a diminishing share of GDP devoted to government R&D while, in the Czech Republic and Latvia, this is combined with an increase in the resources allocated to higher education R&D. In the two newest Member States, Bulgaria and Romania, almost all public R&D is still performed by government institutions.

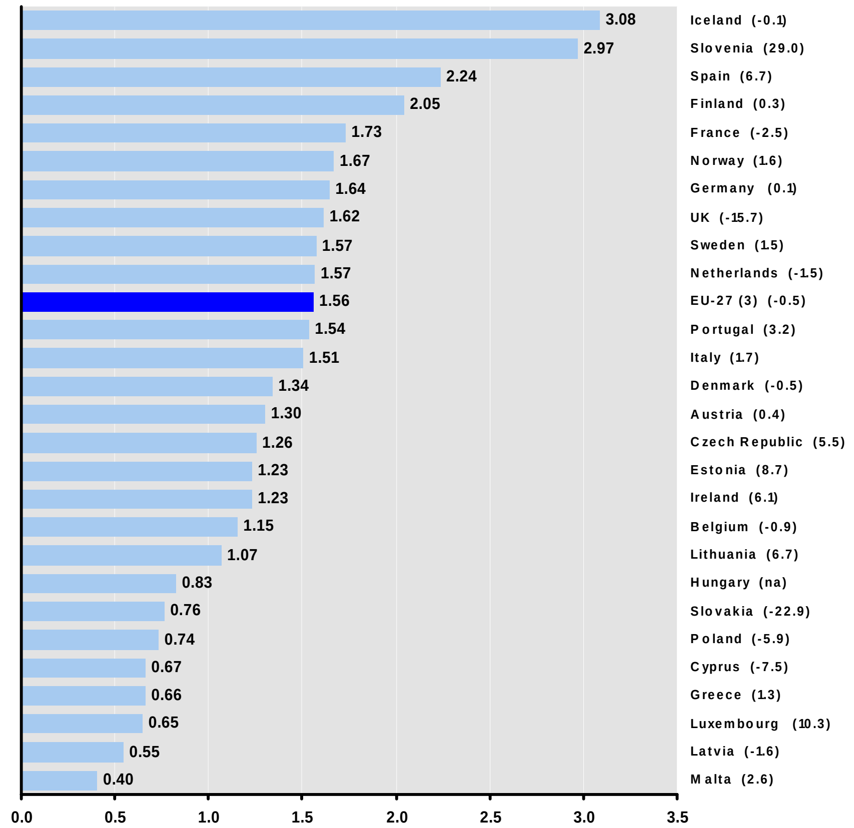
Declining government R&D budgets at EU level in spite of increased commitments by some Member States

In 2005, the EU Government Budget Appropriations or Outlays for R&D (GBAORD) amounted to 1.56% of general government expenditure (Figure II.1.18). Over the period 2001-2005, the R&D share of the government budget slightly decreased in EU-27, with an annual growth rate of -0.5% on average over this period.

Fifteen European countries have a GBAORD of 1-2% of the government budget, with a cluster of countries in the 1.5-1.7% range. Apart from Slovenia, which has the highest level in the EU, all new Member States devoted less than 1.3% of their budgets to R&D. Among old Member States, only Ireland, Belgium, Greece and Luxembourg have R&D shares below 1.3% of the government budget.

In many European countries, the share of the government budget allocated to R&D has evolved considerably since 2001. Slovenia has radically increased the R&D share of its government budget in five years (29% annual growth on average) to reach its current very high level of 3%. Spain also committed a much larger part of its government budget to R&D in 2005 than in 2001, and is now second in the EU. At the other end of the scale, Slovakia and the United Kingdom significantly cut their public R&D budgets, as did France to a much lesser extent.

Figure II.1.18 GBAORD as % of general government expenditure, 2005 (1); in brackets : average annual growth rates (%), 2001-2005 (2)



Source: DG Research
Data: Eurostat
Notes: (1) PL, IS, EU-27 : 2004.
(2) PL, IS, EU-27 : 2001-2004; CZ, SK : 2002-2005; CY, MT : 2004-2005.
(3) EU-27 does not include BG and RO.

Key Figures 2007

The structure of government R&D budgets largely unchanged since 2000

Table II.1.3 shows the structure of GBAORD in the EU. The generic category ‘Research financed from General University Funds’ (GUF) amounted to 32% of total GBAORD in 2005. Together with ‘Non-oriented research’ and ‘Defence’ it accounted for 60% of total GBAORD at the EU level.

Table II.1.3 GBAORD by socio-economic objective (%), 2005 (1)

Socio-economic objective	BE	CZ	DK	DE (2)	EE	IE	EL	ES	FR	IT	CY	LV	LT	LU	HU
Exploration and exploitation of the earth	0.6	2.4	0.8	1.8	0.3	2.6	3.6	1.4	0.9	2.0	1.6	0.6	2.6	:	2.3
Infrastructure and general planning of land-use	0.7	4.4	0.7	1.8	8.1	0.0	2.9	4.0	0.8	0.9	1.6	2.3	3.7	:	2.0
Control and care of the environment	2.5	3.2	1.7	3.4	5.4	0.9	4.0	3.0	2.8	2.5	0.8	0.6	9.6	:	10.3
Protection and improvement of human health	1.7	7.4	6.7	4.3	4.3	5.9	6.9	8.7	6.0	10.0	10.0	4.0	11.0	:	14.6
Production, distribution and rational utilization of energy	2.0	2.6	1.9	2.8	2.2	0.0	2.1	1.6	4.6	4.1	0.0	1.7	3.2	:	11.5
Agricultural production and technology	1.3	5.3	5.3	1.8	13.5	9.9	5.5	5.2	1.5	3.8	20.5	7.3	8.0	:	15.0
Industrial production, and technology	30.9	12.4	5.8	12.6	5.8	15.8	9.2	25.2	7.4	10.2	0.0	5.1	13.0	:	21.5
Social structures and relationships	4.1	3.0	5.3	3.9	6.4	2.7	5.7	2.1	0.7	5.0	8.2	1.7	29.6	:	8.9
Exploration and exploitation of space	8.8	0.8	1.7	4.9	0.0	1.7	2.1	3.2	8.8	9.5	0.0	1.1	:	:	2.3
Research financed from general university funds (GUF)	18.5	25.6	41.5	40.6	0.0	59.4	47.6	18.1	27.1	44.2	31.8	:	:	:	6.4
Non-oriented research	25.2	27.0	26.9	16.3	49.2	1.0	9.2	8.6	9.1	6.3	25.4	74.6	:	:	4.8
Other civil research	3.2	3.2	1.1	0.7	4.0	0.0	0.7	2.8	2.2	0.0	0.0	:	18.8	:	0.3
Defence	0.4	2.8	0.6	5.8	1.0	0.0	0.5	16.1	28.0	1.4	0.0	1.1	0.4	:	0.1
Total	100	100	100	101	100	100	100	100	100	100	100	100	100	:	100
Total appropriations (million euro)	1714	625	1749	17221	45	676	558	7740	14556	8655	40	25	77	93	367

Socio-economic objective	MT	NL	AT (3)	PL	PT	RO	SI	SK	FI	SE	UK	EU-27 (4)	IS	NO	CH
Exploration and exploitation of the earth	3.7	0.7	2.0	1.3	1.6	2.2	0.4	0.0	1.2	0.7	2.3	1.7	:	2.5	0.3
Infrastructure and general planning of land-use	0.0	4.3	2.8	1.3	4.5	2.9	0.8	2.3	2.0	4.0	1.1	1.8	8.4	2.4	0.6
Control and care of the environment	0.1	1.4	2.2	1.4	3.5	4.8	3.1	0.8	1.6	1.8	1.8	2.7	0.4	2.0	0.1
Protection and improvement of human health	5.5	4.0	4.8	1.4	7.7	5.4	2.0	2.6	6.2	1.2	14.7	7.3	7.3	7.8	1.8
Production, distribution and rational utilization of energy	0.0	1.9	1.1	1.7	0.9	2.9	0.5	0.4	4.6	3.6	0.4	2.8	2.2	3.4	1.0
Agricultural production and technology	1.8	5.6	2.4	1.4	9.8	9.0	3.2	9.5	5.8	2.2	3.3	3.4	21.3	8.7	2.8
Industrial production, and technology	4.4	10.8	13.7	5.0	16.5	25.0	22.6	4.5	26.9	5.7	1.7	10.9	2.3	8.1	3.4
Social structures and relationships	18.7	2.1	2.7	1.4	3.4	11.3	2.7	0.8	5.5	4.6	3.5	3.1	8.9	6.4	1.9
Exploration and exploitation of space	0.0	2.4	0.8	:	0.2	1.4	0.0	:	1.7	0.9	2.0	5.0	:	2.0	4.0
Research financed from general university funds (GUF)	63.9	48.9	53.0	:	37.4	:	0.0	23.0	25.4	45.2	21.7	32.0	33.1	37.5	58.9
Non-oriented research	2.0	10.6	14.0	65.1	10.4	13.2	59.7	47.9	16.2	13.3	16.0	14.5	16.1	13.1	9.8
Other civil research	0.0	6.0	0.4	15.0	3.4	18.9	0.2	3.3	:	:	0.5	1.4	0.0	:	14.9
Defence	0.0	1.5	0.0	5.0	0.5	3.0	4.9	5.0	2.8	16.9	31.0	13.6	0.0	6.1	0.4
Total	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
Total appropriations (million euro)	9	3609	1640	639	1148	285	167	129	1680	2618	12950	79425	186	1813	2189

Source: DG Research — Key Figures 2007
Data: Eurostat
Notes: (1) RU : 2001; PL, CH, JP : 2004; CZ, FR, IT, LT, LU, NL, AT, PT, RO, SK, FI, SE, NO : 2006; DK : 2007.
(2) The sum of the values by socio-economic objective is not equal to the total.
(3) Federal or central government only.
(4) EU-27 does not include BG and RO.
(5) Values in italics are estimated or provisional.

Within the EU, the GBAORD structure differs from country to country. For a majority of European countries, GUF has the largest share of GBAORD. For some Member States, though, (Belgium, Spain, Hungary, Romania and Finland) the most important GBAORD objective is ‘Industrial production, and technology’. In most of the new Member States, the most important GBAORD objective by far is ‘Non-oriented research’.

The major part of the European budget allocated to ‘Defence’ is to be found in the United Kingdom and France and, to a much lesser extent, in Spain. In fact, for the United Kingdom and for France, ‘Defence’ is the first priority in terms of GBAORD, followed by GUF and ‘Non-oriented research’. For all other EU Member States, ‘Defence’ is a relatively minor priority.

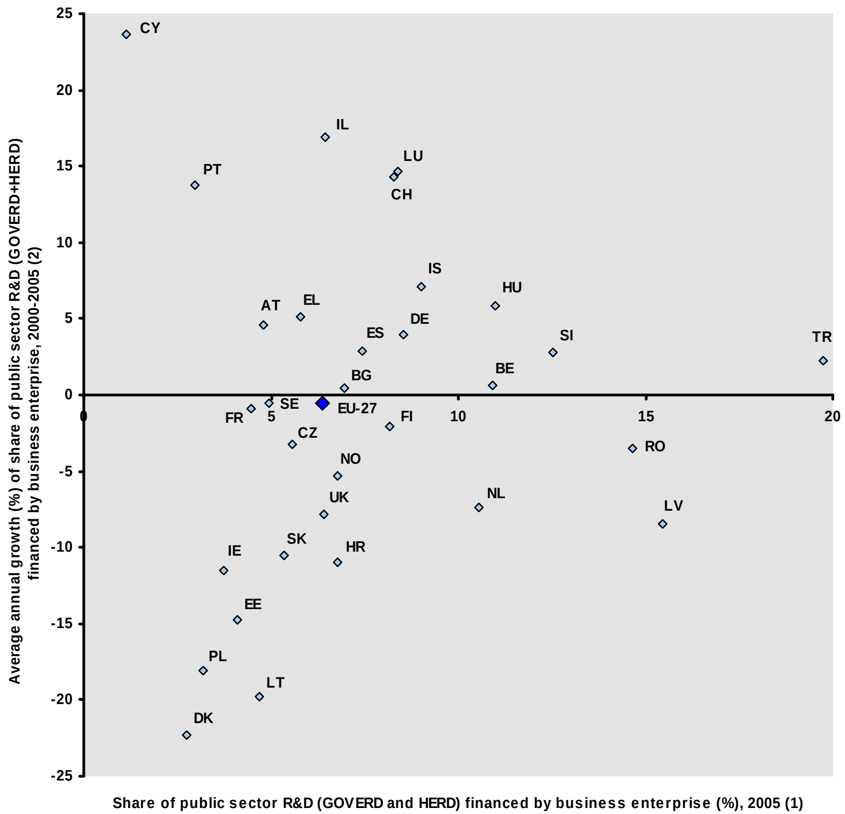
The structure of GBAORD at EU level in 2005 was remarkably similar to that of 2000. In fact, the distribution of government appropriations across the various socio-economic objectives has remained relatively stable for a majority of countries in Europe since 2000.

