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KEY FIGURES 2005 ON SCIENCE, TECHNOLOGY AND INNOVATION
TOWARDS A EUROPEAN KNOWLEDGE AREA

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Highlights

This report takes a detailed look at the most important aspects of EU investment and performance in the knowledge-based economy, where R&D plays a central role, as well as at the most recent progress made in this regard.

Part I of the publication charts recent progress towards the knowledge-based economy in the global macro-economic context. Part II reviews investment in R&D, human resources in science and technology, and higher education. Part III deals with the performance of the EU's research and innovation systems, examining indicators such as scientific publications and patents as well as high-tech trade, productivity and value added at the sector level.

PART I: THE KNOWLEDGE-BASED ECONOMY IN THE GLOBAL MACRO-ECONOMIC CONTEXT

Labour productivity in the EU: no longer catching-up?

After fifty years of catching up to the US level of productivity, since the mid-1990s Europe has been falling behind

From the early 1950s to the beginning of the 1970s, sharp labour productivity growth in Europe was associated with a catching-up process in terms of GDP per capita levels on the US. Then, the comparative growth performance of Europe *vis-à-vis* the United States experienced two marked changes.

Firstly, the gap in terms of GDP per capita levels between the US and the EU did not narrow further after the mid 1970s while the catching-up in terms of labour productivity continued. GDP per capita in the EU remains at only 70% of GDP per capita in the US, *i.e.* roughly the same relative level as 30 years ago. This relative constant gap in GDP per capita can mainly be explained by slowdown in the growth of labour input in Europe reflecting an increased unemployment, a decline in employment rates and a fall in average working hours per capita since the 1970s.

Secondly, the catching-up in terms of labour productivity stopped in the mid-1990s. While the average annual growth of labour productivity per hour declined in Europe by a full percentage point from 2.5% in the first half of the 1990s to 1.5% over 1996-2003, productivity growth in the US rose by a similar amount to 2.4% per year. This deterioration of labour productivity growth in Europe occurs at the time when labour input shows signs of improvement. From a growth accounting perspective, such EU's counter-performance *vis-à-vis* the US in terms of labour productivity growth stems from a reduction in the contribution from capital deepening and a decline in multifactor productivity. This is a serious threat for the international competitiveness of business activities in Europe. An important part of the answer to that threat lies with Europe's ability to leverage science, technology and innovation to create higher productivity and economic growth with more and better jobs.

HARNESSING THE POTENTIAL OF THE KNOWLEDGE-BASED ECONOMY

Activating knowledge is crucial in order to improve economic performance

Policies of macro-economic stability and convergence have delivered substantial results over recent years. However, even though macro-economic stability is necessary for sustainable and long-term economic growth, it is not sufficient. Economic growth is neither a by-product nor an automatic consequence of policies of fine-tuning macro-economic and financial balances. It is widely recognised that productivity gains, sustained economic growth and employment are largely determined by technological progress, innovation and human capital. These factors are in turn largely dependent on investments in knowledge (*e.g.* investments in education and R&D) and their outcomes.

Increasing investment in R&D and its efficiency

In the contexts of the ageing population and of sluggish economic growth, the 2000 Lisbon strategy to make Europe a competitive knowledge-based economy by 2010, and more specifically the Barcelona objectives agreed upon in 2002 to increase R&D investment in the EU to approach 3% of GDP, are more critical than ever. The European Commission's action plan "Investing in Research" adopted in April 2003 advocates increasing both R&D investment and the efficiency with which new ideas are turned into new products, processes, services, and solutions, as well as creating an overall environment making it more attractive for firms to increase investment in R&D. These objectives and orientations were confirmed and strengthened in the review of the Lisbon strategy undertaken earlier this year.

PART II: INVESTMENT IN THE KNOWLEDGE-BASED ECONOMY

TRENDS IN OVERALL INVESTMENT IN R&D

EU R&D intensity is close to stagnation, while China is catching up very rapidly

In 2003, R&D intensity in the EU amounted to 1.93%, well below the US (2.59%) and Japanese (3.15%) intensities, but above China (1.31%). The rate of growth of EU's R&D intensity (+0.7% per year between 2000 of EU's R&D intensity (+0.7% per year between 2000 and 2003) is far from sufficient to reach the 3% objective in 2010: if this trend remains unchanged, EU's R&D intensity will be only about 2.20% in 2010. On the contrary, China experienced a very strong growth of its R&D intensity over recent years, with annual growth rates around 10% since 1997. If current trends for both China and the EU-25 hold on in the coming years, China will have caught up with the EU by 2010 in terms of the share of GDP allocated to R&D. Within the EU, Finland and Sweden ranked highest in terms of R&D intensity in 2003, both with R&D intensities already well above 3%. Moreover, in both countries R&D intensity has increased substantially in recent years. Denmark, Belgium and Austria had both R&D intensity and growth rates above the European average. Among the largest R&D spending countries, only the UK had a R&D intensity below the EU average. Together with France and Germany, it also experienced weak growth in R&D intensity between 1997 and 2003, especially after 2000. Most of the new Member States had relatively low R&D intensities in 2003, but were catching up rapidly with the rest of the EU countries. All the new Member States except Slovakia, Poland and Latvia had R&D intensity annual growth rates far above the EU-25 average between 1997 and 2003.

The contribution from the business sector to the financing of R&D remains low and is even decreasing since 2000

The R&D intensity gap between Europe and its main competitors is almost entirely due to differences in the contributions from the business enterprise sector to the financing of R&D. In 2002, the business enterprise sector financed 55.6% of domestic R&D expenditure in the EU, compared to 63.1% in the US and 73.9% in Japan. The share of R&D financed by the business enterprise sector grew at the rate of 1.2% per year from 1997 to 2000, but decreased by 0.6% per year between 2000 and 2003. The overall target of two-thirds of R&D expenditure financed by the business sector will not be reached by 2010 if current trends remain unchanged.

High R&D-intensive countries maintain high levels of government R&D financing

The role of government in the financing of R&D remains important as evidenced by the fact that the highest levels of business R&D funding go hand in hand in most cases with high levels of government-funded R&D intensity, as in Sweden, Finland, Germany and the US. In low R&D-intensive countries such as the new EU Member States, government-funded R&D in relation to GDP remains higher than the intensity of business-funded R&D.

BUSINESS SECTOR R&D

Business sector R&D intensity remains low in spite of healthy growth in several Member States

Business R&D expenditure amounted to only 1.23% of GDP in the EU compared to 1.78% in the US and 2.36% in Japan in 2003. In China, R&D expenditure by the business enterprise sector is still below the EU-average (0.82%), but it is already higher than in most new Member States, the Southern European countries and Ireland. Furthermore, China's Business R&D intensity has been growing at the tremendous pace of 11% per year over recent years. Business R&D is mainly funded by the business enterprise sector, but the contribution of that sector is much higher in the US and Japan than in Europe. It amounted to 98.1% in Japan and 90.0% in the US in 2003, compared to 82.0% in the EU (year 2002). However, patterns of business R&D funding are changing. Direct government funding of business R&D declined significantly in the EU, Japan and the US between 1997 and 2003. This downward trend is mirrored by a rise in indirect support, in particular R&D tax incentives in many EU countries as well as in the US and Japan.

Europe is losing its attractiveness for international R&D investment

Europe does benefit less from the increased globalisation of R&D than its main competitors. Over the years 1997-2002, R&D expenditure by EU companies in the US increased in real terms much faster than R&D expenditure by US firms in the EU (+54% against +38%). As a result, the net gain for the US increased by a factor 5.4 between 1997 and 2002, from about 300 million € in 1997 to almost 2 billion € in 2002 (€2001 PPS). Furthermore, US outward R&D investment grew over recent years in all major regions of the globe, but growth has been fastest outside the EU-15, particularly in emerging countries such as China. As a result, the share of the EU-15 in total US outward R&D investment is declining since the late 1990s, and these trends are expected to be continued as long as new actors build their science and technology infrastructure and open markets to foreign entrants. These worrying recent developments call for political reaction since they reflect the relatively stronger attractiveness of the US research and innovation systems compared to the EU ones, and the increasing attractiveness of new entrants into the globalised science and technology systems. Without strong reaction, Europe risks entering into a worrying vicious circle as the loss of high value-added R&D activities and jobs is undermining further its capacity to retain such activities.

EU-based firms tend to invest less than US firms in R&D in the services sector and in high-tech manufacturing. In the US, nearly 40% of all business R&D is performed in the services sector whereas in the EU this share is only 15%. This gap has increased considerably due to a much faster growth in the US than in the EU in recent years. However, further study remains necessary to assess the type of services concerned and to draw appropriate policy conclusions. The share of high-tech manufacturing industries in total manufacturing R&D is also lower in the EU (41.4%) than in the US (44.3%).

Business R&D is more concentrated in the services sector and in high-tech manufacturing in the US than in the EU

Nearly a quarter of business R&D is performed by SMEs in the EU (22.4%), a figure substantially higher than in the US (14.1%) and Japan (7.0%). The higher concentration of R&D expenditure in small and medium-sized companies should not be a problem if this supports company expansion. Empirical evidence, however, shows that, if some SMEs (particularly the high-tech ones) can grow rapidly and become critical players in many sectors, European SMEs have more difficulty than US ones to grow into large companies.

SMEs perform a large part of business R&D in the EU

The availability of technology venture capital -a catalyst for the creation and expansion of R&D-intensive SMEs- is still much lower in the EU compared to the US. In 2003, the US's total investment in venture capital in high-tech sectors, as % of GDP, was more than three times the amount invested in the EU. US early stage venture capital investment in the high-tech sectors was twice as high as in the EU-25. At the expansion stage, it was five times the amount invested in the EU-25 (as % of GDP). Furthermore, the average investment in a technology company was in 2003 about nine times larger in the US, and the rate of return of early stage venture investment was 30 to 50 times higher in the US. US venture capitalists appear to be more successful at concentrating their investment on more advanced projects / technologies that are generating higher profits. 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).

High-Tech venture capital investment is three times higher in the US and is better targeted at more mature projects generating higher profits

Public sector R&D and its relationship with the Business entreprise sector

R&D performed in the higher education sector is on the increase in Europe, Japan and the US. In 2003, higher

R&D performed in the higher education sector is on the

education expenditure on R&D amounted to 0.44% of GDP in the EU, well above its 1997 level of 0.38%. Higher education expenditure on R&D is also much greater than government expenditure on R&D.

increase

In the old EU Member States most public expenditure on R&D is executed by the higher education sector, whereas in the new Member States (with the exceptions of Lithuania, Latvia and Estonia) a sizeable share of public R&D is performed in the government sector.

In the new Member States the government sector is performing an important part of R&D

Firms are financing significant levels of public R&D in the EU. The contribution of the business sector to the financing of R&D in the higher education sector is higher in the EU (6.6%) than in the US (4.5%) and Japan (2.6%). Similarly, the business sector funds government R&D in a greater proportion in the EU than in the US and Japan.

The business enterprise sector funds a higher proportion of public research in the EU than in the US or Japan

HUMAN RESOURCES FOR SCIENCE AND TECHNOLOGY

In 2003, the number of researchers (in Full-Time Equivalents) per thousand labour force amounted to only 5.4 in the EU compared to 10.1 in Japan and 9.0 in the US. This overall deficit is mainly located in the business sector, which nevertheless accounts for the bulk of R&D performance. Whereas in the EU about 49.0% of researchers were employed by the business sector in 2003, this share amounted to 67.9% in Japan and 80.5% in the US. In addition, the ageing of the highly-qualified S&T labour force is becoming a concern in many Member States. In 2003, 34.7% of the EU highly qualified S&T employees in the EU were in the 45-64 year old age group, compared to 30.8% in the 25-34 age group. Therefore, it remains crucial to ensure a sufficient replacement rate of the S&T workforce, and to further expand it.

The pool of researchers is much smaller in the EU, especially in the business sector, and the ageing process is eroding the S&T labour force

The EU is producing more S&E graduates than the US and Japan. In 2003, 24.2% of all degrees awarded in the EU were in S&E fields of study, a slight decrease from 1998. The corresponding figures for Japan and the US were 23.1% and 18.5% respectively. Overall funding of tertiary education (both from public and private sources) as a percentage of GDP, however, is lower in the EU than in the US. Women are still under-represented among both researchers and S&E graduates. Their share in the total of researchers (in headcounts) was below 50% in 2002 in nearly all EU Member States.

The supply of human resources is large, but the financial commitment to tertiary education remains low, and women are still under-represented

Making research careers more attractive is necessary to increase the inflow of S&E educated people into research positions and S&E occupations. Various Members States, however, while producing many S&E graduates, retain relatively low levels of Scientists and Engineers in their active population, indicating that a non-negligible part of their human resources opts for a non S&E career or for jobs outside the country. This is particularly true in the case of countries with relatively low R&D intensities and a weak contribution of the business sector to R&D funding. This underlines the importance of the structure of the demand side. While a large production of S&E graduates may benefit the economy overall, low R&D intensities result in few employment opportunities, emigration (brain drain) or out-of-field employment.