Private enterprise finances a substantial and relatively stable part of public R&D

The share of public (higher education and government) sector R&D financed by business enterprise remains substantial in 2005 in EU-27, amounting to 6.4% of the total (Figure II.1.19). The largest shares (more than 10%) are found in a group of seven countries: Turkey, Latvia, Romania, Slovenia, Hungary, Belgium and the Netherlands. For all other countries, business support for public R&D ranges from 3% to 10%, with a cluster of countries at around 5-7% (Cyprus is an exception with less than 3%).

Half of the countries had a positive – and half a negative – annual average growth rate in the level of private funding of public sector R&D over the 2000-2005 period (Figure II.1.19).

Figure II.1.19 Share of public sector R&D financed by business enterprise - latest year and average annual growth



Source: DG Research Key Figures 2007
Data: Eurostat, OECD
Notes: (1) NL, IL : 2002; BE, EL, LU, PT, SE, IS, NO : 2003; BG, DK, DE, ES, FR, CY, AT, RO, FI, UK, HR, TR, CH : 2004.
(2) NL, IL : 2000-2002; BE, LU, PT : 2000-2003; BG, DE, ES, FR, RO, FI, TR, CH : 2000-2004;
EL, SE, IS, NO : 2001-2003; CY, UK : 2001-2004; DK, AT, HR : 2002-2004.

Since 2000, the share of public-sector R&D financed by business enterprise has increased most in Cyprus, Portugal, and Luxembourg, as well as Israel and Switzerland, whereas it has decreased considerably in Denmark, Lithuania, Poland and Estonia. This share has remained relatively stable in half of the countries (annual average growth rate within the range of -5% to +5% and, in EU-27 as a whole, -0.5%).

II-2 Human resources in Science and Technology

Introduction

R&D and other S&T activities are not possible without human resources. If the R&D expenditure target of 3% of GDP is to be achieved, ensuring there are sufficient human resources for research is a preliminary step in the right direction. To this end, the European Commission advocates increasing the proportion of researchers in the labour force from five to eight per thousand.

This section first analyses investment in education and, more specifically, investment in tertiary education. This is followed by an assessment of the number of graduates from tertiary education and the participation of foreign students in tertiary education. Finally, we provide an overview of human resources in science and technology and of R&D personnel and researchers.

Investment in education

Education and in particular tertiary education, not only renews stocks of human capital but also promotes economic growth. Therefore, investment in education can be seen much more as an investment in future economic wellbeing rather than as an investment in individual success.

Within the EU, total public expenditure on education in 2003 amounted to 5.17% of GDP. Only 1.14% of GDP was allocated to tertiary education. However, wide differences exist between the EU Member States, both at all levels of education and specifically at the tertiary level. In terms of public expenditure as a percentage of GDP on tertiary education, the Nordic countries have the highest shares, with Denmark at the top (2.50%), followed by Sweden (2.16%) and Finland (2.05%). Public expenditure on tertiary education also accounts for more than 2% of GDP in Norway (2.32%).

Table II.2.1 Expenditure on education as a % of GDP, 2003

	Total public expenditure on education as % of GDP		Expenditure on educational institutions by source as % of GDP	
	All levels	Tertiary	Public sources	Private sources
Belgium	6.06	1.31	5.74	0.35
Bulgaria	4.24	0.84	3.91	0.67
Czech Republic	4.51	0.94	4.30	0.37
Denmark	8.33	2.50	6.70	0.32
Germany	4.71	1.19	4.36	0.92
Estonia	5.43	1.05	5.11	:
Ireland	4.41	1.09	4.11	0.31
Greece	3.94	1.22	3.86	0.22
Spain	4.28	0.99	4.16	0.54
France	5.88	1.19	5.65	0.60
Italy	4.74	0.78	4.53	0.40
Cyprus	7.30	1.55	6.43	1.35
Latvia	5.32	0.74	4.90	0.83
Lithuania	5.18	1.00	4.81	0.46
Luxembourg	3.80	:	3.71	:
Hungary	5.85	1.21	5.46	0.56
Malta	4.78	0.83	4.33	1.42
Netherlands	5.07	1.33	4.50	0.48
Austria	5.50	1.29	5.21	0.30
Poland	5.62	1.03	5.57	0.66
Portugal	5.61	1.01	5.53	0.09
Romania	3.44	0.68	3.38	:
Slovenia	6.02	1.34	5.44	0.86
Slovakia	4.34	0.85	4.21	0.46
Finland	6.41	2.05	5.91	0.13
Sweden	7.47	2.16	6.55	0.19
UK	5.38	1.06	5.11	0.97
EU-27	5.17	1.14	4.88	0.63
Croatia	4.53	0.84	4.49	:
Turkey	3.74	1.21	3.56	0.05
FormerYugoslav Republic of Macedonia	3.39	0.51	3.31	:
Iceland	7.81	1.35	7.21	0.71
Norway	7.62	2.32	6.45	0.10
Switzerland	6.04	1.64	5.91	0.63

Source: DG Research Key Figures 2007
Data: Eurostat

Expenditure on educational institutions from public sources represented 4.88% of GDP in EU-27 in 2003, compared with 0.63%

of GDP for expenditure from private sources. Among Member States, Malta and Cyprus were the only countries where expenditure on educational institutions from private sources was higher than 1%.

Graduation from tertiary education

New technologies are developed and applied very quickly and, thus, the renewal of a highly skilled workforce is crucial to manage these rapid changes in science and technology. The number of new graduates from tertiary education, particularly graduates in Science and Engineering (S&E), is a measure of the supply of human resources. In EU-27, the total number of graduates from all fields of education amounted to 3.57 million in 2004.

Across all disciplines the United Kingdom and France had the largest number of new tertiary graduates, together corresponding to one-third of the EU-27 total, whereas Poland had the third highest number of new tertiary graduates in the Union. In Science and Engineering, the other large countries such as Germany, Italy and Spain accounted for a much larger share than Poland in the total production of new graduates.

Women accounted for almost 60% of new graduates from all fields of tertiary education. Moreover, the share of women exceeded 50% in all Member States, as well as Iceland and Norway. However women represented only 40% and 24% respectively of European graduates from the fields of Science and Engineering. In Science, the share of women graduates exceeded 50% in only four Member States. In the case of Engineering, the share of women graduates failed to exceed even 40% for any Member State. In fact, Greece with a share of 38% was the Member State with the highest share of women engineering graduates.

Table II.2.2 Number of graduates from tertiary education by field of education, 2004 [(1)]

	All fields of education		Science		Engineering	
	Total (000s)	% women	Total (000s)	% women	Total (000s)	% women
Belgium	77	57.1	7	30.3	8	20.8
Bulgaria	46	58.3	2	56.4	7	37.2
Czech Republic	54	58.0	4	39.5	8	24.2
Denmark	47	58.8	4	33.5	5	31.1
Germany	320	52.7	32	34.9	54	17.1
Estonia	10	71.6	1	47.9	1	33.1
Ireland	56	57.0	8	43.0	7	17.5
Greece	48	60.9	8	41.9	5	38.0
Spain	298	57.7	33	37.2	50	25.8
France	585	56.6	76	41.0	95	21.7
Italy	325	58.1	24	53.7	50	28.7
Cyprus	4	59.7	0	42.9	0	20.2
Latvia	24	69.2	1	39.3	2	28.2
Lithuania	38	66.5	2	43.9	6	33.3
Luxembourg	:	:	:	:	:	:
Hungary	68	63.5	3	37.6	5	23.7
Malta	2	57.3	0	30.0	0	31.3
Netherlands	97	56.1	7	24.1	9	15.9
Austria	31	50.6	3	35.7	6	17.2
Poland	486	65.5	25	41.1	34	27.6
Portugal	69	65.9	7	50.8	10	33.9
Romania	147	57.3	8	58.8	26	32.4
Slovenia	15	60.4	1	40.0	2	21.2
Slovakia	35	56.7	3	41.1	5	31.6
Finland	39	62.0	3	48.8	8	21.8
Sweden	54	61.0	5	45.9	12	28.6
UK	596	57.7	87	37.4	48	20.1
EU-27	3570	58.7	355	40.3	465	24.3
Turkey	259	44.0	25	45.1	50	23.2
Iceland	3	66.6	0	42.0	0	29.7
Norway	32	60.3	3	26.2	3	22.7
Switzerland	60	44.1	6	21.8	7	11.4

Source: DG Research — Key Figures 2007
Data: Eurostat
Note: (1) FR, MT, FI : 2003.

International mobility flows of foreign tertiary students

With the free movement of people within the European Union and also with the progress of economic globalisation, the international migration of students and/or human capital has become more and more important.

Table II.2.3 Share of foreign students (%) participating in tertiary education by field of education, 2004 [(1)]

	All fields of education	Science	Engineering
Belgium	9.6	9.7	7.7
Bulgaria	3.6	2.1	2.7
Czech Republic	4.7	5.6	3.2
Denmark	7.9	11.3	12.9
Germany	11.2	12.1	12.9
Estonia	1.7	:	:
Ireland	5.6	:	:
Greece	2.4	:	:
Spain	2.3	1.0	1.0
France	:	:	:
Italy	2.0	1.7	1.8
Cyprus	32.0	21.5	8.9
Latvia	2.0	1.0	0.4
Lithuania	0.4	0.1	0.4
Luxembourg	:	:	:
Hungary	3.1	3.7	3.1
Malta	5.6	2.4	2.6
Netherlands	3.9	5.0	4.8
Austria	14.1	14.1	13.6
Poland	0.4	0.1	0.2
Portugal	4.1	5.2	3.7
Romania	1.5	0.5	0.6
Slovenia	1.1	1.9	1.0
Slovakia	1.0	0.7	0.8
Finland	2.6	2.5	2.9
Sweden	8.5	11.3	10.0
UK	16.2	16.3	26.4
EU-27	7.6	7.6	5.9
Turkey	0.8	0.9	0.8
Iceland	3.3	4.1	2.4
Norway	5.8	9.3	6.2
Switzerland	18.2	23.0	20.4

Source: DG Research — Key Figures 2007
Data: Eurostat
Note: (1) EE, IE, LV, RO : 2003.

At the European level, almost eight out of every hundred students participating in tertiary education in 2004 were foreigners. After Cyprus, where 32% of students in tertiary education were foreign, the United Kingdom had the highest European share with 16.2%. Only two other Member States – Germany and Austria – had shares of foreign students higher than 10%. Estonia, Lithuania, Romania, Slovenia and Slovakia had very low shares of foreign students participating in tertiary education. Shares were also low in Greece, Spain, Italy, Latvia and Finland.

In the field of Science the situation was similar, with Cyprus and the United Kingdom also having the highest shares of foreign students. In the field of Engineering, the share of foreign students participating in tertiary education was lower at EU-27 level. However, this was not the case for several countries, including the United Kingdom, where more than one-quarter of the students in this field were foreign.

S&T labour Force

The role of human resources educated *and* employed in science and technology occupations (‘highly-qualified S&T workers’) is fundamental in knowledge-driven economies, because these people contribute directly to the expansion of R&D activities and to the development of technological innovations.

Within EU-27, half (50.6%) of the S&T human resources with a tertiary education were also *employed* in S&T. The highest shares were found in Luxembourg (64.5%), Sweden (62.5%), Romania (62.4%) and Portugal (61.4%), while outside the EU Iceland’s share of 71.7% was noticeably high.

In 2006, highly-qualified S&T workers represented 15.4% of the EU-27 labour force. At the national level, they accounted for more than one fifth of the labour force in Belgium, Denmark, Luxembourg, the Netherlands, Finland and Sweden, as well as in Norway. As one might expect, highly R&D-intensive countries have the largest shares of core S&T workers in the total labour force.