Moreover, in several EU Member States S&T careers lack attractiveness (demand side)

PART III: PERFORMANCE OF THE KNOWLEDGE-BASED ECONOMY

S&T OUTPUT

In terms of both the total number and the world share of scientific publications, the EU maintains a comfortable lead. In 2003, its world share was 38.3% (showing a slight decline compared to its level in 1997) whereas the US was responsible for 31.1% of the world scientific publication output. When relating publications to population, however, the US led with 809 scientific publications per million population, followed by Europe with 639, and Japan with 569. Within the EU, this ratio was particularly high in the Nordic countries. As regards technological output, the EU accounted for a lower world share of triadic patents than the US in 2000 (31.5% against 34.3% in the US). When standardised by population size, the picture is even bleaker: Japan has the highest number of triadic patents per million population (93) followed by the US (53) and the EU (31). In Europe, only Finland and Sweden can keep pace with Japan, whereas both Germany and the Netherlands outperform the US. In contrast, no less than 13 EU Member States were producing less than 5 triadic patents per million population in 2000.

The EU is the world leader in scientific output, but is failing in fully exploiting its scientific base

The scientific and technological output, as measured by scientific publications and patents is more diversified in the EU than in either the US or Japan in terms of scientific disciplines and technological fields. This is a potentially rich resource for the medium and long term, but it also requires supplementary efforts to ensure that

The S&T knowledge bases are highly diversified in the EU

both public research and industrial R&D are not too fragmented. The degree of technological specialisation varies sharply among the EU countries and does not seem to depend on their levels of R&D effort. For example, some low R&D spending countries – including the Czech Republic, Greece, Poland and Spain – exhibit a relatively high diversification compared to the available means. Such diversification at national level reinforces the need for European integration.

INDUSTRY, TECHNOLOGY AND COMPETITIVENESS

Manufacturing exports from the EU are less technology-intensive than those from the US and Japan

Trade in high-tech products reflects both the specialisation patterns of an economy and the competitiveness of its domestic high-tech industries on the global marketplace. In 2003, high-tech industries accounted for about 20% of total EU manufacturing exports, whereas they accounted for more than 25% of total manufacturing exports in Japan and the US. Moreover the US high-tech industries account for more exports at world level than the EU (nearly 20% against 16.7% in 2002). Finally, while the US and Japan show a structural trade surplus in high-tech manufacturing industries, the EU is characterized by a structural trade deficit in these industries.

Most of the EU-US R&D gap stems from the combined effect of low R&D intensities and sizes of the services sector and ICT manufacturing

The services sector produces more than three quarters of total output in the US and the EU. In 2002, the services sector share in total value added amounted to about 84.7% in the US and 79.1% in the EU compared to 80.8% and 77.1%, respectively, in 1997. The share of ICT-related manufacturing industries (*i.e.* radio, television, and communication equipment; office, accounting and computing machinery; medical precision and optical instruments) in manufacturing output is much bigger in the US than in the EU. In contrast to the US and Japan, the EU mainly shows a technological specialisation in traditional manufacturing industries such as transport related industries, and is under-specialised in ICT manufacturing industries. Furthermore, the services sector invests considerably more in R&D in the US (0.7% of GDP) than in the EU (less than 0.2% of GDP). Compared to the EU, the R&D performed by the manufacturing sector in the US is heavily concentrated in ICT manufacturing industries. As a result, most of the EU-US R&D gap stems from a smaller R&D intensive services sector, as well as, to a lesser extent, a smaller size and lower R&D intensity in the ICT manufacturing sector.

Similarly, most of the productivity growth differentials between the US and the EU since the mid-1990s stem from the New Economy. In particular, the ICT-using services sector -especially distribution and financial services- has dramatically contributed to boost productivity growth in the US over those years, while its contribution in the EU has been much more limited. As regards the ICT-producing manufacturing sector, its contribution to overall productivity growth in the US and the EU has been much more modest because of its reduced share in aggregate value added. Consequently, a large ICT-producing sector does not seem to be a prerequisite to obtain the full benefits of ICT. Moreover, ICT alone is not sufficient to elevate productivity growth because ICT use requires complementary investments, in particular investment in intangible assets (*e.g.* skills, new work practices), and adequate framework conditions (*e.g.* product market regulation).

The productivity growth problem in the EU compared to the US is mainly located in the ICT-using services sector and to a lesser extent in the ICT-producing manufacturing industries

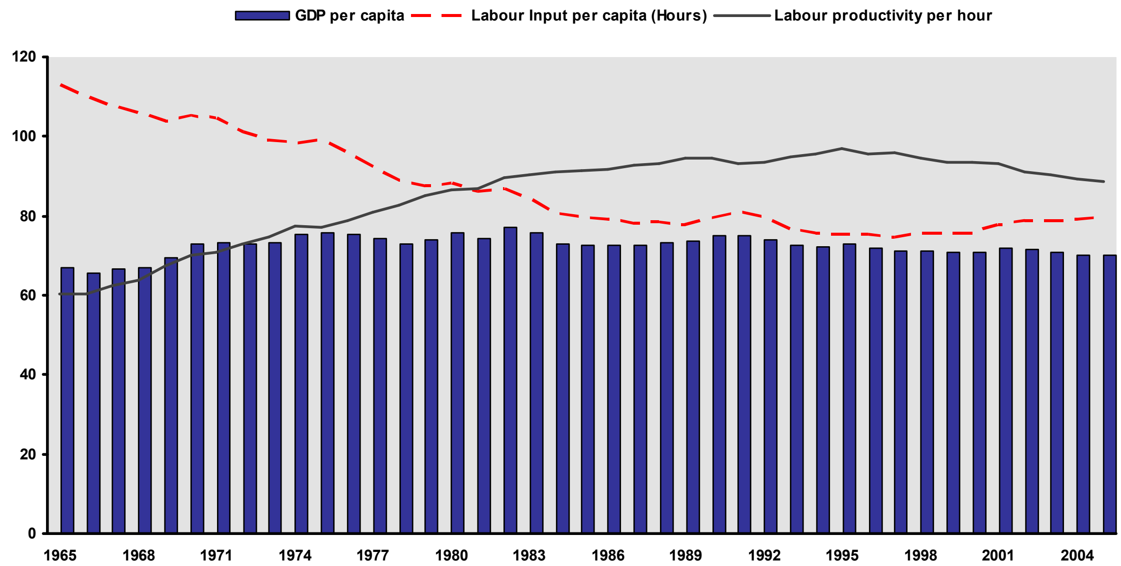
1. The knowledge-based economy in the global macro-economic context

1.1. Labour productivity growth in Europe: no longer catching-up?

Throughout the years from the early 1950s to the beginning of the 1970s, sharp labour productivity growth in Europe was associated with a catching-up process in terms of GDP per capita levels on the US. Then, the comparative growth performance of Europe *vis-à-vis* the United States experienced two marked changes.

Firstly, the gap in terms of GDP per capita levels between the US and the EU did not narrow further after the mid 1970s while the catching-up in terms of labour productivity continued. GDP per capita in the EU remains at only 70% of GDP per capita in the US, *i.e.* roughly the same relative level as 30 years ago. This relative constant gap in GDP per capita can mainly be explained by slowdown in the growth of labour input in Europe reflecting an increased unemployment, a decline in employment rates and a fall in average working hours per capita since the 1970s.

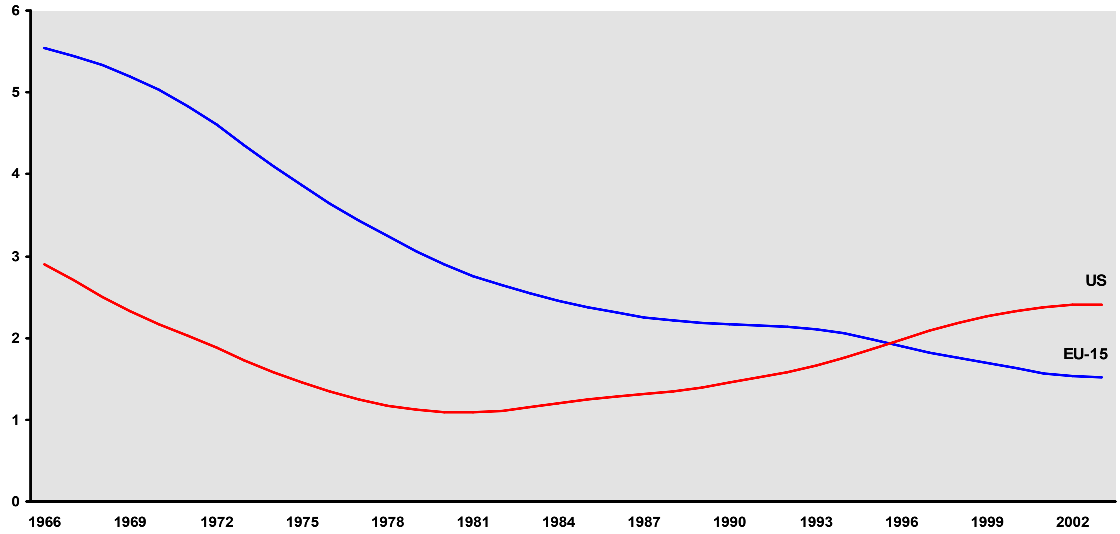
Figure 1.1.1 GDP per capita levels accounting - EU-15 relative to the US (US=100) (proportion of income differences due to labour utilisation/productivity)



Source: DG ECFIN — Key Figures 2005
Data: DG ECFIN (AMECO database)

Secondly, the catching-up in terms of labour productivity came to end in the mid-1990s with EU's labour productivity growth rate declining under the US one. While the average growth of labour productivity per hour in Europe amounted to around 2.5% per year in the first half of the 1990s, well above the US growth rate, it then declined by a full 1 percentage point to 1.5% over 1996-2003, compared with an acceleration of an approximately similar amount in the United States to 2.4%. This deterioration of labour productivity growth in Europe occurs at the time when labour input shows signs of improvement.

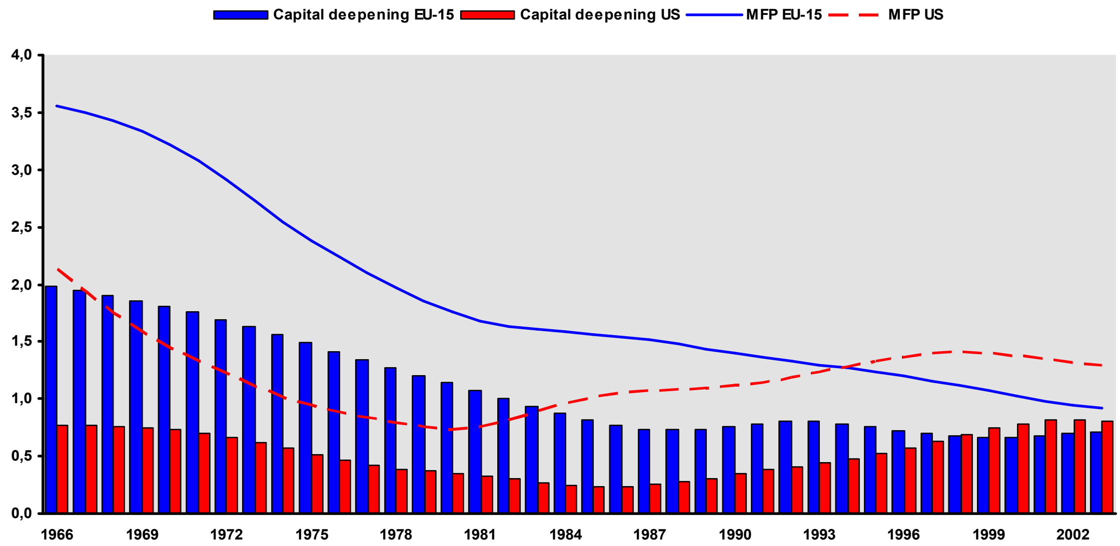
Figure 1.1.2 Labour productivity per hour growth trends (percentage change from previous year)



Source: DG ECFIN
Data: DG ECFIN (AMECO database)
Key Figures 2005

From a growth accounting perspective, such EU's counter-performance *vis-à-vis* the US in terms of labour productivity growth stems from both a reduction in the contribution from capital deepening and a decline in multifactor productivity. The latter may partially reflect an EU's counter performance in the creation, diffusion, and utilization of new knowledge over recent years[1].

Figure 1.1.3 Decomposition of US and EU-15 labour productivity growth trends into capital deepening and multifactor productivity (in percentage points)



Source: Denis, McMorrow, Röger and Veugelers (2005).
Data: DG ECFIN (AMECO database)
Key Figures 2005

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[1] It is important to note that, multifactor productivity growth is not necessarily caused by technological change. Indeed, other factors can impact on multifactor productivity growth. These factors include adjustment costs, economies of scale, cyclical effects, changes in efficiency (e.g. organizational change) and measurement errors.

1.2. Harnessing the potential of the knowledge-based economy

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

Against this background, and despite the fact that the EU's main competitors were generally hit by the same economic slowdown after 2000, the aforementioned developments show that the EU is no longer catching-up and is not meeting the Lisbon targets as highlighted in the 2004 Kok report[2]. Economic performance is determined by a variety of macroeconomic policies and structural conditions and thus differs significantly among regions and countries. For instance, stability-oriented macroeconomic policies (*e.g.* inflation, fiscal policy), trade policy, financial market conditions and labour market institutions have a substantial impact on economic performance. However, in the long run, the economic performance of countries is strongly determined by knowledge-related factors (*e.g.* technical change, human capital). In particular, R&D and technological innovation have contributed substantially to the strong US economic performance over recent years[3]. More generally, the contribution of knowledge investments and activities to employment, productivity and economic growth has been emphasised in many studies.