Table II.2.4 Highly qualified scientific and technical workers (HRSTC) [(1)] as % of labour force and as % of total S&T human resources with tertiary education (HRSTE), share of women and age distribution, 2006 [(2)]

	as % of labour force	as % of HRSTE	share of women (%)	Age distribution (%)		
				25-34	35-44	45-64
Belgium	21.1	46.9	53.0	31.9	30.6	30.9
Bulgaria	14.7	45.2	67.7	24.9	29.2	42.8
Czech Republic	10.8	59.3	45.6	31.6	25.8	37.8
Denmark	23.6	58.9	56.6	27.2	30.1	40.6
Germany	15.8	49.0	43.0	20.9	34.1	42.4
Estonia	16.8	41.7	71.6	27.6	25.9	36.2
Ireland	16.9	44.1	54.2	37.1	25.8	27.8
Greece	15.8	53.4	49.6	29.9	33.8	33.0
Spain	16.6	43.8	50.6	36.8	29.5	28.3
France	17.1	47.8	52.0	35.8	28.0	30.5
Italy	11.0	57.0	50.8	27.7	33.8	35.2
Cyprus	18.8	49.3	50.0	41.4	24.3	27.1
Latvia	13.8	50.0	71.1	29.6	24.5	32.7
Lithuania	16.6	45.3	71.2	35.2	27.7	28.8
Luxembourg	24.3	64.5	44.9	36.7	32.7	30.6
Hungary	14.1	53.2	57.2	34.3	23.6	37.6
Malta	12.0	58.8	50.0	45.0	20.0	25.0
Netherlands	20.4	54.7	48.1	28.6	28.4	37.8
Austria	11.2	48.2	46.6	28.0	33.2	35.6
Poland	13.7	53.7	59.1	43.1	23.6	28.1
Portugal	9.8	61.4	61.5	38.3	28.6	28.3
Romania	9.8	62.4	52.0	35.6	24.1	36.4
Slovenia	16.6	59.6	59.6	33.9	29.2	33.9
Slovakia	10.6	57.0	50.0	33.7	23.0	39.0
Finland	20.1	49.1	59.0	25.5	30.3	43.0
Sweden	21.6	62.5	59.0	28.9	25.7	41.8
UK	17.0	50.3	51.6	28.9	27.3	36.6
EU-27	15.4	50.6	51.4	30.6	29.3	35.3
Iceland	19.5	71.7	54.5	30.3	27.3	36.4
Norway	23.2	62.2	54.9	27.9	29.2	39.0
Switzerland	18.3	55.3	35.0	26.7	31.6	38.2

Source: DG Research Key Figures 2007
Data: Eurostat
Notes: (1) Highly qualified scientific and technical workers (HRSTC) refer to the group of people both educated AND employed in scientific and technical occupations (see box).
(2) LU, IS, CH : 2005.

Women represent more than half of highly-qualified S&T workers in Europe (51.4%). They were highly represented in Estonia, Latvia and Lithuania, with more than 70% of the total. Conversely, women were less numerous than men among highly-qualified S&T workers in six Member States – the Czech Republic, Germany, Greece, Luxembourg, the Netherlands and Austria – and also in Switzerland.

Box: Researchers and human resources in science and technology

According to the OECD Frascati Manual, researchers are professionals engaged in the conception or creation of new knowledge, products, processes, methods and systems and also in the management of the projects concerned. Researchers are classified in ISCO-88 Major Group 2 (sub-major groups 21, 22, 23, 24), 'Professionals', and in 'Research and Development Department Managers' (ISCO-88, 1237).

Human resources in science and technology (HRST) comprise people who have successfully completed education at the third level in a S&T field of study (natural sciences, engineering and technology, medical sciences, agricultural sciences, social sciences and humanities – Canberra Manual, §71) and also people who, although not formally qualified in this way, are employed in an S&T occupation where such qualification is normally required (corresponding to professionals and technicians – ISCO-88 International Standard Classification of Occupations levels 2 and 3 and also certain managers, ISCO 121, 122 and 131). Human Resources in Science and Technology – Core (HRSTC) comprise people who have successfully completed education at the third level in an S&T field of study and are employed in an S&T occupation. HRSTE refer to human resources educated in science and technology, but not necessarily employed in an S&T occupation

At EU-27 level, 35.3% of highly-qualified S&T workers were aged 45-64 years. Denmark, Finland, Sweden and Germany – the four Member States with the highest R&D intensities – had the oldest population of highly-qualified S&T workers with the 45-64 years age group exceeding 40% of the total. By contrast Cyprus, Malta and Poland had shares of more than 40% of highly-qualified S&T workers in the youngest age group of 25-34 years.

R&D personnel and researchers

If S&T is a key element of knowledge, the numbers of R&D personnel and in particular, researchers are key indicators of its dissemination and development as they demonstrate the human resources going directly into R&D activities.

Table II.2.5 Total R&D personnel and researchers (FTE), by sector of performance, 2004 [(1)]

	All sectors		Business enterprise		Government		Higher education		Private non-profit	
	R&D personnel	Researchers	R&D personnel	Researchers	R&D personnel	Researchers	R&D personnel	Researchers	R&D personnel	Researchers
Belgium	52911	31465	31436	16322	3813	2124	17062	12742	600	277
Bulgaria	15647	9827	2158	1239	10384	6168	3036	2362	69	58
Czech Republic	28765	16300	15064	7297	7422	4661	6104	4274	175	68
Denmark [(2)]	42687	26167	28040	15877	3250	2287	11139	7846	258	157
Germany	470971	270749	298017	162339	76862	42646	96092	65764	:	:
Estonia	4735	3369	1083	661	810	486	2752	2162	90	60
Ireland	15713	10910	9650	6200	1222	559	4841	4151	:	:
Greece	34004	17024	11099	4328	5509	2307	17189	10251	206	138
Spain	161933	100994	71123	32054	27166	17151	63331	51616	313	173
France [(3)]	352485	200064	197223	106439	51931	24779	97036	65498	6295	3350
Italy	164026	72012	67519	27594	32401	14237	60694	28226	3412	1955
Cyprus	1017	583	224	108	352	104	368	349	72	22
Latvia	5103	3324	881	448	1013	490	3208	2385	1	1
Lithuania	10557	7356	981	484	3041	1676	6535	5196	:	:
Luxembourg	4318	2031	3655	1546	512	342	151	143	:	:
Hungary [(3)]	22826	14904	6704	4309	7595	4693	8527	5902	:	:
Malta	717	436	383	199	45	19	288	218	0	0
Netherlands	91594	:	49915	23158	13579	7752	28100	:	:	:
Austria	42891	25955	29143	16508	2035	1030	11502	8281	212	137
Poland	78362	60944	12978	8334	19685	12804	45572	39716	127	90
Portugal	25590	20623	6166	3954	4545	3194	11520	10600	3360	2875
Romania	33361	21257	16368	9092	9853	6326	6917	5654	223	185
Slovenia	7132	4030	3855	1657	1750	1124	1482	1204	45	45
Slovakia [(3)]	14329	10718	3473	1815	3493	2345	7285	6509	77	49
Finland	58281	41004	32612	23397	7337	4200	17822	13037	510	370
Sweden	77925	54041	56941	34055	3391	2844	17223	16792	370	350
UK	:	:	151908	96747	20796	9205	:	:	:	:
EU-27	2089675	1248608	1114016	609407	312422	172102	642266	453796	20972	13302
Croatia	11162	7140	2831	1015	3634	2420	4697	3705	:	:
Iceland	3050	1987	1422	879	794	479	746	576	88	54
Norway	29745	21161	16260	11061	4985	3300	8500	6800	:	:
Switzerland [(4)]	52250	25400	33085	12640	810	425	18355	12335	:	:

Source: DG Research — Key Figures 2007
Data: Eurostat
Notes: (1) EL, SE : 2005.
(2) DK : Data on researchers in the private non-profit sector refer to the number of university graduates.
(3) FR, HU, SK : Defence is not included in the data for the government sector.
(4) CH : Government sector refers to federal or central government only.

In 2005, the EU employed more than two million R&D personnel measured in Full Time Equivalent (FTE). This unit is a measure of the real volume of R&D performed.

Germany and France were the most important R&D employers in the EU, with more than 40% of the EU's R&D personnel employed in these two countries. Among the new Member States, the main countries employing R&D personnel were Poland, Romania and the Czech Republic.

With the exception of the Czech Republic, Malta and Romania, most of the R&D personnel in the new Member States were employed in the public sector (government and higher education). This is in contrast to most of the other Member States, where the private sector accounted for the highest share.

Of the two million R&D personnel in the EU, approximately 60% are employed as researchers, i.e. professionals who are engaged in the conception or creation of new knowledge, products, processes, methods and systems.

The most important European employers of researchers are, again, Germany and France but the highest proportions of researchers among R&D personnel are to be found in Portugal, Poland and Slovakia.

II-3 Scientific Output

Introduction

The aim of countries to maintain and develop their scientific knowledge base has led to an increasing focus on a number of indicators related to scientific output. These indicators relate to questions such as: What is the importance of a country in the overall production of scientific publications? What is the impact of these scientific publications? To what extent, and how, do certain countries specialise in research in certain scientific fields?

Bibliometric indicators are currently the most easily available and widely used proxies for measuring the scientific production of different actors such as universities, public research institutes and, to some extent, private enterprise. Using this type of information, it is possible to get an insight into the degree of specialisation and into the specialisation profiles of different countries. In particular, by looking at international scientific journals as the basis for bibliometric indicators, one has not only a tangible representation of scientific knowledge, but also the means to compare the research performance of different countries. As such, these journals provide a significant amount of information for the European Research Area, giving an indication of the level of Europe's science base as well as that of its individual Member States.

EU-27 world shares of scientific publications

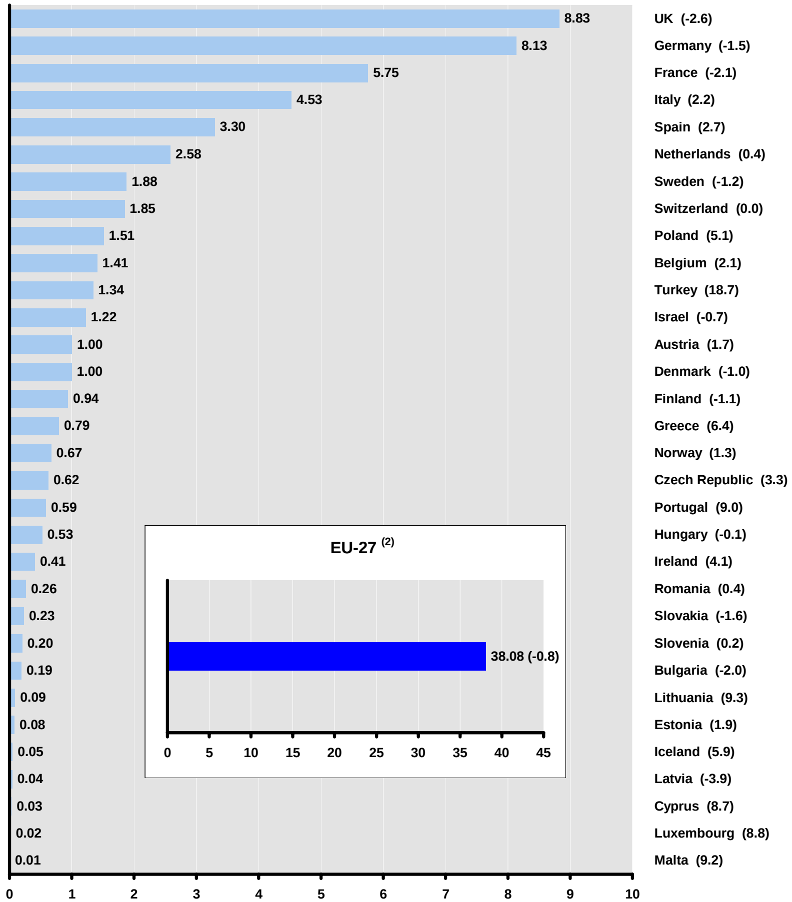
The EU is the world's largest producer of scientific output, as measured by its share in the total world number of peer reviewed scientific articles (see Figure II.3.1). Its world share in 2004 was 38.1%, showing a slight decline compared to 2000. Among individual EU Member States, the United Kingdom, Germany, France and Italy were the largest producers of scientific publications in absolute terms, accounting for more than 70% of the EU's scientific publication output in 2004, and some 27% of the world share (double countings are not excluded when aggregating the world shares of individual countries in Figure II.3.1).