Box 1. The links between knowledge and economic performance: results from some quantitative studies

A quantitative analysis undertaken by the Erasme team for the EC on the expected macro-economics benefits from an increase in R&D intensity in Europe shows that if R&D investment reaches 3% of GDP in 2010, the European economy will experience by 2015 a rise in the number of jobs of 3.1 million and an additional boost to GDP of 4.2%[4].

The 2004 European Competitiveness Report[5] shows that in the OECD area increasing R&D expenditure in the higher education and business sectors has a significant positive impact on GDP per capita growth. The results are more mitigated concerning the impact of R&D expenditure in the government sector.

A recent empirical OECD study[6] points to the positive impacts of increases in human capital (as measured by average years in education), suggesting high returns to investment in education. The results of this study also point to a marked positive effect of business-sector R&D.

The EU Economic Review[7] shows the relative importance of knowledge investments (R&D and education) for determining long run productivity growth rates, with a simulation indicating that a substantial increase in EU knowledge production 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 US's superiority in terms of its capacity to produce and absorb new technologies.

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2 KoK W. (2004), *Facing the Challenge: The Lisbon strategy for growth and employment*, Report from the High Level Group chaired by Wim Kok, November 2004.
3 European Commission (2004), EU Economy Review 2004, Brussels.
4 ZAGAME, P. (2004), *3% d'effort de R&D en Europe en 2010 : analyse des conséquences à l'aide du modèle Némésis*, January 2004, Report to DG RTD.
5 European Commission (2004), *The European Competitiveness Report 2004*, Brussels.
6 OECD (2003), *The Sources of Economic Growth*, OECD, Paris.
7 European Commission (2004), *EU Economy Review 2004*, Brussels.

In this context, the 2000 Lisbon strategy and more specifically the Barcelona objective set up in 2002 are more critical than ever for Europe. It is essential that knowledge is fully recognised as a key engine for productivity and sustained economic growth and 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 sped up. In particular, 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. In this respect, the European Commission's action plan "Investing in Research" adopted in April 2003 proposed a set of actions to boost public and private R&D efforts in order to approach R&D intensity (*i.e.* R&D expenditure-to-GDP ratio) of 3% by 2010.

Box 2. The composite indicators on the knowledge-based economy

Composite indicators, by aggregating a number of key variables, attempt to summarise into one single measure various aspects of complex, multidimensional phenomena such as the transition to the knowledge-based economy. Two composite indicators have been developed: a first one summarises the various forms of investment in the knowledge based economy, whereas the second one measures the overall performance in the transition to the knowledge-based economy.

In order to advance effectively towards the knowledge-based economy, countries need to invest in both the creation and the diffusion of new knowledge. The composite indicator of investment in the knowledge-based economy addresses these two crucial dimensions of investment. It includes key indicators such as R&D expenditure, investment in human resources, or expenditure for the purchase of new capital equipment that may contain new technology (see table below).

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

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

Investment in the knowledge-based economy is, however, only part of the story. In particular, investment also needs to be allocated in the most effective way in order to increase productivity and economic growth. The second composite indicator regroups the four most important elements of the performance in the knowledge-based economy: overall labour productivity, scientific and technological output, usage of the information structure and effectiveness of the education system.

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

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

The results of the composite indicators presented here only refer to the EU-15 Member States.

Speeding up the transition to a knowledge-based economy has admittedly been an important objective of European policies during recent years, especially after the European Council of Lisbon in March 2000. Such objective has been reaffirmed in the revised Lisbon strategy in 2005[8]. Below an assessment is made of progress towards this important target using two "composite indicators". These indicators focus on the 'knowledge dimension' of this transition and, therefore, do not take into account the other dimensions (*e.g*. employment, sustainable development etc) of the Lisbon Agenda.

Investment in the knowledge-based economy varies greatly across Member States. The Nordic countries are characterised by a level of investment which is far beyond that of the EU-15 average and by growth rates close to or above the average. These countries are well prepared and are rapidly transforming their economies into knowledge-based economies. The UK, Belgium and Austria show an investment level ahead of the EU-15 average and growth rates close to or above the average. The Southern countries are lagging behind, although Portugal has almost reached the average investment level. Spain, in particular, is not catching up with the rest of Europe. Greece is catching up very rapidly. Finally, a last group consisting of Germany, Ireland, the Netherlands and France is close to or slightly ahead of the EU-15 average in terms of investment level but is losing momentum with low investment growth rates over the past five years.

Countries that invest heavily in the knowledge-based economy, such as the Nordic countries, perform better than other countries. Conversely, countries with low levels of investment, such as the southern European countries, exhibit weaker performance levels. A closer analysis shows nevertheless that there exists substantial variation in the way investment is being translated into performance. Portugal and Germany have comparable levels of investment in knowledge, but differ widely from each other in terms of performance. On the other hand, countries such as Austria and Denmark have identical performance levels although the level of investment is much lower in Austria.

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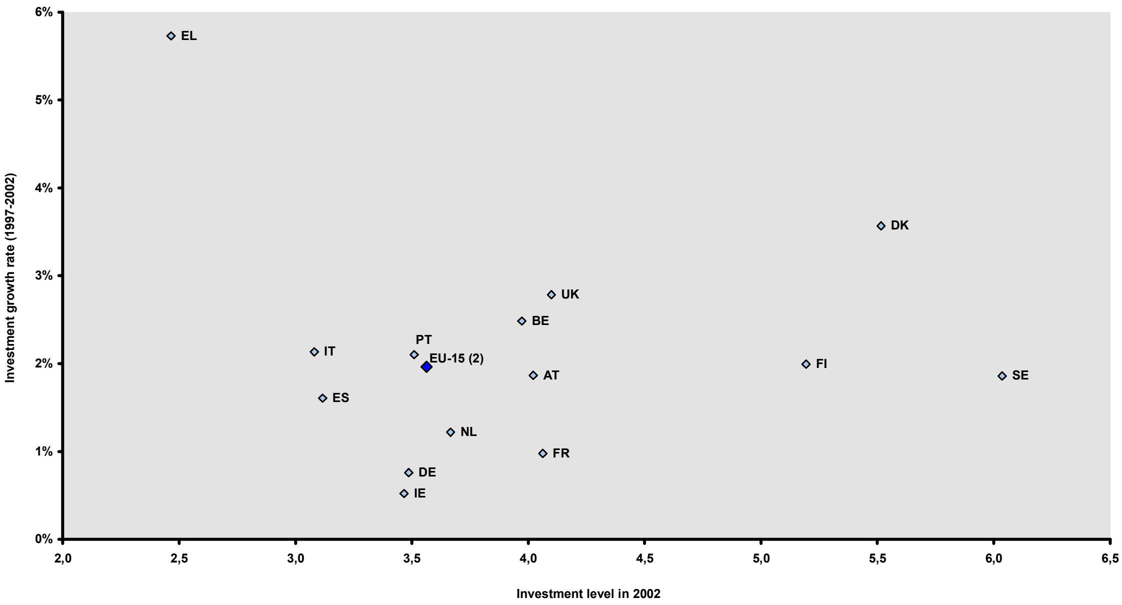
[8] European Commission (2005), *Working together for growth and jobs: Next steps in implementing the revised Lisbon strategy*, (Commission Staff Working Document SEC(2005) 622/2).

Figure 1.2.1 Composite indicator of investment in the knowledge-based economy - relative country positions in 2002 and annual growth rate 1997-2002 (1)



Source: DG Research Key Figures 2005

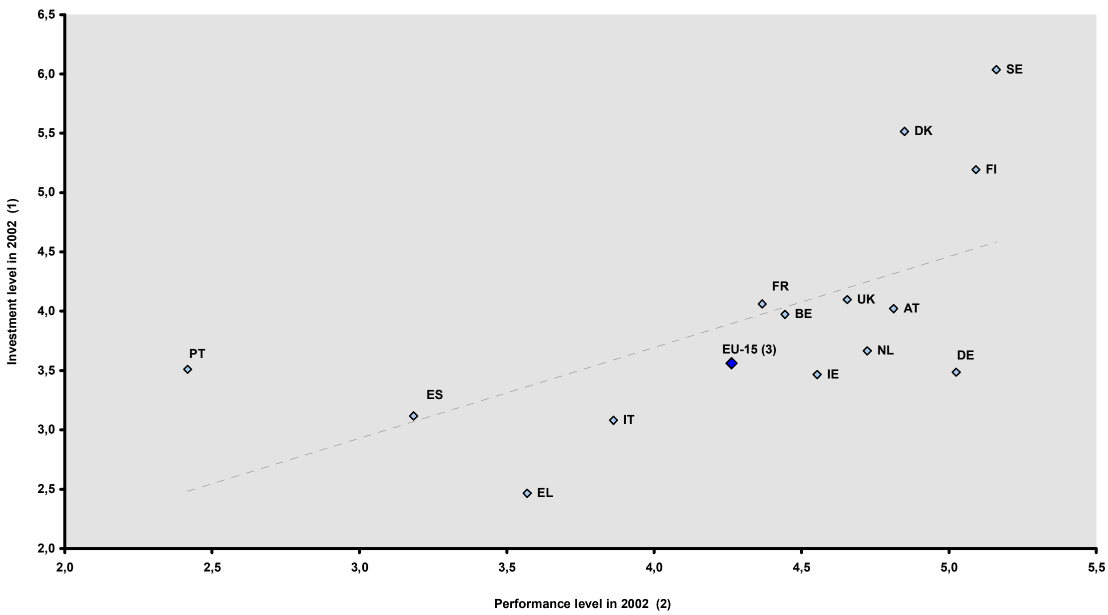
Data: Eurostat, OECD, DG Information Society

Notes: (1) For the composition of the composite indicator, see Box 2.

All 7 sub-indicators were included for the investment level 2002 (horizontal axis), but the indicator on e-government could not be included in the comparison of the growth rates (no data available for 1997)

(2) EU-15 does not include LU.

Figure 1.2.2 Investment vs Performance in the knowledge-based economy - relative country positions in 2002



Source: DG Research Key Figures 2005

Data: Eurostat, OECD, DG Information Society

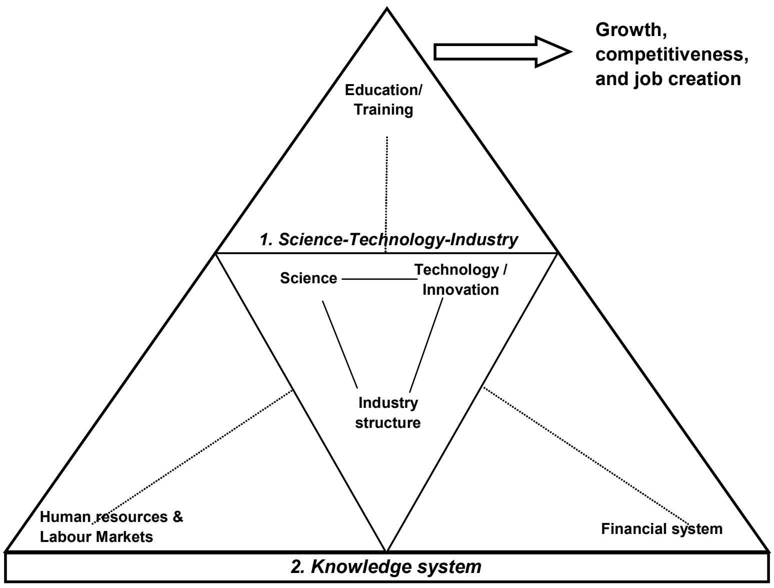
Notes: (1)(2) For the composition of the composite indicators, see Box 2

(3) EU-15 does not include LU.

From knowledge to the "knowledge system"

These examples show that the relationship between investment in knowledge and performance is complex and non-linear. What factors can explain the differences in innovative performance across countries? An important source of diversity between industrialized 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 such as the industry structure, the education and training system, the human resources and the labour market, the financial system, etc. State intervention should also be emphasized as it plays a horizontal role with regards to the influence of the other institutions involved in the "knowledge system". From this perspective, it covers infrastructure, the education system, legislation (*e.g.* IPRs, anti-trust policy, labour market), and broadly speaking corrective measures for market failures and policies aiming at ensuring macro-economic stability.

Figure 1.2.3 The 'Knowledge System', its various constituting blocks and the interrelations between them.



Source: Adapted from Boyer R., Amable B., and Barré R. ,
Les systèmes d'innovation à l'ère de la globalisation, Economica, 1999.

Key Figures 2005

By examining all the different institutions in a country which jointly and individually contribute to the production, diffusion and utilisation of knowledge, it is possible to identify the main building blocks of a "knowledge system". 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. Such interactions between various policies and above all the need for better coherence between them are stressed in the recent "Integrated Guidelines for Growth and Jobs (2005-2008)" dealing with macro-economic, micro-economic and employment issues and proposed by the European Commission in the framework of the revised Lisbon strategy[9].

Box 3. The New Integrated Guidelines for Growth and Jobs (2005-2008)

On March 22 and 23, 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 macro-economic, micro-economic 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 introduced a Lisbon Action Plan that outlines actions to be taken at EU and at national level under 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
(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 micro-economic 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. Modernizing economic and employment coordination in the EU will help deliver on the new Lisbon objectives to create growth and jobs. The proposed Integrated Guidelines will constitute the beginning of a new governance cycle. On the basis of the guidelines, Member States will draw up 3-year national reform programmes. Member States will report each autumn on the implementation of the reform programmes in a single national Lisbon report. The Commission will analyse and summarise these reports in an EU Annual Progress Report in January each year. On the basis of the progress report, the Commission can propose amendments to the integrated guidelines, if necessary.