The majority of the Member States contribute only very small shares to worldwide publication output. In fact, sixteen Member States contribute with less or, in many cases, very much less than 1% each. Taken together, these sixteen Member States only contribute some 6% of the world's scientific output (possible double countings not excluded).

Publications in relation to population and public expenditure on R&D

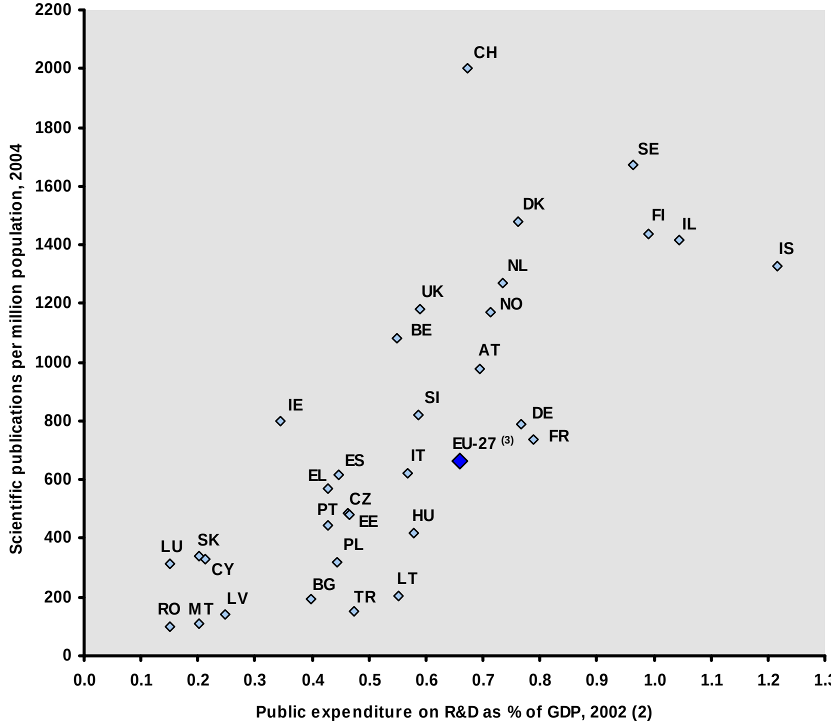
However, adjusting for size gives a different picture (Figure II.3.2). According to the number of publications per million population, Switzerland has a dominant position. The ratio is also particularly high in the Nordic countries. Israel is also ranked high, as are the Netherlands, the United Kingdom, Belgium and Austria. The new Member States can be found at the lowest end of the scale, the exception being Slovenia which is well above the EU average.

Figure II.3.1 World shares of scientific publications (%), 2004 (1); in brackets : average annual growth rates (%), 2000-2004



Source: DG Research Key Figures 2007
Data: Thomson Scientific / CWTS, Leiden University
Notes: (1) Full counting method was used at country level. At the aggregate level, double countings were avoided.
(2) EU-27 : BG and RO are not included.

Figure II.3.2 Scientific publications in relation to public expenditure on R&D (1)



Source: DG Research Key Figures 2007
Data: Thomson Scientific / CWTS, Leiden University, Eurostat, OECD
Notes: (1) In order to take into account the gap between R&D input and scientific output, a two year lag between public expenditure on R&D and scientific publications per million population has been applied.
(2) EL, LU, SE : 2001.
(3) EU-27 does not include BG and RO. Full counting method was used at country level. At the aggregate level, double countings were avoided.

There is a positive relationship between the level of public expenditure on R&D (relative to GDP) and scientific output (relative to population). The countries with a high number of scientific publications in relation to their population also tend to be the countries with a high level of public expenditure on R&D in relation to their GDP. This is particularly evident for the Nordic countries and also for the Netherlands, the United Kingdom, Belgium and Israel. Switzerland is the country showing the clearest divergence from this global pattern, with a relatively high scientific output level compared to its public R&D expenditure.

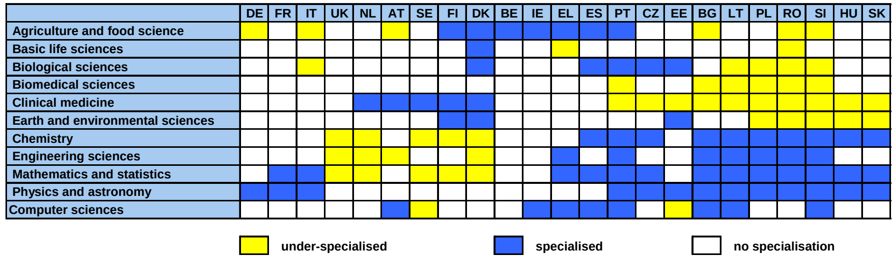
However, it should be noted in this context that different scientific fields are characterised by different publication tendencies. The position of a country on the graph, therefore, largely depends on its scientific specialisation, meaning that countries specialised in ‘publication-intensive’ scientific fields (such as basic life sciences or clinical medicine) will tend to have a higher level of publication per capita for a given level of investment than countries more specialised in domains generating lower publication output (such as computer sciences or engineering sciences). The relative specialisations of the Member States are further described below.

Scientific publications – Relative specialisation index

In order to assess the areas of relative specialisation of countries, it is useful to examine their scientific activity profiles. A country’s level of activity in a given scientific field is measured by comparing the world publication share of the country in the particular field to the world share of the country for all fields combined. Figure II.3.3 shows the relative activity index for the EU Member States. Multidisciplinary sciences and social sciences have been left out, as well as the smallest Member States in terms of publication output: Luxembourg, Malta, Cyprus and Latvia.

Moreover, it should be borne in mind that, as the relative activity index is calculated based on the shares of each country in the world total (per discipline and across all disciplines), large countries (in terms of publication output) influence the average more than small countries, and will thus tend to be less ‘specialised’ than the small countries (as they deviate less from the average).

Figure II.3.3 Scientific publications - relative specialisation index, 2001-2004 - EU Member States (1)



Source: DG Research — Key Figures 2007
Data: Thomson Scientific / CWTS, Leiden University
Note: (1) CY, LV, LU and MT are not displayed due to low overall publication numbers.

The EU countries show diversity with regard to their scientific activity profile. Among the largest publishing Member States, Germany is particularly active in physics and astronomy, but less involved in agriculture and food science. France and Italy are relatively active in mathematics and statistics as well as in physics and astronomy, but Italy shows under-specialisation in agriculture and food science and in biological sciences. The United Kingdom, finally, is relatively under-specialised in chemistry, engineering sciences, and mathematics and statistics.

A group of medium-sized (in terms of publication output) R&D-intensive countries consisting of the Netherlands, Austria and the three Nordic Member States of Sweden, Finland and Denmark appear to be specialised in clinical medicine. For Denmark, this is coupled with a relative specialisation in basic life sciences and biological sciences.

Both Finland and Denmark also belong to a group of countries specialised in agriculture and food science, together with Belgium, Ireland, and the southern European countries of Greece, Spain and

Portugal. Finland and Denmark, together with Estonia, form a smaller group of northern European countries specialised in earth and environmental sciences.

The new Member States show a high level of similarity with regard to their scientific activity profiles. The eastern European countries indeed represent a large cluster relatively specialised in physics and astronomy, mathematics and statistics and chemistry. To a lesser extent, they are also relatively active in engineering sciences. In this regard, their scientific activity profiles show some similarities with those of the southern European countries of Greece, Portugal and Spain.

II-4 Technological output

Introduction

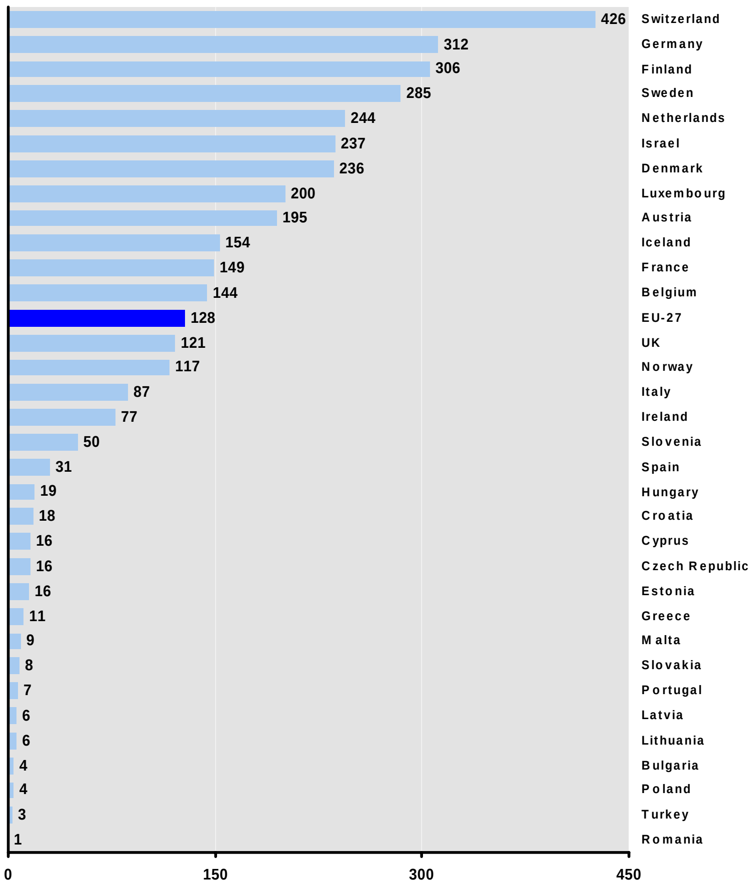
The potential output of R&D activities can be both scientific and technological. Patent-based indicators are among the most frequently used proxies to measure technological output. Patents allow inventors to protect and exploit their inventions over a given time period, and provide a valuable measure of the inventiveness of countries, regions and enterprises. Moreover, since they disclose information about new inventions, patents also play a role in the diffusion of knowledge. Patent indicators not only help to shed light on patterns of technological change, but also measure activities that are closely associated with competitiveness in many important international markets.

Large differences in patenting intensity across Member States

Figure II.4.1 shows the number of patent applications submitted to the European Patent Office (EPO), standardised per million inhabitants to allow a better comparison between countries.

The overall picture is heterogeneous but nevertheless there are some distinct tendencies. Not surprisingly, countries with high R&D intensities show a ratio above the EU-27 average. Germany leads with 312 patent applications per million inhabitants, followed by Finland and Sweden with respectively 306 and 285 applications per million. Conversely, low R&D-intensive countries such as the new Member States and the southern European countries of Portugal, Greece and Spain are at the lower end of the scale. Slovenia, with 50 patent applications per million inhabitants, is the most active patenting country among the new Member States.

Figure II.4.1 EPO patent applications per million population, 2003 (1)



Source: DG Research
Data: Eurostat
Note: (1) By priority year.

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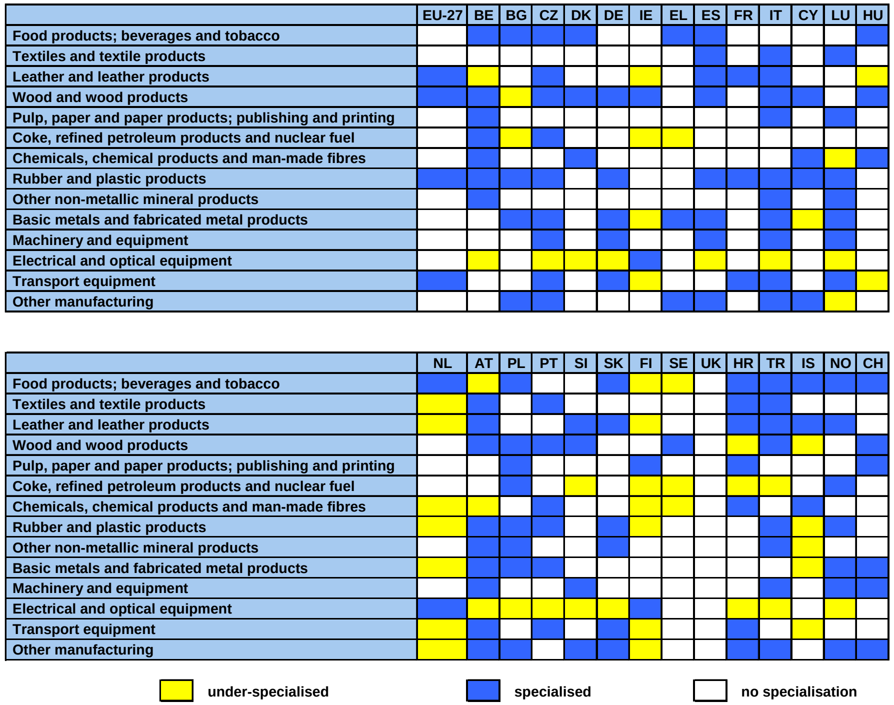
No less than eight Member States produced less than ten patent applications per million inhabitants in 2003. When the other countries of the European Research Area (ERA) are taken into account, we find that Switzerland is far ahead with 426 patent applications per million inhabitants. Israel is also among the top-performing countries, with 237 patent applications per million inhabitants in 2003.

Technological specialisation profiles within the EU: diversity rules

In order to assess the relative technological strengths and weaknesses of countries, it is useful to examine their technological specialisations. A country's level of specialisation in a given field of technology is measured by comparing the world share of the country in that particular field to the world share of the country for all fields combined. The number of patent applications submitted to the EPO, analysed by economic activity (NACE Rev 1.1), is used as base data for the calculation of the relative technology activity index.

Technological specialisation within EU-27 shows a high degree of diversity. An examination of the EPO patent applications in the manufacturing sector over the period 2000-2003 reveals that the EU is specialised in traditional industries such as leather products, wood products, rubber and plastic products, and transport equipment. Although not significantly diverging from the world average, Europe's technological output seems to be under-specialised in the electrical and optical equipment industry. This is also the manufacturing sector where the largest number of under-specialised Member States can be found.

Figure II.4.2 EPO patent applications in the manufacturing sector - relative activity index (RAI), 2000-2003 (1)



Source: DG Research | Key Figures 2007
Data: Eurostat
Note: (1) By priority year and by sector of economic activity (NACE class derived through concordance with IPC).

A closer look at the technological specialisation of each Member State does not reveal any clear pattern. The United Kingdom does not show any specialisation at all, nor any under-specialisation. Sweden specialises in only one economic activity (wood and wood products), whereas Ireland (wood and wood products, electrical and optical equipment), Lithuania (food products, beverage and tobacco, other manufacturing), the Netherlands (food products, beverage and tobacco, electrical and optical equipment) and Finland (electrical and optical equipment, pulp, paper and paper products, publishing and printing) each specialise in two economic activities. Obviously, Sweden's and Finland's specialisation patterns are largely determined by the abundance of timber as a natural resource.

At the other end of the scale are countries with a high degree of technological diversification, such as Italy which specialises in ten manufacturing industries, and the Czech Republic and Austria which both specialise in nine.

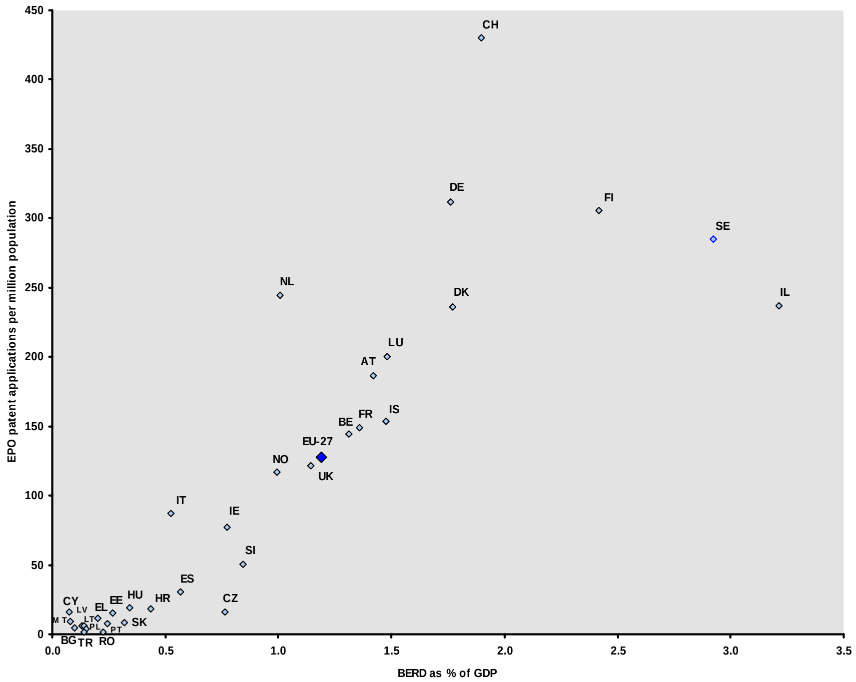
Most of the Member States are under-specialised in only a very few economic activities; France even in none of them. Exceptions are Estonia, Malta, the Netherlands and Finland, all of which exhibit an under-specialisation in seven manufacturing industries.

Positive correlation between patenting activity and private investment in R&D

There is a strong positive relationship between patenting intensity (number of patents per capita) and the level of private expenditure on R&D (BERD as a percentage of GDP). European countries with high levels of business R&D expenditure relative to GDP, such as Germany, Sweden, Finland, Denmark and Switzerland, also have the largest numbers of patent applications per million population. In contrast, countries such as the new Member States have both low business R&D intensities and low levels of patenting activity.

The degree of technological diversification does not seem to impede patenting performance. Germany specialises in five manufacturing industries and yet produces more patent applications per million inhabitants than Sweden, which specialises in only one manufacturing industry. At the same time Sweden has a higher business expenditure on R&D as a percentage of GDP than Germany. These national divergences reveal in part substantial differences in the industrial structure of each country.

Figure II.4.3 EPO patent applications per million population (1) in relation to BERD as % of GDP, 2003 (2)



Source: DG Research
Data: Eurostat, OECD
Notes: (1) By priotity year.
(2) CH : 2000; AT : 2002.

Key Figures 2007

II-5 The impacts of S&T performance on competitiveness

Introduction

Education, scientific and technological progress and innovation have always been crucial ingredients of economic activity and an important source of competitiveness. The transition to the knowledge-based economy is enhancing the level of competitiveness of our economies. On the one hand, the industries that are most involved in the production and exploitation of knowledge are gaining weight and having to compete globally. On the other hand, the integration of new, competitive knowledge in the day-to-day processes of all parts of the economy is influencing the way productive activities are organised and thus having an impact on overall economic output and competitiveness.

This section analyses, with the help of the relevant indicators, the impact of scientific and technological performance on aspects of Member State economies, such as trade in high-tech products and intangible knowledge, value added in high-tech industries and in knowledge-intensive services, and labour productivity growth.

Selling high technology products on global markets

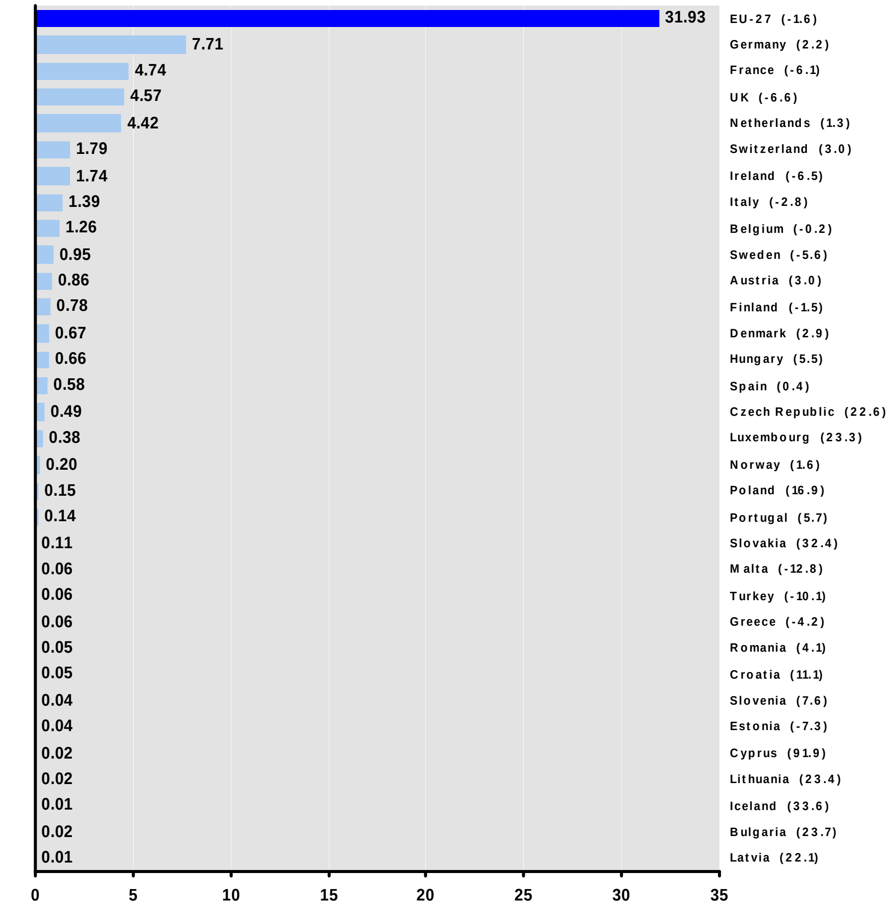
High-tech products are products with a high R&D intensity; they therefore represent the technological leading edge of traded goods. They are also amongst the most dynamic traded internationally, and the growth in their trade has been significantly stronger than that of other traded goods.

According to the OECD, technology-intensive exports, and high-tech exports in particular, accounted for much of the growth in overall trade over the past decade.[63] 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.

Figure II.5.1, showing the shares of the EU Member States in world high-tech exports in 2005 and the growth of these shares between 2000 and 2005, gives an indication of EU competitiveness in the global high-tech market.

In 2005, EU-27 represented 31.9% of total world exports of high-tech products (including intra-Europe exports). Germany, France, the United Kingdom and the Netherlands accounted for two-thirds of that world share. Almost all of the new Member States experienced a strong growth of their market share between 2000 and 2005. The rapid growth seen in these catching-up economies reflects the restructuring process which has been taking place in recent years. Among the R&D-intensive countries, Austria, Switzerland, Denmark and Germany were able to further expand their market share over recent years, while France, Sweden, the United Kingdom and, to a lesser extent, Finland and Belgium showed declining high-tech market shares.

Figure II.5.1 World market shares of exports of high-tech products (%); in brackets: average annual growth rates (%), 2000-2005 (1)

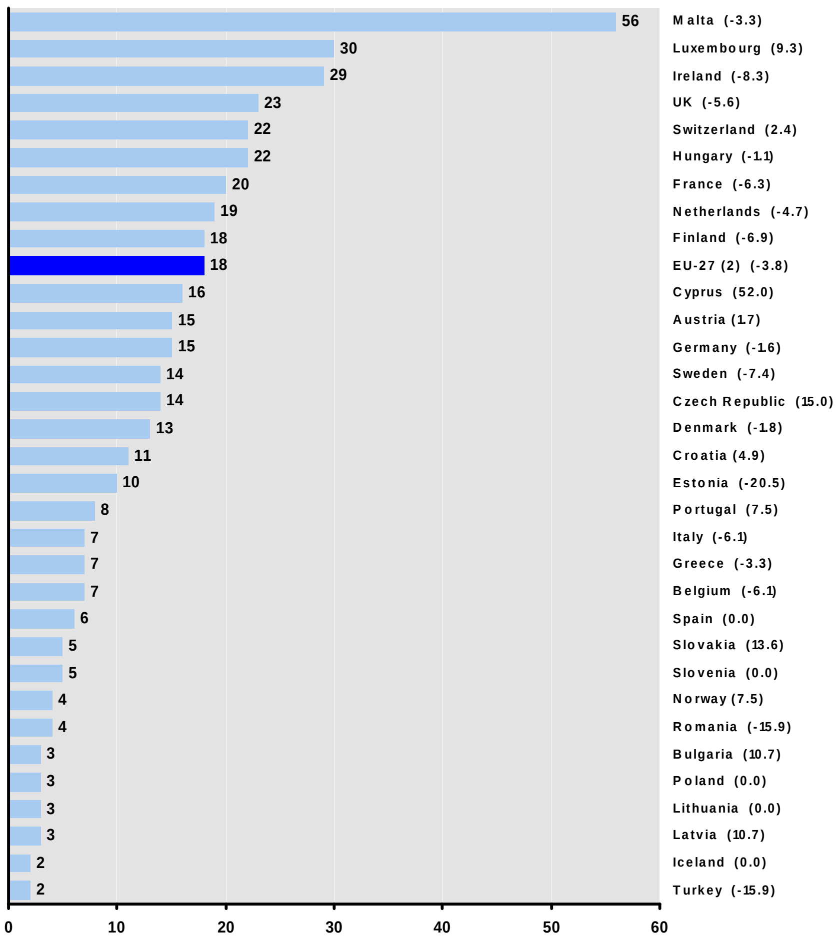


Source: JRC/Ispra, DG Research
Data: Eurostat (Comext), UN (Comtrade)
Note: (1) Intra-EU exports are included.