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[9] European Commission, "Integrated Guidelines for Growth and Jobs (2005-2008)", COM(2005)141.

Because national systems have developed at different times and under different conditions, the characteristics of the “knowledge system” of a country are often rather specific. These disparities between “knowledge systems” are for a 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.

The rest of this report takes a detailed look at the most important aspects of EU investment and performance in the knowledge-based economy. Part I of the publication presents indicators of investment in R&D, human resources in science and technology and higher education, which are key components of the “knowledge system”. Part II deals with the performance of the EU’s research and innovation systems, presenting indicators such as scientific publications and patents, as well as high-tech trade, productivity and value added at the sector level.

2. INVESTMENT IN THE KNOWLEDGE-BASED ECONOMY

2.1. Introduction

The interest in the contribution of R&D and human capital to the creation and growth of a knowledge-based economy has reached new heights in the EU in recent years. Today, it is widely agreed that research and technological advancement together with the availability of a highly skilled workforce are among the key factors for innovation, competitiveness and socio-economic welfare. Likewise, the capacity to exploit knowledge has become a crucial element for the production of goods and services.

Relevant statistical data and analysis are presented below. First, investment in research and R&D expenditure by the main sources of funding is analysed. Second, since in most countries the business sector plays a major role in the financing and execution of R&D, private investment is looked at in more detail. Trends in venture capital investment are also presented. Third, key indicators on human resources for science and technology, such as the number of researchers and education data are analysed. The analysis covers all EU-25 Member States, the US and Japan.

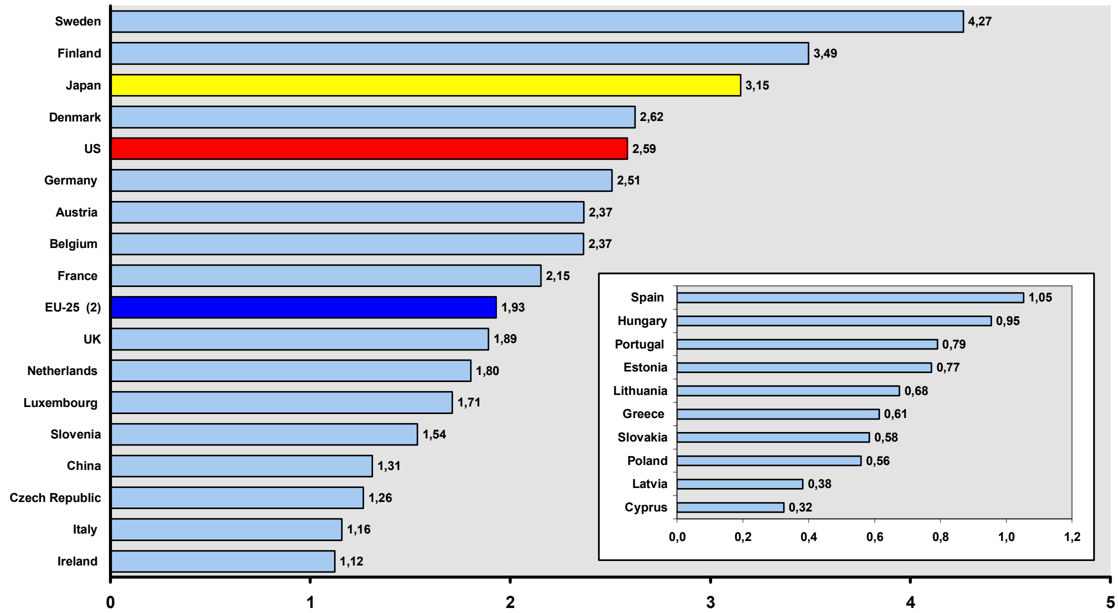
2.2. Trends in overall investment in R&D

This section examines the latest developments in R&D investment. Figures on investment are derived from the data on gross domestic expenditure on R&D (GERD). It provides an overall picture of the level of commitment to the creation of new knowledge and to the exploitation of research results in different countries. The volume of R&D investment is a proxy for countries' innovation capacity, and reflects the magnitude of both the accumulation and the application of new knowledge. The 'R&D intensity' indicator compares countries' R&D expenditure with their GDP. It also facilitates comparisons of the R&D activities between countries. R&D expenditure broken down by main sources of funds reveals information on the structure of financing and the relative importance of the various sources in different national R&D systems.

EU R&D intensity is close to stagnation, while China is catching up very rapidly

In 2003, EU R&D intensity was 1.93%, well below the US (2.59%) and Japan (3.15%), but above China (1.31%). Finland and Sweden ranked highest in terms of R&D intensity in 2003 and they were the only two EU Member States in which R&D intensity exceeded 3%. Denmark, Germany, Austria, Belgium and France also had R&D intensities significantly above the European average. Among the countries with the highest R&D expenditures, i.e. Germany, France and the UK (representing about two-thirds of the total R&D investment in the EU-25), only the UK had an R&D intensity below the EU average. Most of the new Member States had relatively low R&D intensities, with only Slovenia and the Czech Republic exceeding 1%.

Figure 2.2.1 R&D intensity (GERD as % of GDP), 2003 (1)



Source: DG Research Key Figures 2005
Data: Eurostat, OECD
Notes: (1) LU : 2000; SE : 2001; IE, IT, NL : 2002; BE : 2004; AT : 2005.
(2) EU-25 was estimated by DG Research and does not include LU and MT.

Table 2.2.1 Gross domestic expenditure on R&D (GERD), 2003 (1) and average annual real growth (%), 2000-2003 (2)

	GERD	
	Total mio euro	Average annual real growth %
Belgium	*6713*	5,3
Czech Republic	1013	3,5
Denmark	*4907*	5,8
Germany	54310	1,2
Estonia	*62*	16,7
Greece	943	1,5
Spain	8213	6,7
France	*34122*	1,4
Ireland	1436	5,2
Italy	14600	5,2
Cyprus	*38*	12,4
Latvia	38	1,8
Lithuania	*110*	12,4
Luxembourg	364	:
Hungary	693	9,7
Malta	:	:
Netherlands	8018	-1,6
Austria	*5774*	5,7
Poland	1036	-3,5
Portugal	*1033*	-0,1
Slovenia	*377*	5,0
Slovakia	169	0,6
Finland	5005	2,8
Sweden	10459	11,0
UK	30085	2,6
EU-25 (3)	*189584*	2,4
US (4)	*251577*	0,4
Japan	119748	2,2
China	16435	18,6

Source: DG Research Key Figures 2005
Data: Eurostat, OECD
Notes: (1) LU : 2000; SE : 2001; IE, IT, NL : 2002; BE : 2004; AT : 2005.
(2) SE : 1999-2001; EE, IE, IT, NL : 2000-2002; BE : 2000-2004; AT : 2000-2005; EL : 2001-2003.
(3) EU-25 was estimated by DG Research and does not include LU and MT.
(4) US does not include most or all capital expenditure.
Values in *italics* are provisional.

Some conclusions can be drawn concerning the rate of progress towards the 3% objective over recent years. At EU-25 level, the rate of growth of R&D intensity did not significantly decrease after 2000. However, an annual growth rate of 0.7% (average annual growth between 2000 and 2003) is far from sufficient to reach the 3% objective by 2010. If this trend remains unchanged, the EU's R&D intensity will be only about 2.20% in 2010[10]. On the contrary, China experienced a very strong growth of its R&D intensity since the end of the 1990s, with annual growth rates above 10% (total R&D expenditure grew, in real terms, by almost one fifth each year). In this regard, China is growing faster than any other economy in the Triad. If current trends for both China and the EU-25 hold on in the coming years, China will have caught up with the EU by 2010 in terms of GDP allocated to R&D. The EU's R&D intensity, however, grew at a higher rate than that of the US. As a result, the EU-25 as a whole has been catching up with the US since 2000. The growth of R&D intensity is higher in Japan than in both the EU and the US, although this seemingly good performance can be partially explained by the low growth rate of Japan's GDP (denominator) over recent years.

An examination of the individual Member States and their pace of progress before and after 2000, reveals a distinction between five groups of EU countries.

A first group consisting of the new Member States Cyprus, Estonia, Hungary, Lithuania and the two Southern countries Italy and Spain was able to accelerate its catching up process with the EU average after 2000. The R&D intensity in these countries remains low, but its rate of growth is above average and has even been increasing after the turn of the millennium.

Slovenia, the Czech Republic, Latvia, Portugal and Greece represent a second group of low R&D intensive countries. Up to 2000, R&D intensity in these countries was increasing much faster than average. Their catching-up process, however, has slowed (Slovenia) or has even come to an end (Czech Republic, Latvia, Portugal and Greece) after 2000.

A third cluster consisting of the low R&D intensive countries Poland, Slovakia and Ireland is falling further behind. This group is not catching up with the rest of Europe. Furthermore, R&D intensity in these countries is still on a decline since 2000.

Amongst the countries with average to high R&D intensities, Sweden, Belgium, Austria, were able to sustain (Austria), slightly accelerate (Belgium) or strongly accelerate (Sweden) their rate of growth after 2000. These countries are pulling further ahead.

On the contrary, other high R&D intensive countries Finland, Denmark, Germany and the UK are slowing down their pace of progress. Finland, and to a lesser extent Germany, experienced a significant deceleration of R&D intensity growth, down since 2000 to a level very close to the EU average. For Denmark the slowdown is negligible and R&D intensity is still growing at a much higher pace than average. Finally, while France's decline stopped after 2000, the Netherlands continues on its negative path.

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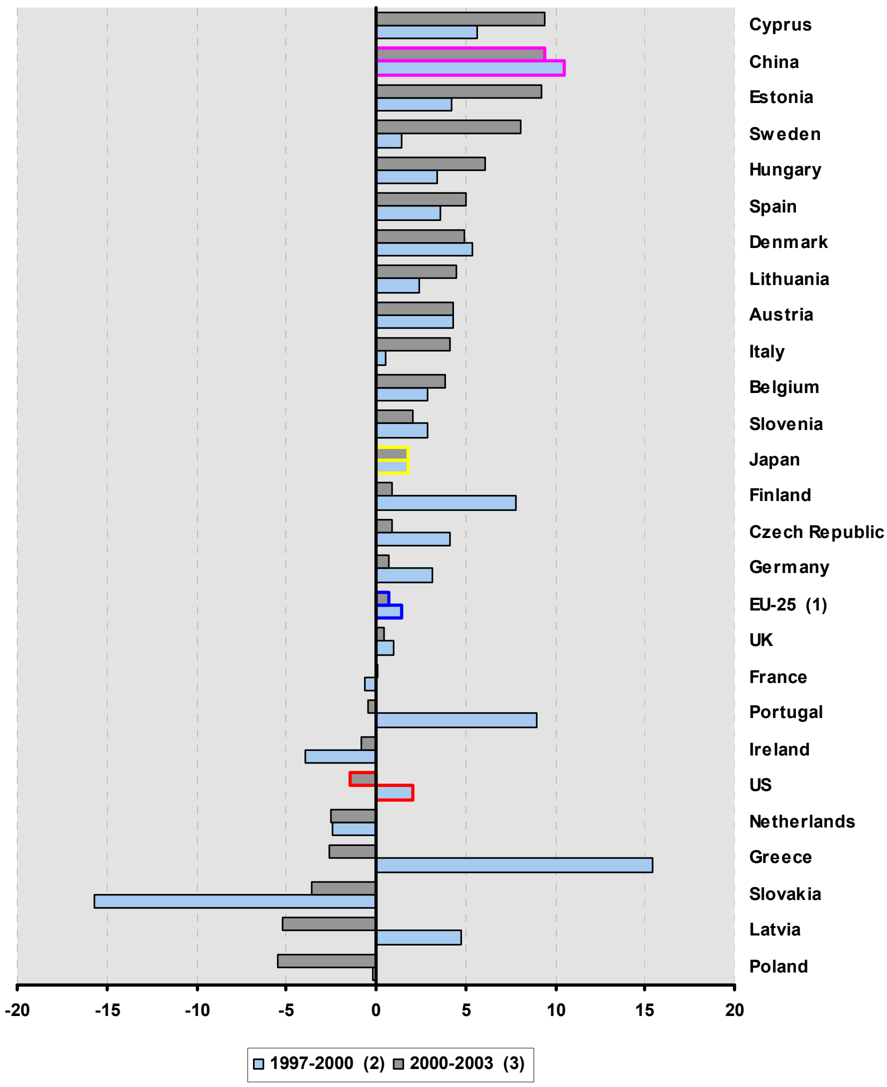
[10] Linear forecast on years 2000-2003.