Key Figures 2007

63 OECD (2005), Science, Technology and Industry Scoreboard 2005, Paris, p. 170-173.

Figure II.5.2 High-tech exports as % of total exports, 2004; in brackets: average annual growth rates (%), 2000-2004 (1)



Source: JRC/Ispra, DG Research   Key Figures 2007
Data: Eurostat (Comext), UN (Comtrade)
Notes: (1) The value for EU-27 does not include Intra-EU exports. BG and RO are not included in EU-27.
(2) EU-27 : BG and RO are not included.

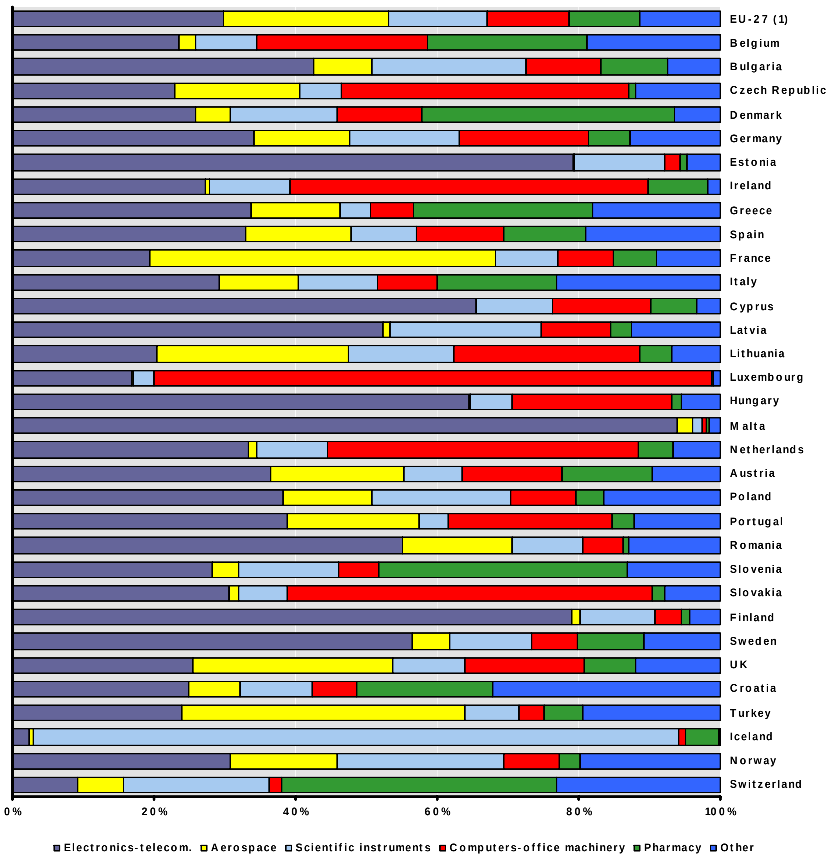
The extent to which countries' exports are more or less focused on high-tech products can be seen from Figure II.5.2. Of the goods exported by EU-27 in 2004, 18% were high-tech products (excluding intra-Europe trade). However, the differences between European countries are substantial; the high-tech share of total exports ranges from more than 50% in Malta to less than 3% in Turkey and Iceland. Malta has an especially high concentration of high-tech products in its exports, due to sales of electronic components which have increased dramatically since the 1980s. With the exception of Hungary, all the other new EU Member States are below the EU average.

Between 2000 and 2004, the high-tech intensity of exports increased in a majority of the new Member States, including Cyprus, the Czech Republic, Slovakia, Latvia and Bulgaria. Conversely, after a long period of sustained growth during the Nineties, it decreased between 2000 and 2004 for the Union as a whole, as well as for a large group of technologically advanced economies, in particular Sweden, Finland and Ireland.

Looking at the composition of high-tech exports (Figure II.5.3), by far the most traded group is 'electronics-telecommunications'. Together with 'computers and office machinery' (another typical ICT product group), the group accounts for more than 40% of the high-tech exports of the Union. However, although these two product groups make up the largest share of high-tech exports in most of the Member States, the composition of high-tech exports varies significantly from country to country.

France and the United Kingdom, respectively the second and third largest exporters of high-tech products within EU-27, recorded high shares of exports in 'aerospace', with 49% and 28% respectively, while in Denmark, Switzerland and Slovenia high-tech exports were more concentrated in 'pharmacy'.

Figure II.5.3 Composition of high-tech exports, 2004



Source: DG Research Key Figures 2007
Data: Eurostat (Comext)
Note: (1) EU-27 does not include BG and RO.

The economic downturn following the dotcom bubble in 2000 markedly affected the global trade of ICT goods. According to the OECD, in 2003 the share of ICT goods in total goods trade fell back to its 1996 level in EU-15, the OECD area and Japan.[64] Therefore, countries with a relatively high concentration of high-tech exports in 'pharmacy' (e.g. Switzerland, Denmark, Slovenia) were much less affected than countries with high-tech exports heavily concentrated in telecommunication equipment (e.g. Sweden or Finland) or in computers (e.g. Ireland, the Netherlands).

Trading knowledge: the technology balance of payments

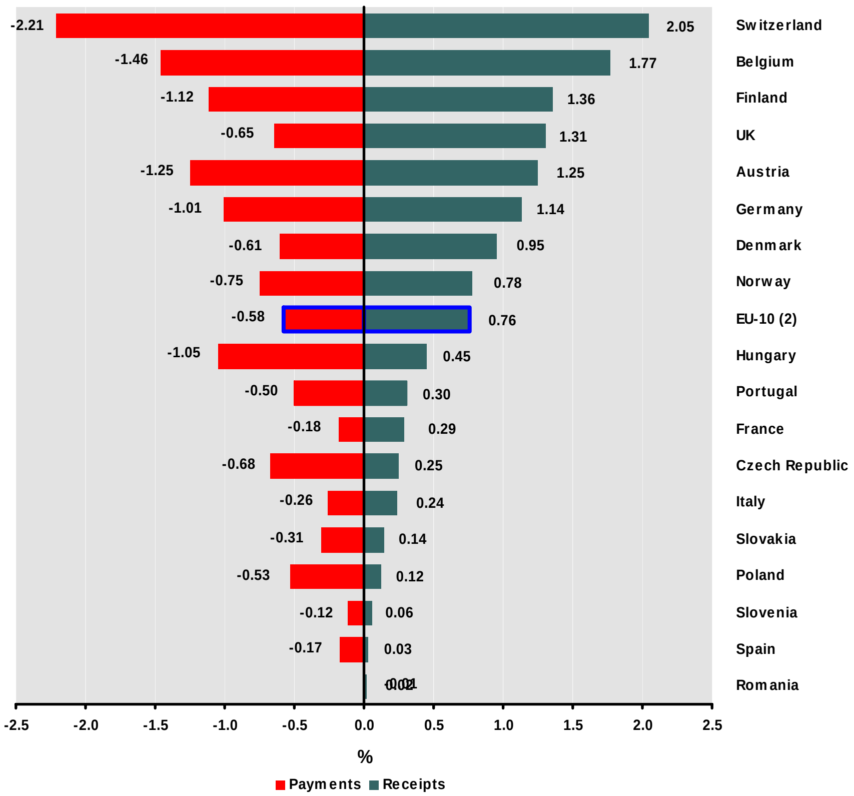
As well as high-tech products, countries can also buy and sell intangible knowledge. These transactions are measured by the technology balance of payments (TBP), which records a country's exports and imports of technical knowledge and services (including licence fees, patent purchases and royalties paid, know-how, research and technical assistance). The indicator examined here relates to a country's exports of technology (TBP receipts), which reflects its competitiveness on the international market for knowledge. Such trade in technology is also an important vehicle for international technology transfer.

The main exporters of technology as a percentage of GDP are also Europe's most R&D-intensive countries: Switzerland, Belgium, Finland, the United Kingdom, Austria, Germany and Denmark are far above the EU average. The only exception is France, which in 2003 was clearly below the EU average. Even though R&D-intensive countries also import foreign technology to a large extent, their balance is generally positive (net exporters). Conversely, most low R&D-intensive countries have low levels of technology exports (as a percentage of their GDP). These countries are mainly net

64 OECD (2005), Science, Technology and Industry Scoreboard 2005, Paris, p. 126-127.

importers of technology, since their technology development relies to a large extent on the acquisition of foreign knowledge.

Figure II.5.4 Technology balance of payments and receipts as % of GDP, 2005 (1)



Source: DG Research

Key Figures 2007

Data: OECD, Eurostat

Notes: (1) ES : 1998; DK, HU : 1999; AT, SI : 2000; SK : 2001; PL : 2002; FR, RO, EU-10 : 2003.

(2) EU-10 includes BE, CZ, DE, FR, IT, LU, PT, RO, FI, UK.

TBP flows are highly internationalised and, as in the case of a number of other indicators, multinational companies are involved in a significant proportion of these transactions. Some of these receipts may therefore be going to foreign affiliates based in the country in question.

High-tech industries and knowledge-intensive high-tech services

All industries generate and/or exploit new technology and knowledge to some extent, but some are more technology-intensive or knowledge-intensive than others. To assess the importance of technology and knowledge within the industrial texture, it is useful to focus on the leading producers of high-tech goods and on the activities, including services, which make intensive use of high technology. This section looks at the share of value added accounted for by high-tech manufacturing industries[65] and knowledge-intensive high-tech services[66]. Such indicators show the relative weight in an economy of those activities that require both high-level R&D input and high qualification levels of employees.

65 'High-tech' manufacturing industries re-group the following five sectors: 1) Chemicals (including pharmaceuticals), 2) Office, accounting and computing machinery, 3) Radio, television and communication equipment, 4) Medical, precision and optical instruments, 5) Aircraft and spacecraft (see methodological annex for further details).

66 'Knowledge-intensive high-tech services' re-group the following three sectors: 1) post and telecommunications, 2) computer and related activities, 3) research and development (see methodological annex for further details).

Table II.5.1 EU-27 (1) - % distribution of value added by sector, 1997-2003

	1997	1998	1999	2000	2001	2002	2003
Manufacturing	20	20	20	19	19	18	18
Services	68	69	70	70	70	71	72
Other	11	11	11	11	11	11	11
TOTAL	100	100	100	100	100	100	100

Source: DG Research Key Figures 2007
Data: Groningen Growth and Development Centre
Note: (1) EU-27 does not include BG, EE, CY, LV, LT, MT, RO and SI.

However, when interpreting the results it should be borne in mind that each country has a unique economic structure. At the EU level services represented, in 2003, 72% of total value added and their share is increasing, while the weight of manufacturing industry in the economy is shrinking and accounts now for less than one-fifth of total value added.

Although the increasing importance of services is a general pattern common to all European countries, in some Member States manufacturing still represents a very significant proportion of all economic activities (e.g. in the Czech Republic, Hungary, Slovakia, Ireland, Finland and Germany, where manufacturing activities accounted for 23-31% of total value added in 2003), while others are more dominated by service activities (e.g. Luxembourg, the Netherlands, the United Kingdom, Belgium and France, where services represented 74-83% of total value added in 2003).