Figure 2.2.2 R&D intensity (GERD as % of GDP) - average annual growth (%)

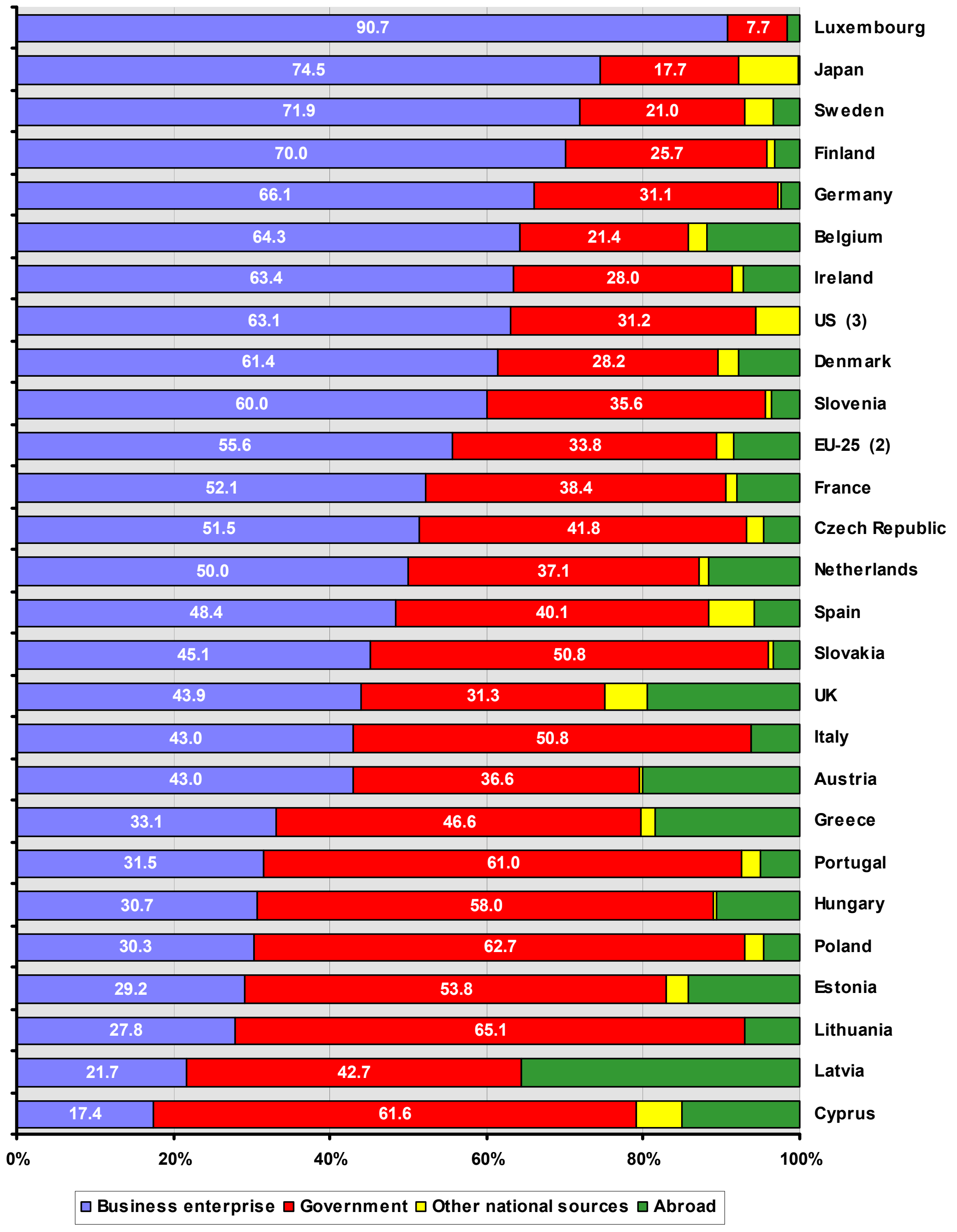


Source: DG Research — Key Figures 2005
Data: Eurostat, OECD
Notes: (1) EU-25 was estimated by DG Research and does not include LU and MT.
(2) EL, FR, SE, CN : 1997-1999; EE; CY; US : 1998-2000.
(3) SE : 1999-2001; EE, IE, IT, NL : 2000-2002; BE : 2000-2004; AT : 2000-2005; EL : 2001-2003.

The contribution from the business sector to the financing of R&D remains too limited and is even decreasing since 2000

The business enterprise sector constitutes the most important source of funding of domestic R&D in the EU. In spite of increases since 1997, however, its role remains less significant than in the US and Japan. In 2002, the share of R&D financed by the business sector amounted to 55.6% in Europe, compared to 63.1% in the US and 73.9% in Japan. Within the EU, Luxembourg, Sweden, Finland and Germany ranked most highly in terms of the share of R&D expenditure funded by the business sector. Conversely, the government sector is still a large source of R&D funding in low R&D-intensive countries such as the Southern European countries and the new Member States. In 2002, Cyprus, Lithuania, Poland and Portugal received more than 60% of their R&D funding from the government sector.

Figure 2.2.3 R&D expenditure by main sources of funds (%), 2002 (1)



Source: DG Research

Key Figures 2005

Data: Eurostat, OECD

Notes: (1) IT : 1996; LU : 2000; BE, DK, EL, PT, SE : 2001; CZ, DE, ES, HU, PL, SK, FI, UK, US, JP : 2003; AT : 2005.

(2) EU-25 was estimated by DG Research and does not include LU and MT.

(3) US does not include most or all capital expenditure.

Box 4. 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.

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.

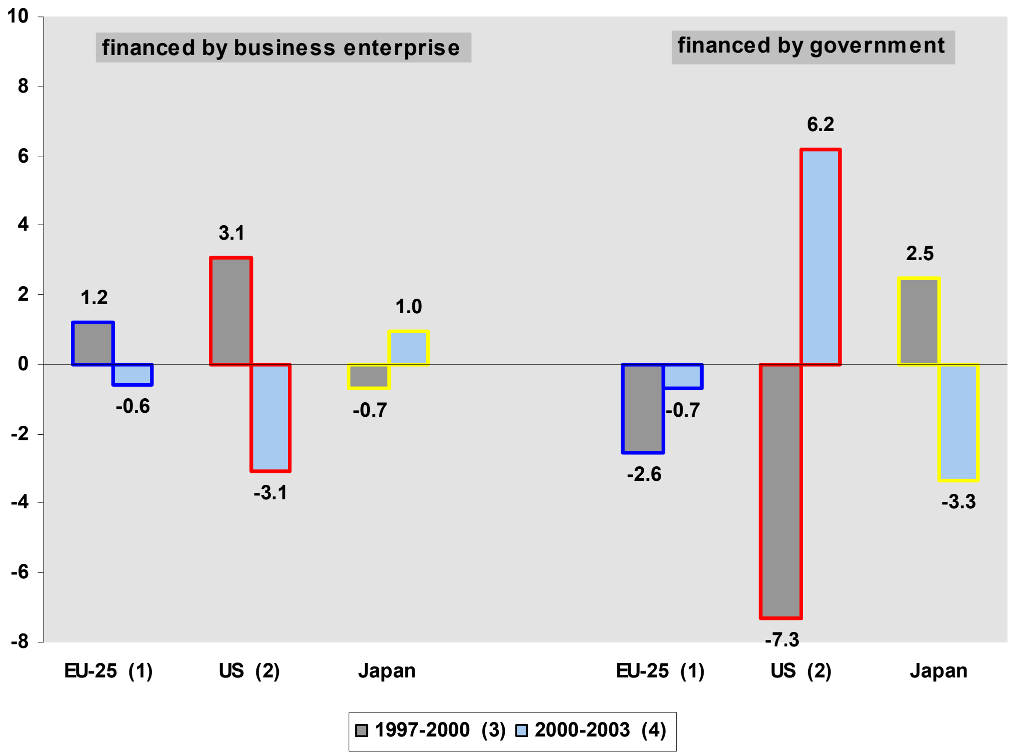
The higher education sector consists of all universities, colleges of technology and other institutions of post-secondary education, whatever their source of finance or legal status. It also includes all research institutes, experimental stations and clinics operating under the direct control of or administered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

The sector abroad 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.

A particular source of concern is the fact that the contribution of the business sector to the funding of R&D is decreasing since 2000. After modest growth in the late 1990s, the share of the business enterprise sector in the funding of total R&D has decreased by 0.6 per year between 2000 and 2003.

In recent years, the contributions of business sector versus government to the financing of R&D have evolved in the same way in both the EU and the US. In both regions the contribution from the business sector first increased between 1997 and 2000 and then was reduced after 2000, whereas the government contribution followed almost the opposite pattern. The significant difference between the EU and the US here comes from the magnitude of movements: the redistribution of the funding roles in the US is much more cyclical than in the EU. During the period of economic downturn, there was in the US a much sharper reduction of the private contribution than in the EU, which in turn was compensated by a larger increase of governmental involvement compared to the EU.

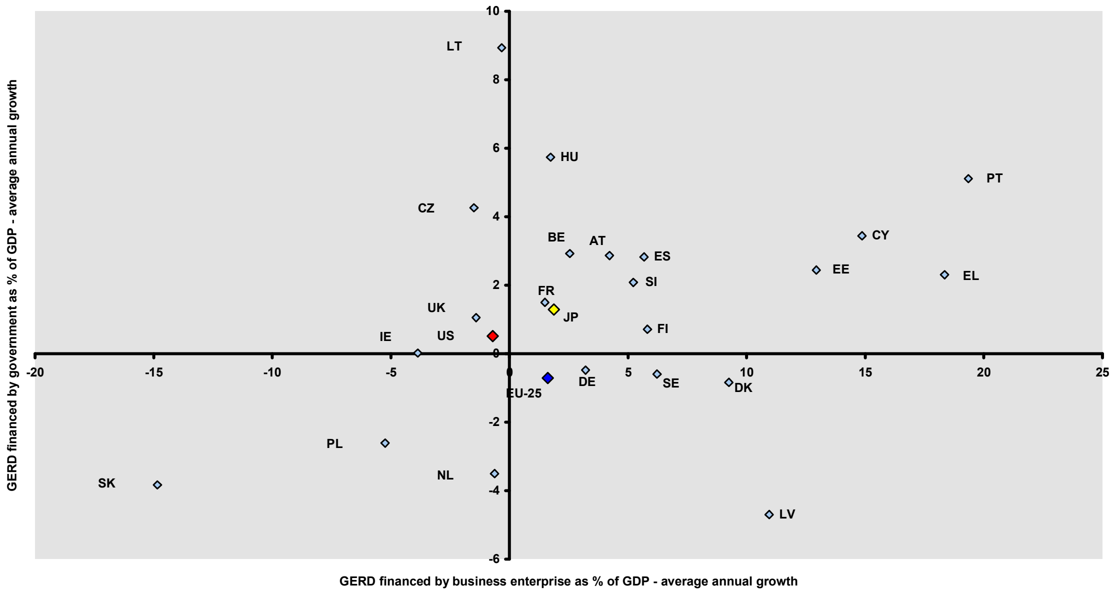
Figure 2.2.4 Share of GERD financed by business enterprise and by government - average annual growth (%)



Source: DG Research Key Figures 2005
Data: Eurostat, OECD
Notes: (1) EU-25 was estimated by DG Research and does not include IT, LT, LU and MT.
(2) US : Most or all capital expenditure is not included.
(3) US : 1998-2000.
(4) EU-25 : 2000-2002.

In most of the EU countries, rising R&D intensity has largely been driven by increased funding from the business sector. This is particularly true for the rapidly catching-up countries such as Portugal, Greece, Estonia and Cyprus. In contrast, in Lithuania, Hungary and the Czech Republic, the rapid catching-up process has mainly been caused by an increase in government contributions. The low and declining R&D intensities of Poland and Slovakia were caused by decreases in the contributions from both the business and the government sectors. For the countries with established high R&D intensities, growth was exclusively driven by the business sector (Denmark, Sweden, Germany), whereas in Belgium, Austria, Spain, Slovenia, France and Finland, government-funding also played an important role.

Figure 2.2.5 GERD financed by business enterprise and by government as % of GDP - average annual growth, 1997-2002 (1)



Source: DG Research — Key Figures 2005

Data: Eurostat, OECD

Notes: (1) BE, DK, EL, PT, SE : 1997-2001; DE, ES, HU, PL, SK, UK, JP : 1997-2003; AT : 1997-2005; EE, CY : 1998-2002; CZ, FI, US : 1998-2003; FR, LT : 2000-2002.

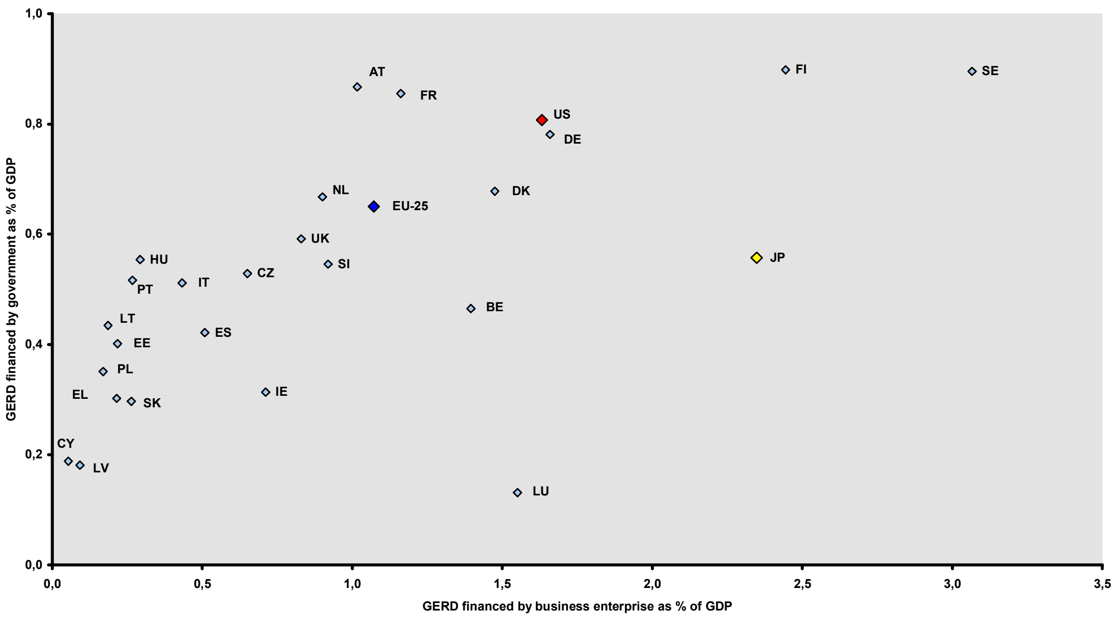
(2) EU-25 was estimated by DG Research and does not include IT, LU and MT.