The high-tech component of manufacturing industry

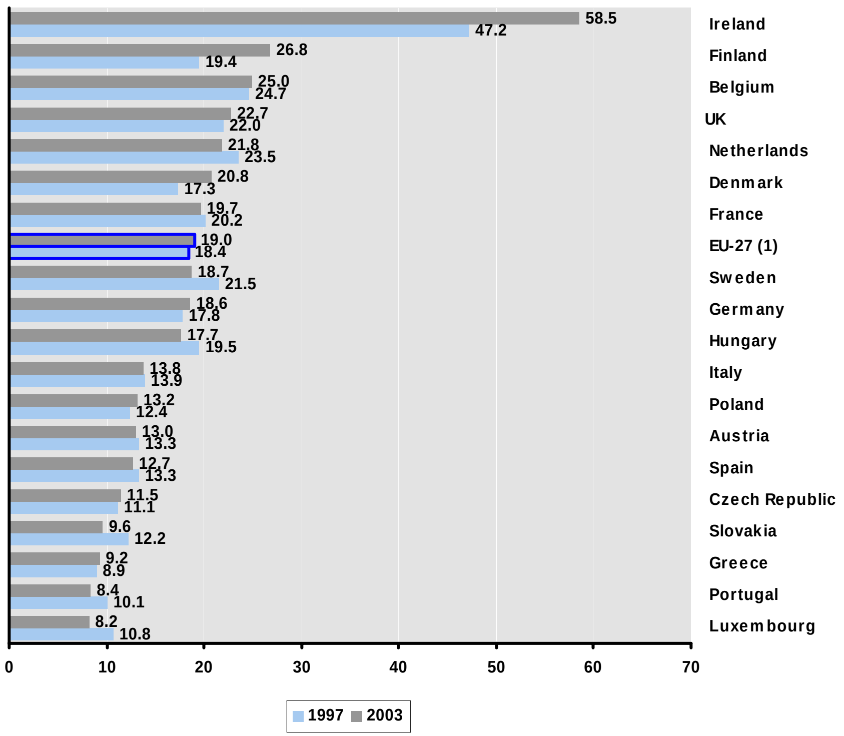
At the EU level, 19% of manufacturing value added is accounted for by high-tech industries. Ireland is at the top of the group, with more than half of manufacturing value added generated by high-tech industries (the industry sector of 'chemicals' – including pharmaceuticals – represents almost half of this). It is interesting to note that among the top performing countries there are countries with a relatively high overall share of manufacturing in their economic base (e.g. Ireland, Finland), as well as countries which are mainly service-based but have an important element of high-tech activity in their manufacturing (e.g. Belgium, the United Kingdom, the Netherlands, France).

Conversely at the lower end of the range Luxembourg, as well as the southern European countries and the new Member States, are characterised by a weak presence of high-tech activities within their manufacturing industry. For Luxembourg and Greece, the low importance of manufacturing industry in the economy (10% of total value added in both cases) should be borne in mind when considering these figures.

For the other countries in this group, however, manufacturing industry represents a significant share (16-26%) of the total economy and is primarily concentrated in medium-low-tech and low-tech activities. This explains the relatively low shares of Austria and Italy, which have higher concentrations of manufacturing value added in medium-low-tech and low-tech industry. Finally, the unexceptional shares of Germany and Sweden are due to the fact that medium-high-tech activities very clearly dominate manufacturing activities.

It should be expected that, with a gradual shift to a knowledge-based economy, the value added of those industries with a higher component of R&D would grow at the expense of other more traditional industries. Between 1997 and 2003 the weight of high-tech industries in total manufacturing value added in EU-27 increased from 18.4% to 19.0%. This shift towards more high-tech activities occurred at the expense of low-tech industry, the share of which declined from 33.7% to 33.1% in the same period. Medium-high-tech and medium-low-tech activities have maintained, since the end of the 1990s, a relatively unchanged share of total manufacturing value added at about 23.6% (medium-high) and 24.1% (medium-low).

Figure II.5.5 Value added of high-tech manufacturing industries as % of total manufacturing value added, 1997 and 2003



Source: DG Research — Key Figures 2007
Data: Groningen Growth and Development Centre
Note: (1) EU-27 does not include BG, EE, CY, LV, LT, MT, RO and SI.

The share of high-tech industries in manufacturing value added increased in nine Member States between 1997 and 2003,: not only in countries where manufacturing has a weak high-tech component (e.g. Greece, the Czech Republic, Poland), but also in the Member States where high-tech industries already represent the largest share of manufacturing activities (e.g. Ireland, Finland, Belgium, the United Kingdom, Denmark). The high-tech component of manufacturing industry gained ground particularly rapidly in Finland and in Ireland. In the former this was due to the strong expansion of the ‘telecommunication equipment’ manufacturing sector, while in the latter the sector ‘chemicals (including pharmaceuticals)' was responsible for most of the growth. In contrast to Finland, Sweden's decreasing high-tech share was entirely due to the collapse of the 'telecommunication equipment' sector after 2000, where value added (in current terms) dropped by more than 90% in 2000-2003.

The absence of a growing share of the high-tech component in some Member States does not necessarily mean that there is no shift within the manufacturing sector towards higher-tech activities. In a lot of countries medium high-tech industry became more important within the industrial structure at the expense of low-tech activities, even though no strong growth of the high-tech share was recorded. In France, Germany, Austria, Hungary and Slovakia, for instance, the slight decrease (or modest growth) in the high-tech share between 1997 and 2003 was accompanied by an increase of the medium-high-tech component, a *status quo* of the medium-low-tech share and a clear decline in the low-tech segment of manufacturing value added. This increasing importance of medium high-tech activities was primarily due to the strong expansion of the manufacturing sectors 'motor vehicles' (for France, Germany and Slovakia), 'mechanical engineering' (for Austria) and 'electrical machinery' (for Hungary).

Finally, in the southern European countries of Italy, Spain and Portugal, as well as in the Netherlands, manufacturing industry has become more low-tech between 1997 and 2003. In Italy and the Netherlands, value added in the high-tech and medium-high-tech manufacturing sectors decreased (in absolute, current terms) after 2001, while it continued to increase in the medium-low-tech and low-tech sectors. In Portugal and Spain, value added in the low-tech and medium-low-tech sectors increased much faster than in the two other sectors (current terms).

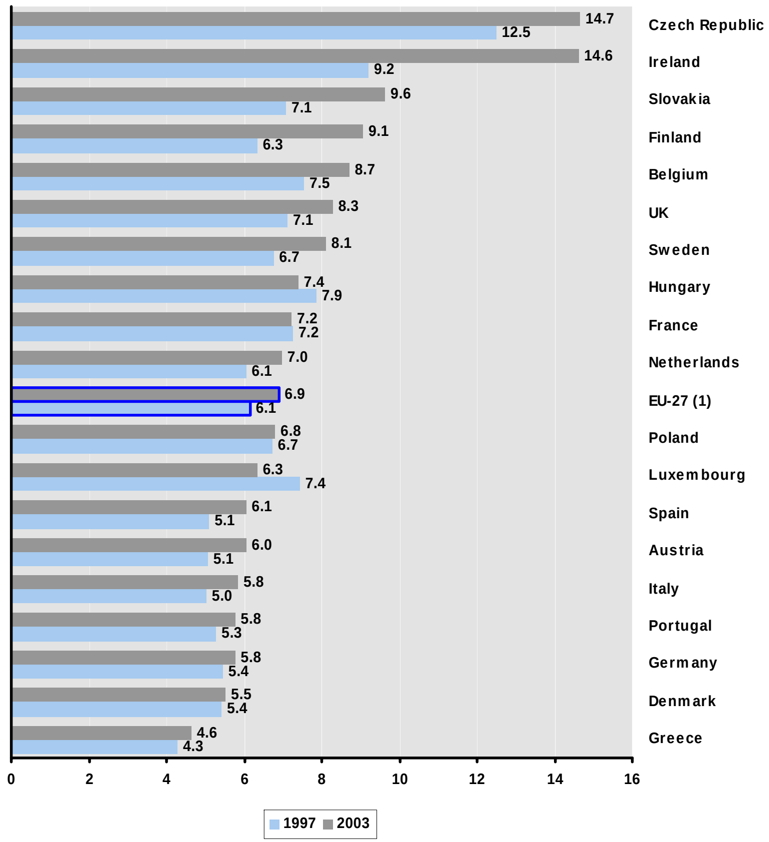
Knowledge-intensive activities in the services sector

Knowledge-intensive high-tech services (KHTS) play an increasingly important role in all developed economies. They cover a sector with high requirements for qualifications and the application of knowledge, and this gives them a special importance for economic growth. The development of KHTS is closely linked to the growing specialisation of industries and the need for even more specialised services emanating from other service and manufacturing sectors. Very often, specialisation is conditioned by a more sophisticated demand and, as a consequence, may lead to increases in productivity.

The value added created by KHTS is an important indicator of the overall knowledge intensity of a given economy. Moreover, the share of value added accounted for by KHTS has been constantly growing in the EU in recent years. In 2003, KHTS accounted for 6.9% of the total value added in the services sector, against 6.1% in 1997. The share of KHTS in the total services sector has been growing in almost all EU Member States between 1997 and 2003.

However, there were quite substantial differences between individual Member States, with the Czech Republic the top performing country, followed by Ireland, Slovakia and Finland, while the lowest scoring countries were Greece, Denmark and Germany.

Figure II.5.6 Value added of knowledge intensive high-tech services as % of total services value added, 1997 and 2003



Source: DG Research — Key Figures 2007

Data: Groningen Growth and Development Centre

Note: (1) EU-27 does not include BG, EE, CY, LV, LT, MT, RO and SI.

Labour productivity growth within the EU: convergence between the East and the West, divergence between the South and the North

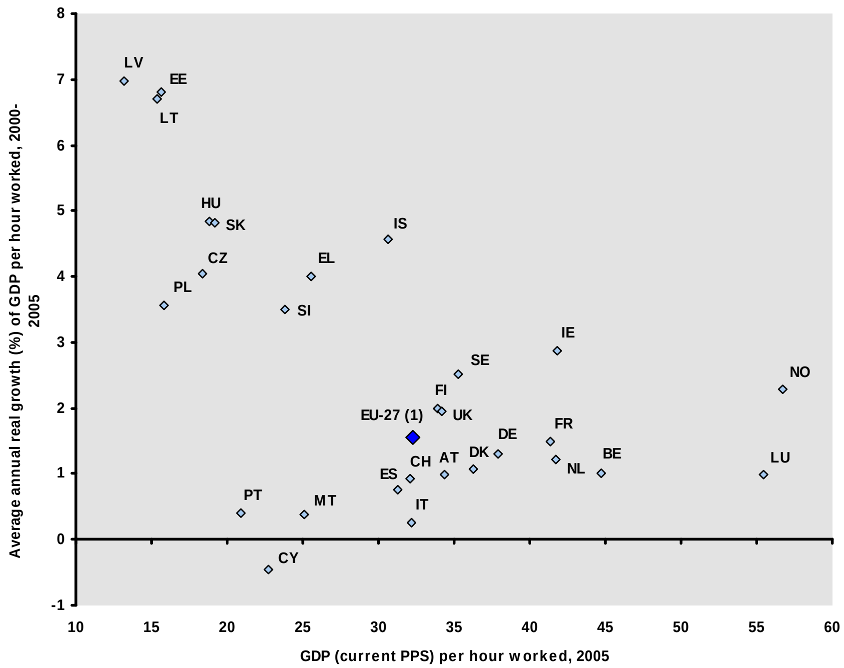
In the long run, increasing labour productivity constitutes the surest way to increase the standard of living of a population in a sustainable manner. Moreover, labour productivity is heavily impacted upon by innovation performance, as largely measured by total factor productivity. Since the middle of the 1990s, the EU has ceased to catch up with the US in terms of labour productivity, reflecting relatively weak innovation performance.

Within EU-27 a first large group, consisting of all the southern and eastern European countries, is characterised by low levels of labour productivity. With the exceptions of Spain and Italy, which show productivity levels around (for Italy) or slightly below (for Spain) the EU average, all these Member States have significantly below-average levels of output per hour worked.

Within this group, a clear distinction can nevertheless be made when examining growth performance. The eastern European Member States, as well as Greece, have been rapidly catching up with the rest of the Union since 2000. In particular, the Baltic States of Latvia, Lithuania and Estonia recorded a very impressive growth of more than 6% per annum. The opposite is true for Spain, Italy, Cyprus, Malta and Portugal, which have the lowest growth rates of the Union (even negative in the case of Cyprus). As a result, Italy's labour productivity level has now fallen below the EU average.

Among the remaining European countries, labour productivity is very high in Luxembourg and Norway, is well above the EU average in Belgium, France, Ireland and the Netherlands, and is slightly above the EU average in the Nordic countries, Germany, Austria and the United Kingdom. Labour productivity has been growing over the past years at the high pace of 2-3% per annum in Ireland, Finland, Sweden and the United Kingdom; these countries are consequently pulling further ahead. Conversely in Belgium, Denmark, Germany, France, the Netherlands and Austria, labour productivity growth was rather weak between 2000 and 2005.

Figure II.5.7 Labour productivity (GDP per hour worked), 2005 and average annual real growth 2000-2005



Source: DG Research
Data: Eurostat, DG ECFIN (AMECO database)
Note: (1) EU-27 does not include BG and RO.

Key Figures 2007

Annex: Definitions and Sources

Symbols and abbreviations

Country codes

BE	Belgium	SI	Slovenia
BG	Bulgaria	SK	Slovakia
CZ	Czech Republic	FI	Finland
DK	Denmark	SE	Sweden
DE	Germany	UK	United Kingdom
IE	Ireland	EU-27	European Union
EL	Greece	HR	Croatia
ES	Spain	TR	Turkey
FR	France	IS	Iceland
IT	Italy	NO	Norway
CY	Cyprus	CH	Switzerland
LV	Latvia	IL	Israel
LT	Lithuania	US	United States
LU	Luxembourg	JP	Japan
HU	Hungary	CN	China
MT	Malta	RU	Russian Federation
NL	Netherlands	KR	South Korea
AT	Austria	IN	India
PL	Poland		
PT	Portugal		
RO	Romania		

Other abbreviations

FTE Full-time equivalent

: 'not available'

- 'not applicable' or 'real zero' or 'zero by default'

General Indicators

Gross domestic product (GDP)

Definition: Gross domestic product (GDP) data have been compiled in accordance with the European System of Accounts (ESA 1995). Since the publication of Key Figures 2005 GDP has been revised upwards for the majority of EU Member States following the allocation of FISIM (Financial Intermediation Services Indirectly Measured) to user sectors. This has resulted in a downward revision of R&D intensity for individual Member States and for the EU.

Source: Eurostat.

Value Added

Definition: Value added is current gross value added measured at producer prices or at basic prices, depending on the valuation used in the national accounts. It represents the contribution of each industry to GDP.

Sources: Groningen Growth and Development Centre, OECD.

Small and medium-sized enterprises

Definition: For the purposes of this publication small and medium-sized enterprises (SMEs) are defined as enterprises having fewer than 250 employees.

Sources: Eurostat, OECD.

Purchasing Power Standards (PPS)

Definition: Financial aggregates are sometimes expressed in Purchasing Power Standards (PPS), 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. The calculations on R&D investments in real terms are based on constant 2000 PPS.

Source: Eurostat

Labour Productivity

Definition: Labour productivity is defined as GDP (in PPS) per hour worked. According to the growth accounting methodology, labour productivity can be decomposed into capital deepening and multifactor productivity.

Source: Eurostat, DG Ecfin (Ameco Database).

Total Factor Productivity

Definition: Total Factor Productivity (TFP) or Multifactor Productivity (MFP) is usually defined as the overall efficiency level of the production process. TFP is affected by factors such as labour quality/skill mix improvements; capital quality (vintage and asset composition); pure technological progress; sectoral reallocation effects; changes in capacity utilisation rates and measurements errors with respect to the contributions from physical capital / labour.

Capital Deepening

Definition: Capital deepening is defined as the capital / labour ratio.

Technology Categories

Definition: The four manufacturing industry technology categories are defined as follows (NACE codes are given in brackets) :

(1) High-tech : office machinery and computers (30), radio, television and communication equipment and apparatus (32), medical, precision and optical instruments, watches and clocks (33), aircraft and spacecraft (35.3), pharmaceuticals, medicinal chemicals and botanical products (24.4)

(2) Medium-high-tech : machinery and equipment (29), electrical machinery and apparatus (31), motor vehicles, trailers and semi-trailers (34), other transport equipment (35), chemicals and chemical products excluding pharmaceuticals, medicinal chemicals and botanical products (24 excluding 24.4)

(3) Medium-low-tech : coke, refined petroleum products and nuclear fuel (23), rubber and plastic products (25), non-metallic mineral products (26), basic metals (27), fabricated metal products except machinery and equipment (28), building and repairing of ships and boats (35.1)

(4) Low-tech : food products and beverages (15), tobacco products (16), textiles (17), wearing apparel; dressing and dyeing of fur (18), tanning and dressing of leather; manufacture of luggage, handbags, saddlery and harness (19), wood and products of wood and cork,

except furniture (20), pulp, paper and paper products (21), publishing, printing and reproduction of recorded media (22), furniture and other manufacturing (36), recycling (37).

R&D expenditure

Gross domestic expenditure on R&D

Definition: Gross domestic expenditure on R&D (GERD) is defined according to the OECD Frascati Manual definition. GERD can be broken down by four sectors of performance : (i) Business enterprise expenditure on R&D (BERD); (ii) Government intramural expenditure on R&D (GOVERD); (iii) Higher education expenditure on R&D (HERD); and (iv) Private non-profit expenditure on R&D (PNPRD). GERD can also be broken down by four sources of funding: (i) Business enterprise; (ii) Government; (iii) Other national sources; and (iv) Abroad.

Sources: Eurostat, OECD

Government budget for R&D

Definition: The government budget for R&D is defined as government budget appropriations or outlays for R&D (GBAORD) according to the OECD Frascati Manual definition. The data are based on information obtained from central government statistics and are broken down by socio-economic objective in accordance with the nomenclature for the analysis and comparison of scientific programs and budgets (NABS).

Source: Eurostat

Tax subsidies

Definition: The relative generosity of R&D tax subsidies has been calculated in the manufacturing sector of most OECD countries for the years 1991, 2000 and 2006. The rate of tax subsidy for 1 euro of R&D is equal to one minus the so-called *B-index*. The value of the *B-index* is based on the before-tax income required to break even on one euro of R&D outlay and takes into account corporate income tax rates, R&D tax credits, special R&D allowances from taxable income, and depreciation of capital assets (machinery, equipment and buildings) used in R&D.
The *B-index* is the present value of before-tax income necessary to cover the initial cost of R&D investment and to pay corporate income taxes so that it becomes profitable to perform research activities. Algebraically, the *B-index* is equal to the after-tax cost of an expenditure of one USD on R&D divided by one minus the corporate income tax rate.

Source: OECD (see OECD, Tax incentives for Research and Development: trends and issues, 2003)

Venture Capital investment

Definition: Venture Capital in the early stages of a company – i.e. seed and start-up stages – provides financing mainly for the initial business plan, research activities, product development and first marketing. Expansion and replacement Venture Capital can provide finance for increased production capacity, market or product development, bridge financing, rescue/turnaround financing, refinancing of bank debt and the purchase of existing shares in a company. Total Venture Capital itself is a part of total private equity capital for enterprises not quoted on a stock market.

Source: Eurostat

Human Resources

Researchers

Definition: Researchers (Research Scientists and Engineers, RSEs) include the occupational groups ISCO-2 (Professional Occupations) and ISCO-1237 (Research and Development Department Managers). See the "Frascati Manual" (OECD 2002a). The data for researchers are generally given in full-time equivalents (FTE).

Sources: Eurostat, OECD

Classification: ISCO: International Standard Classification of Occupation (version 1988).

S&E graduates

Definitions: Graduates are defined by the levels of education classified in ISCED 1997. In these key figures graduates include all tertiary degrees (ISCED 5a and 5b) and PhDs (ISCED 6). The S&E fields of study are: life sciences (ISC42), physical sciences (ISC44), mathematics and statistics (ISC46), computing (ISC48), engineering and engineering trades (ISC52), manufacturing and processing (ISC54), architecture and building (ISC58).

Particularities: BE: data for the Flemish community exclude second qualifications. CY: Data exclude tertiary students graduating abroad. The fields of study in Cyprus are limited. EE: Data exclude master degrees (ISCED 5A). LU: Luxembourg does not have a complete university system; data refer only to ISCED 5B first degree.

Sources: Eurostat.

Classification: ISCED: International Standard Classification of Education (1997 version).

Scientific Performance

Scientific Publications

Definition: Publications are research articles, reviews, notes and letters that were published in referenced journals which are included in the SCI database of the Institute of Scientific Information (ISI). A full counting method was used at the country level, however for the EU aggregate, double counts of multiple occurrences of EU Member States in the same record were excluded.

Co-publications are publications by two or more authors from two or more countries. Despite the possibility of several authors from one country, each country involved is counted only once.

Source: ISI, Science Citation Index; treatments and calculations: University Leiden, CWTS.

Scientific specialisation

Definition: The relative scientific specialisation index (or relative activity index RAI) is calculated for 11 fields on the basis of publications from 2001-2004. The fields 'Multidisciplinary' and 'Social Sciences' have been left out. RAI = a/b, where a = % of a country in all publications in a field and b = % of publications of that country compared to total publication output of all countries. Normalised score: RAI*=(RAI-1)/(RAI+1) AI*. Scores below -0.1 mean a significant under-specialisation in a given scientific field, scores between -0.1 and +0.1 are around field average and mean no significant (under-)specialisation, and scores above +0.1 mean a significant specialisation in a given field.

Source: ISI, Science Citation Index; treatments and calculations: University Leiden, CWTS. Calculation of broad fields: DG-Research.

Triadic Patents

Definitions: 'Triadic' patents are the set of patented inventions for which protection has been sought at all three major patent offices (the European Patent Office – EPO, The US Patent and Trademark Office – USPTO and the Japanese Patent Office – JPO). The country of origin is defined as the country of the inventor. The advantage of triadic patents is that they can eliminate the 'home advantage effect'. 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.

Source: OECD based on data from EPO, USPTO and JPO.

Technological specialisation

Definition: The relative technological specialisation index (or relative activity index RAI) is calculated for 17 manufacturing sectors on the basis of EPO patents from 1997-2000. RAI = a/b, where a = % of a country in all patents in a sector/technology field and b = % of patents of that country compared to total patent output of all countries. Normalised score: RAI*=(RAI-1)/(RAI+1) AI*. Scores below -0.1 mean a significant under-specialisation in a given scientific field, scores between -0.1 and +0.1 are around field average and mean no significant (under-)specialisation, and scores above +0.1 mean a significant specialisation in a given field. The data was classified by earliest priority date and country of residence of the inventor.

Source: DG Research, based on OECD data.

Competitiveness

High-tech trade

Definition: High-tech trade covers exports and imports of products whose manufacture involved a high intensity of R&D. They are defined in accordance with the OECD's high tech product list (see OECD (1997). Revision of the High-technology Sector and Product Classification (1997), *STI Working Papers* 2/1997, OECD, Paris. The indicators used in this report use the so-called 'product approach', i.e. they measure the world market share of exports of high-tech products.

Sources: Eurostat (Comext), UN (Comtrade).

Technology balance of payments receipts

Definition: The technology balance of payments (TBP) records a country's exports and imports of technical knowledge and services (including licences, know-how, trademarks, technical services, etc.). TBP statistics are defined according to the Technology Balance of Payments Manual of the OECD.

Sources: OECD, Eurostat, Member States.

Labour productivity

Definition: Labour productivity is defined as GDP per hour worked.

Sources: Eurostat, Member States.

High-tech and medium high-tech industries

Definition: High-tech and medium high-tech industries are defined by the average shares of their expenses dedicated to R&D, or R&D-intensity. According to the Eurostat definition, high-tech and medium high-tech industries consist of the following manufacturing sectors: manufacture of chemicals and chemical products, manufacture of machinery, motor vehicles and of other transport equipment, mechanical and automotive engineering, machinery and transport, and manufacture of office machinery, electrical machinery, radio, television and communication equipment, medical, precision and optical instruments (i.e. NACE 24, 29, 30-33, 34, 35 – 352, 353, 354 and 355).

The OECD definition of medium high-tech manufacturing differs slightly from that of Eurostat as it is based on the ISIC Rev. 3 classification. This explains the differences between the data presented in graphs comparing the EU Member States and Accession and Candidate countries on the one hand (Eurostat method), and the data presented in the graphs comparing the Triad (OECD method).

Sources: Eurostat (SBS, CLFS, National Accounts) and OECD (Science, Technology and Industry Scoreboard).

Classification: NACE Rev. 1. For Eurostat, ISIC, Rev. 3 for OECD

High-Tech Knowledge intensive services

Definitions: High-Tech knowledge intensive services are defined according to the Eurostat definition as: post and telecommunications, computer and related activities, research and development (i.e. NACE Rev.1 codes 64, 72, 73).

The output of knowledge intensive high-tech services is defined as the value added of knowledge intensive services. Total output is defined as total gross value added at basic prices according to the National Accounts definition.

Sources: Eurostat (SBS, CLFS and National Accounts), OECD (Science, Technology and Industry Scoreboard).