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

Domestic R&D efforts are largely financed by business sector R&D in the US, Japan and Europe, while governments are playing a smaller role. Although the R&D intensity gap between Europe and its main competitors is almost entirely due to differences in business-financed R&D, the role of government in the financing of R&D should not be under-estimated.

The level of government-funded R&D is still substantial in many high R&D-intensive countries such as the three Nordic countries, Germany, France and the US, a sign also that high private involvement in the funding of R&D does not preclude government funding. Moreover, in low R&D-intensive countries such as the new EU Member States, government funded R&D in relation to GDP is higher than the level of business-funded R&D. Government funding of R&D is critical for creating and developing research infrastructures, carrying out mission-oriented research (e.g. defence, energy, public health) and for supporting research projects with high expected social benefits, which the business sector would not find sufficiently attractive.

Figure 2.2.6 GERD financed by business enterprise and by government as % of GDP, 2002 (1)



Source: DG Research Key Figures 2005
Data: Eurostat, OECD
Notes: (1) IT : 1996; LU : 2000; BE, DK, EL, PT, SE : 2001; CZ, DE, ES, HU, PL, SK, FI, UK, US, JP : 2003; AT : 2005.
(2) EU-25 was estimated by DG Research and does not include LU and MT.

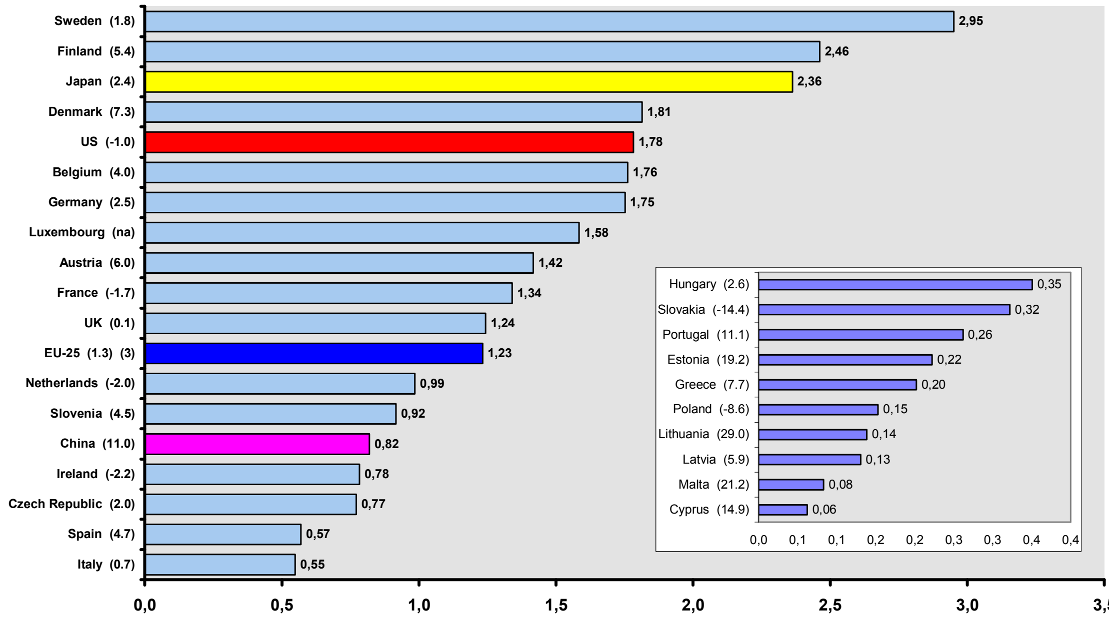
2.3. Business sector R&D

The level and intensity of overall expenditure on R&D are key determinants of the future competitiveness of an economy. But it is also important to look at the sectors in which this R&D is performed. The business sector is probably most important in this regard. It is closest to consumers and best positioned to significantly improve or develop new products based upon new combinations of existing knowledge or knowledge newly developed through research in-house or elsewhere and to exploit this commercially. Business R&D expenditure is market-driven and accounts for an important share of innovation expenditure. In a direct way and through stimulating other sectors this in turn leads to employment and economic growth. The level and intensity of business R&D expenditure, as well as the structure of its funding, is therefore a key determinant of an economy's future competitiveness, and a key concern for policy-makers. This is why the European Council has stipulated that two thirds of R&D expenditure should be financed by the business sector.

Business R&D intensity remains low in spite of healthy growth in several Member States

Business R&D intensity was only 1.23% in 2003 in the EU compared to 1.78% in the US and 2.36% in Japan. The EU and Japan enjoyed an increase in business R&D intensity over 1997-2003 while the US experienced a decline. In China, R&D expenditure by the business enterprise sector is still below the EU-average (0.82%), but it is already higher than in most new Member States, the Southern European countries and Ireland. Furthermore, China's Business R&D intensity has been growing at the tremendous pace of 11% per year over recent years. Among the EU countries, Sweden and Finland had the highest business R&D intensities, with values far above 2%, while the majority of the new Member States as well as the Southern European countries were below the EU average. Most of these countries nevertheless experienced sharp increases in business R&D intensity between 1997 and 2003. Among the highest R&D spending countries, Germany, France and the UK have business R&D intensities exceeding the EU average. France, however, saws a decline in its business R&D intensity during the period 1997-2003.

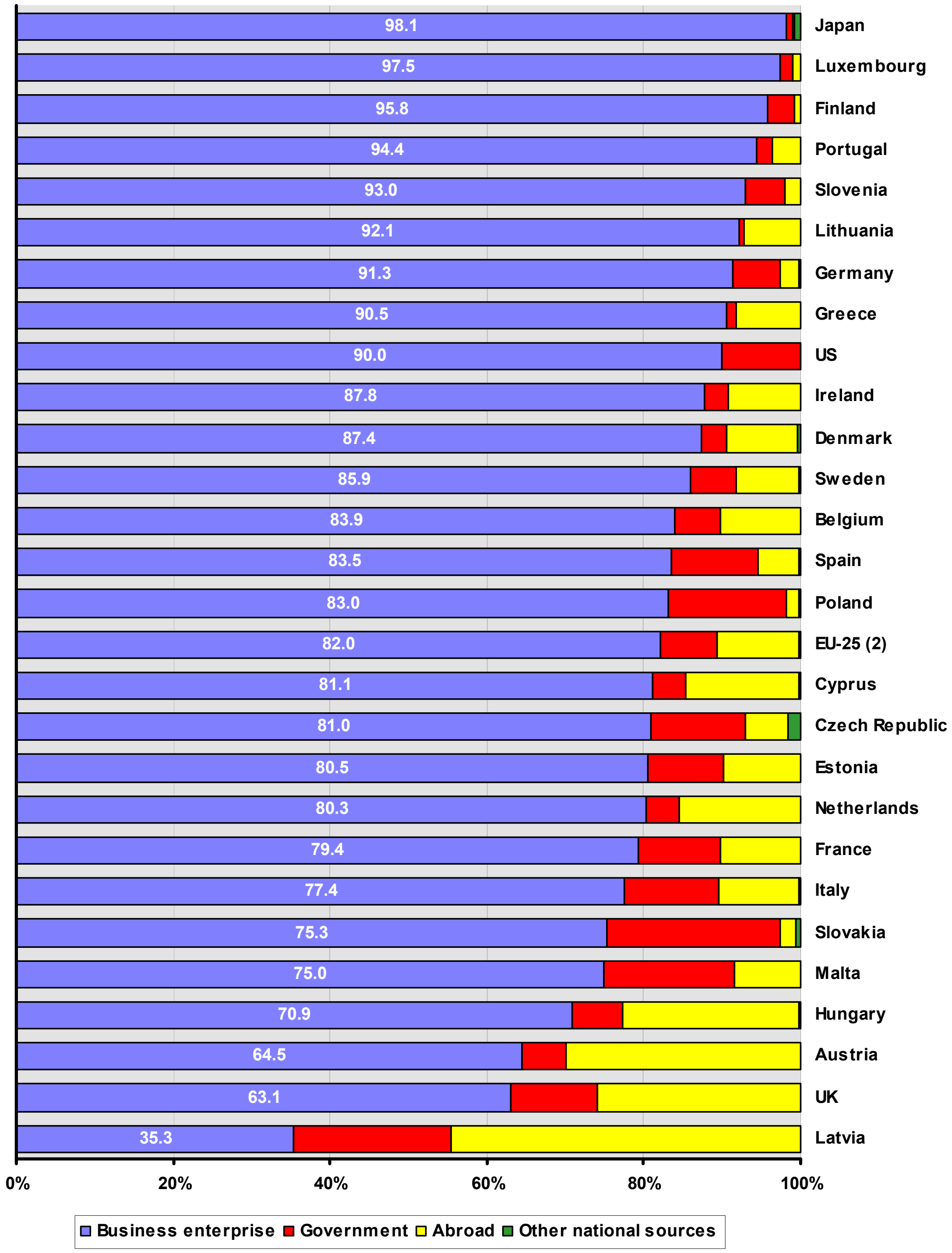
Figure 2.3.1 Business enterprise expenditure on R&D (as % of GDP), 2003 (1); in brackets: average annual growth rate s



Source: DG Research — Key Figures 2005
Data: Eurostat, OECD
Notes: (1) LU : 2000; AT : 2002; BE, IE, IT : 2004.
(2) ES : 1997-2001; BE, IE, IT : 1997-2004; EE, AT : 1998-2002; CY : 1998-2003; CN : 2000-2003; FR, UK : 2001-2003; MT : 2002-2003.
(3) EU-25 was estimated by DG Research and does not include LU and MT.

Business R&D is mainly funded by the business enterprise sector itself, but the contribution of that sector is much higher in the US and Japan than in Europe. In 2002, it amounted to 82.0% in the EU compared to 98.1% in Japan and 90.0% in the US (the values for the US and Japan refer to 2003). The share of the business sector in the financing of business R&D varies widely across EU countries. It ranged from 35% in Latvia to 96% in Finland. Moreover, several low R&D-intensive EU countries such as Portugal, Lithuania and Greece enjoy relatively strong business support for business R&D. Conversely, France combines a relatively high business R&D intensity with a share of the business sector in the funding of business R&D which is lower than the EU average.

Figure 2.3.2 BERD by main sources of funds, 2002 (1)



Source: DG Research

Key Figures 2005

Data: Eurostat, OECD

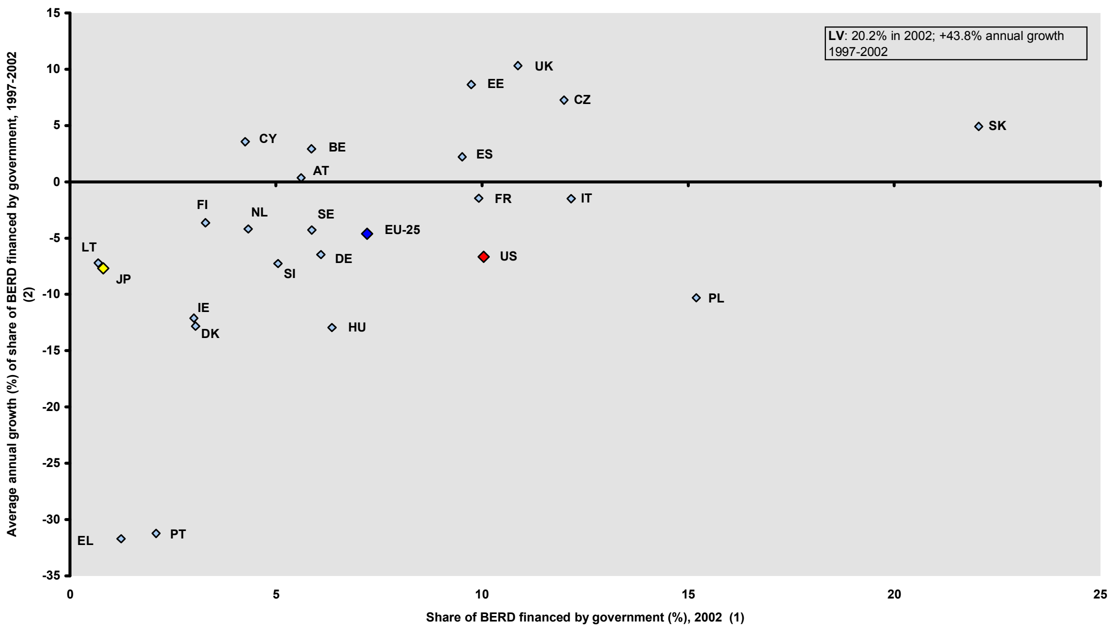
Notes: (1) LU : 2000; DK, EL, PT : 2001; CZ, DE, ES, IE, HU, PL, SK, FI, SE, UK, US, JP : 2003.

(2) EU-25 was estimated by DG Research and does not include LU.

The financing of business R&D is changing

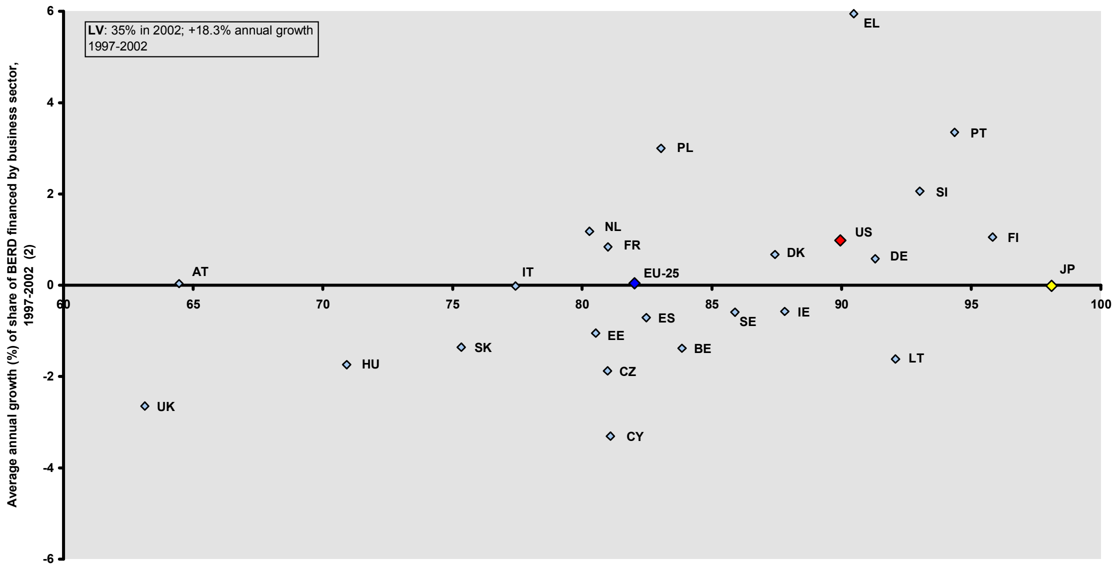
The roles of government and business sector in the financing of business R&D are changing. Between 1997 and 2002, the share of direct government funding declined significantly in the EU, Japan and the US (by -4% to -7%), even if it remains non-negligible in the US and in the EU countries, especially in the new Member States and in France. Within Europe, the drop was particularly significant in Portugal and Greece. On the other hand, there were slight increases in the proportions of business R&D financed by the business sector in the EU and in the US (0.1% and 1% average annual growth respectively) between 1997 and 2002. Within the EU, the share of business R&D funded by the business sector increased significantly in a few new Member States such as Latvia or Poland, as well as in Greece and in Portugal.

Figure 2.3.3 Share of Business entreprise R&D expenditure financed by government - latest year and average annual growth



Source: DG Research — Key Figures 2005
Data: OECD, Eurostat
Notes: (1) FR : 2000; DK, EL, ES, PT : 2001; CZ, DE, IE, HU, PL, SK, FI, SE, UK, US, JP : 2003.
(2) FR : 1997-2000; DK, EL, ES, PT : 1997-2001; CZ, IE, HU, PL, SK, FI, SE, US, JP : 1997-2003; EE, CY, AT : 1998-2002; DE : 1998-2003; LT : 2000-2002; UK : 2001-2003.
(3) EU-25 was estimated by DG Research and does not include LU and MT.

Figure 2.3.4 Share of Business entreprise R&D financed by business enterprise sector - latest year and average annual growth



Source: DG Research — Key Figures 2005
Data: Eurostat, OECD
Notes: (1) FR : 2000; DK, EL, ES, PT : 2001; CZ, DE, IE, HU, PL, SK, FI, SE, UK, US, JP : 2003.
(2) FR : 1997-2000; DK, EL, ES, PT : 1997-2001; CZ, IE, HU, PL, SK, SE, US, JP : 1997-2003; EE, CY, AT : 1998-2002; DE, FI : 1998-2003; LT : 2000-2002; UK : 2001-2003.
(3) EU-25 was estimated by DG Research and does not include LU and MT.

Figure 2.3.5 Rate of tax subsidies for 1 EUR of R&D, large firms and SMEs, 2004

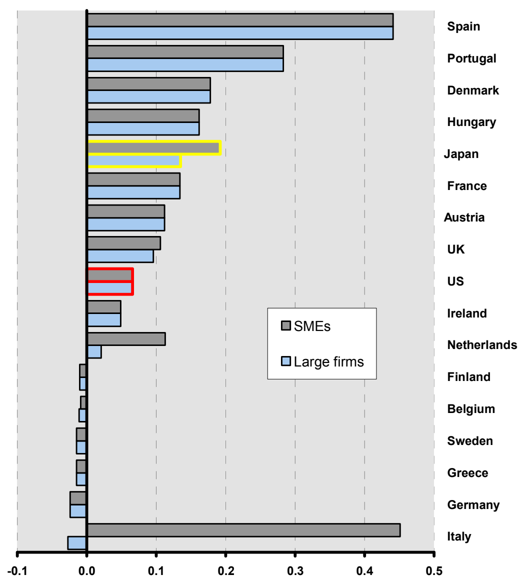
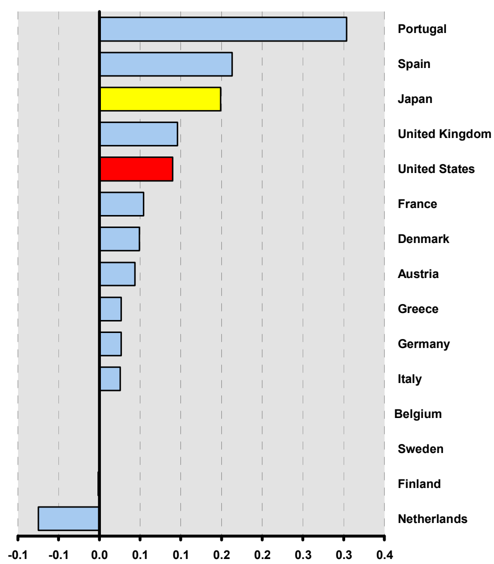


Figure 2.3.6 Change in the rate of tax subsidies for 1 EUR of R&D, large firms, between 1995 and 2004



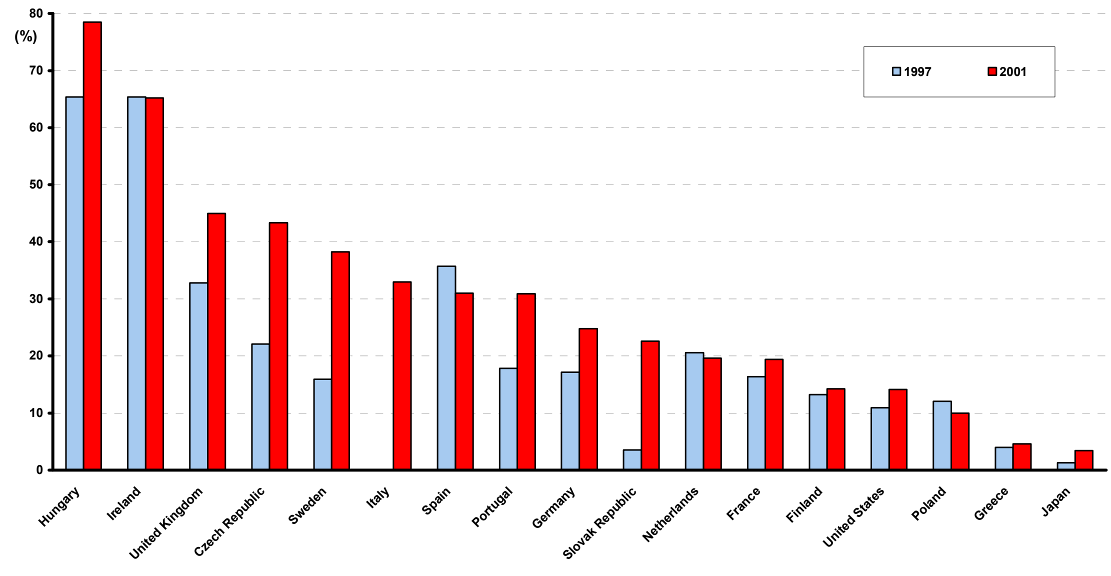
Source: DG Research — Key Figures 2005
Data: OECD

While the share of direct government funding is decreasing, governments in many Member States are increasingly using indirect policy measures to encourage higher business R&D expenditure. In particular there are an increasing and diversifying number of R&D tax incentives in many EU countries since the mid-1990s. Some of these new incentives are based on the level of R&D spending during a given year, others are targeted at SMEs (*e.g.* in Italy) or at identified R&D fields. Austria, France and the Netherlands have made more generous tax concessions. Germany has reduced its corporate tax rates to leave companies more resources for R&D. As a result, most of the EU countries saw an increase in the rate of tax subsidies since the mid-1990s. Tax incentives for R&D directed at large firms and at SMEs were particularly high in Spain, Portugal and Denmark in 2004. While many EU countries had approximately the same level of subsidies for both large firms and for SMEs, incentives of Italy and the Netherlands were particularly generous to small firms.

Europe is losing its attractiveness for international R&D investment

Recent years have seen increased globalisation of R&D. R&D expenditure by affiliates of foreign companies is increasingly contributing to R&D spending in most of EU Member States, as well as in the US and Japan. The share of foreign affiliates in total R&D expenditure by enterprises has risen most noticeably in the new Member States Slovakia, the Czech Republic and Hungary, and in the UK, Sweden and Portugal. In Germany, France, Finland, the US and Japan, the increase was less marked but still substantial. In other countries, their proportion in total R&D remained relatively constant, which indicates that R&D by affiliates of foreign companies has increased roughly as fast as domestic R&D.

Figure 2.3.7 R&D investments by foreign affiliates, 1997 and 2001 (1)
As % of R&D expenditure by entreprises

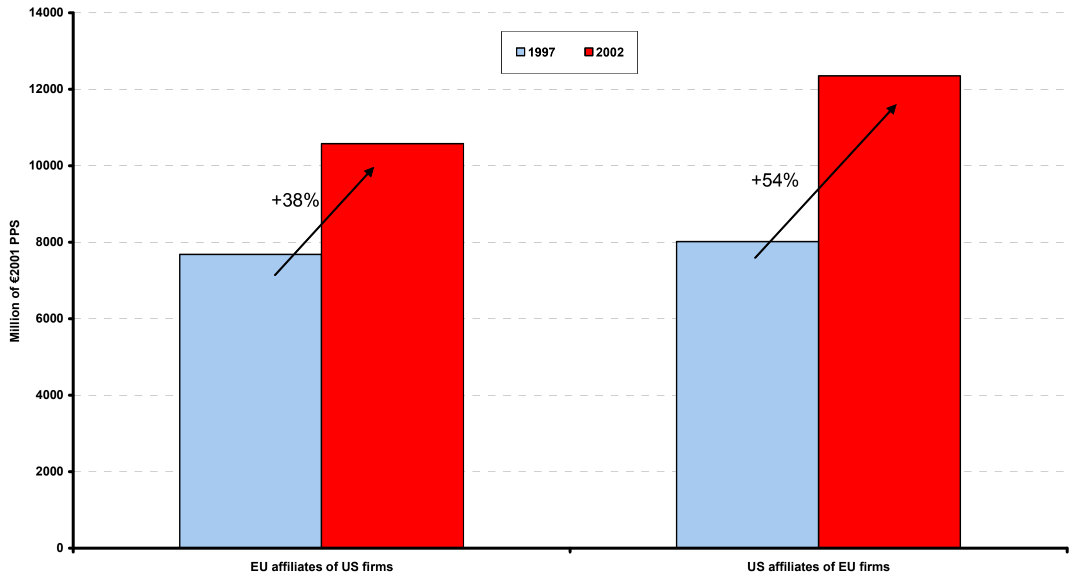


Source: DG Research
Data: OECD, Activity of Foreign Affiliates database.
Notes: (1) UK: 1997-2003; CZ, US: 1997-2002; HU: 1997-1998; PT: 1999-2001; SK: 1996-2002; FR: 1998-2002; PL: 2000-2002; EL: 1997-1999; IT: no data available before 2001.

Key Figures 2005

Since the mid-1990s, the US experienced a gain in its share of foreign affiliates R&D spending. A large part of this shift towards the US came from EU companies having affiliates on the US territory. Between 1997 and 2002, R&D expenditures of US-based affiliates of EU manufacturing firms increased by 54% in real terms, from approximately 8 billion € to more than 12 billion € (€2001 PPS). US firms increased their R&D expenditure in EU-based affiliates by 38% only, from 7.6 billion € to 10 billion €. As a result, the net gain for the US increased by a factor 5.4 over the recent years, from about 300 million € in 1997 to almost 2 billion € in 2002 (€2001 PPS). During that period, foreign R&D investments in the US were mainly targeted at high-technology areas. Pharmaceuticals and communication equipment alone accounted for more than half of the R&D expenditures by foreign affiliates in 2000[11]. These data tend to confirm that companies increasingly locate new R&D facilities near centres of scientific and technological excellence, not just near markets of interest.

Figure 2.3.8 Changes in R&D spending by foreign affiliates in manufacturing, 1997 and 2002



Source: DG Research
Data: OECD, Activity of Foreign Affiliates database.

Key Figures 2005

Although there is evidence showing that EU companies might benefit from this "technology-sourcing" thanks to knowledge spill-overs to the parent company resulting in increased marginal productivity at company level in the region of origin, such a net outflow also reflects the relatively stronger attractiveness of the US research and innovation systems compared to the EU ones. It risks leading Europe into a worrying vicious circle as the loss of high value-added R&D activities and jobs is undermining further its capacity to retain such activities.

Furthermore, US outward R&D investment grew over recent years in all major regions of the globe, but growth has been fastest outside the EU-15, particularly in emerging countries such as China, where US outward R&D investment increased by 25% per year since the mid-1990s (against 8% per year in the EU-15) (€1995 PPS). As a result, the share of the EU-15 in total US outward R&D investment is declining since the late 1990s. These trends are expected to be continued as long as new actors build their science and technology infrastructure and open markets to foreign entrants.

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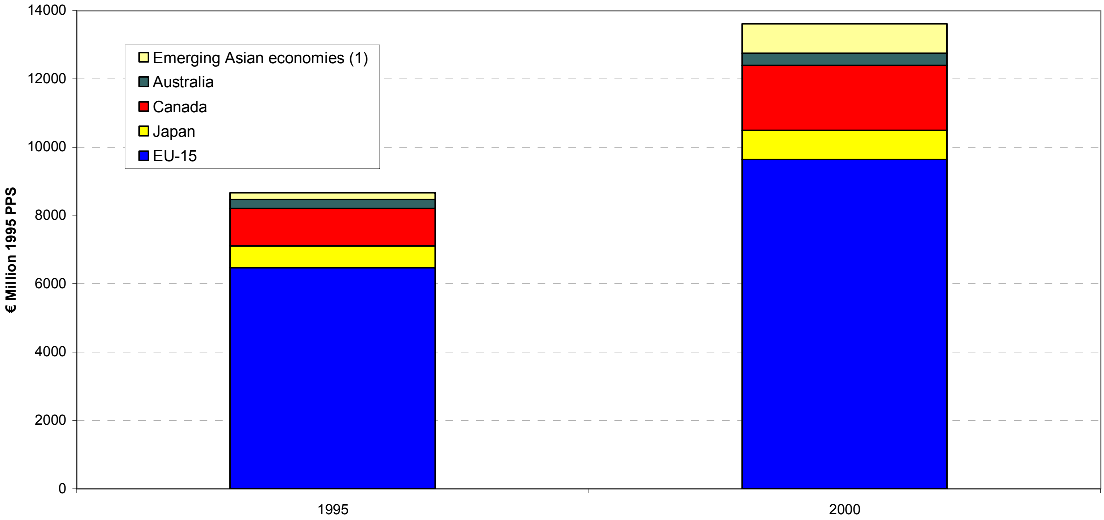
[11] OECD Science, Technology and Industry Outlook 2004.

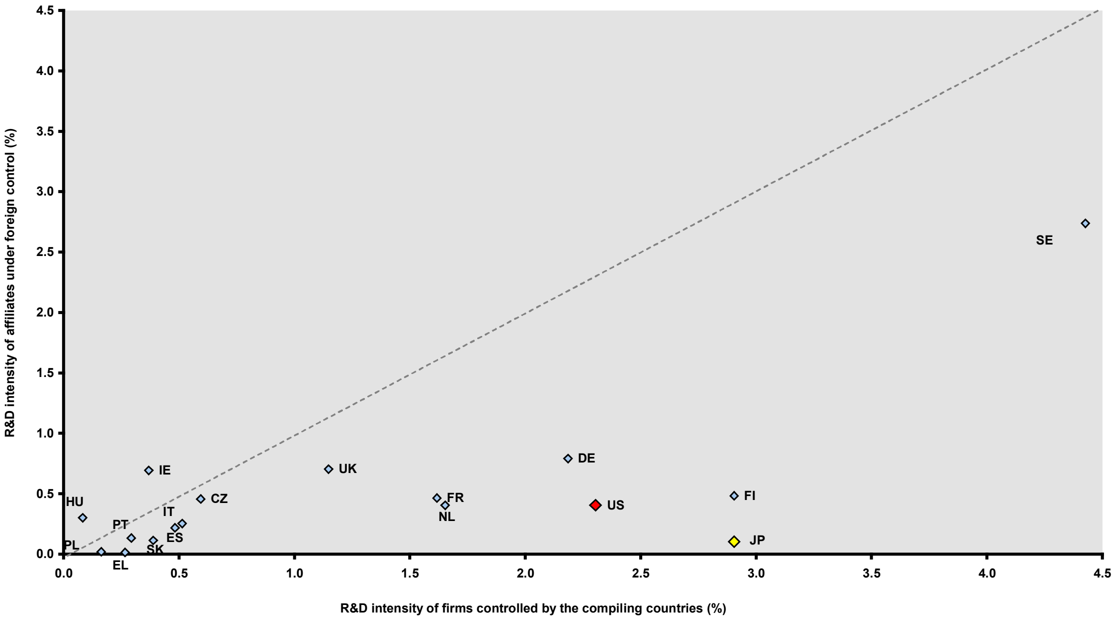
Figure 2.3.8b US Overseas R&D expenditure, 1995 and 2000



Source: DG Research
Key Figures 2005
Data: US Bureau of Economic Analysis: U.S. Direct Investment Abroad - Operations of U.S. Parent Companies and Their Foreign Affiliates (Washington, DC, annual series).
Note: 'US overseas R&D Expenditure' refers to R&D expenditure performed by majority-owned non-bank foreign affiliates of non-bank U.S. 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; (1) China, Hong Kong, Singapore and Taiwan.

Therefore, policy measures to increase the attractiveness of the European Knowledge Area are an important means of increasing business R&D intensity and generating spill-overs than can be beneficial to EU firms. Specific attention needs to be paid to the development of policies that may attract or retain high R&D-intensive companies.

Figure 2.3.9 R&D intensity of foreign companies and national firms as % of value added in industry, 2001 (1)

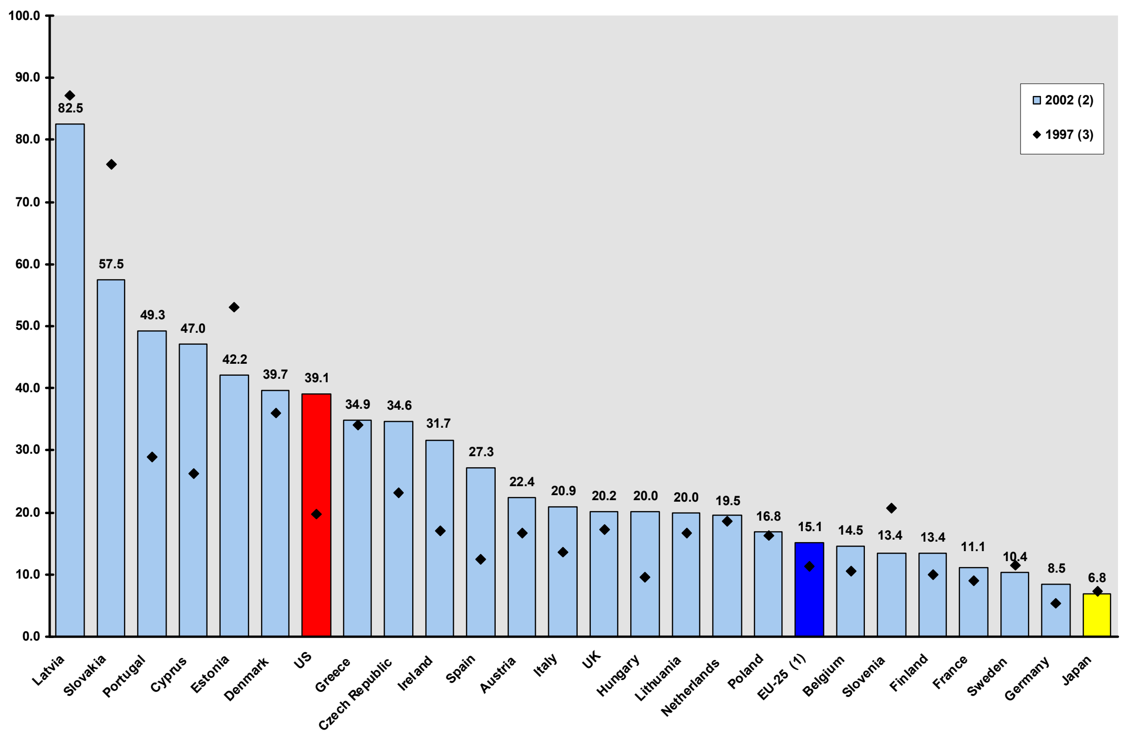


Source: DG Research Key Figures 2005
Data: OECD.
Notes: (1) HU : 1998; EL : 1999; TR : 2000; CZ, SI, UK : 2002.

EU-based firms tend to invest less than US firms in R&D in the services sector and in high-tech manufacturing

In the US, nearly 40% of all business R&D is performed in the service industries, whereas in the EU this share is only 15%. However, since 1997, an increasing proportion of business R&D is being performed in the services sector in Europe (from 11.5% in 1997 to 15.1% in 2002). The increasing importance of services sector R&D is mainly due to three factors: an improvement in the measurement of services sector R&D; a growth in R&D intensity in the services sectors and an increase in the outsourcing of R&D by both the business and government sectors. Within Europe, the shares of R&D expenditure performed in the services sector vary greatly. The share of EU R&D performed in the services sector remains particularly low in a few key EU countries, namely Germany, Sweden, France and Finland.

Figure 2.3.10 Share of BERD performed in the services sector (%)



Source: DG Research Key Figures 2005
Data: Eurostat, OECD
Notes: (1) EU-25 was estimated by DG Research and does not include LU and MT.
(2) AT : 1998; EL, IE, PT : 2001; CZ, DE, IT, HU, PL, SK, FI, SE, : 2003.
(3) AT : 1993; EE, CY : 1998; LV : 2000; JP : 2001.

In 2002, the share of high-tech manufacturing industries in total manufacturing R&D expenditure was at almost the same level in the EU (41%) and Japan (42%) whereas the share for the US was higher at 44%. European industrial R&D is more likely to be concentrated in medium-high-tech manufacturing. There are sharp national differences within Europe win the distribution of manufacturing R&D by technology intensity. The share of manufacturing R&D performed in high-tech industries amounted to more than 60% in Finland, Hungary and Ireland compared to just 26.6% in Germany, which, however, has a very high concentration of R&D in the medium-high-tech manufacturing.

Table 2.3.1 Manufacturing BERD by type of industry, 2002 (1)

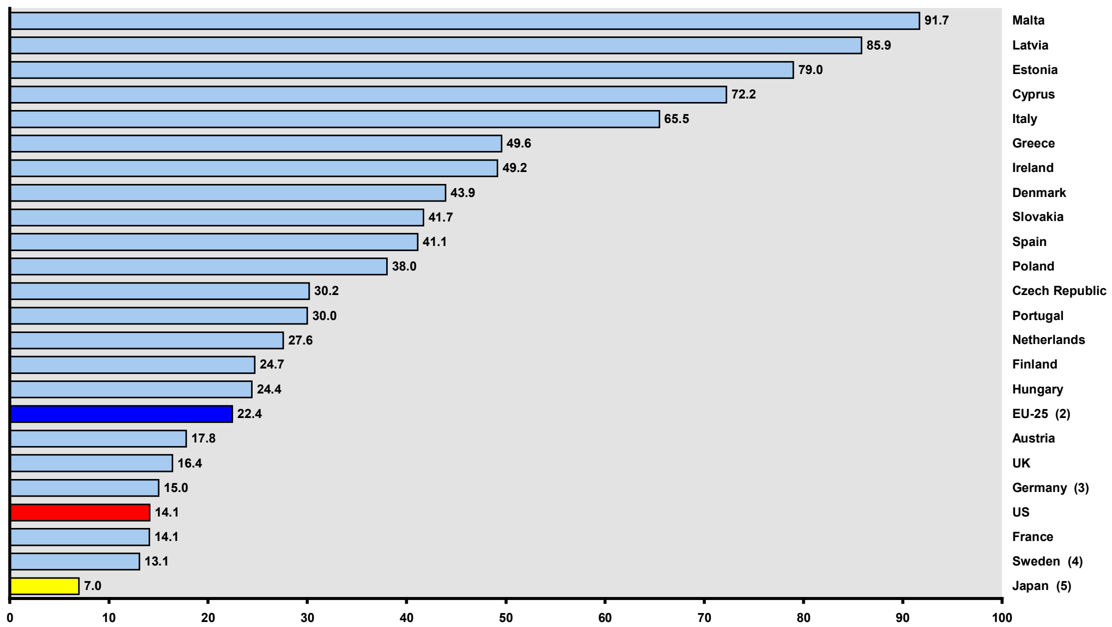
	High-Tech	Medium-High-Tech	Medium-Low-Tech and Low-Tech
Czech Republic	14,9	70,5	14,6
Germany	26,6	65,6	7,7
Malta	28,5	42,8	28,6
Latvia	29,3	45,5	25,2
Poland	34,2	45,9	20,0
Spain	36,0	41,8	22,3
Italy	40,9	47,5	11,5
EU-25 (2)	41,4	47,7	10,9
Japan	41,6	45,9	12,5
Cyprus	43,8	27,3	28,9
US	44,3	44,9	10,8
France	44,6	42,0	13,4
Denmark	46,1	39,3	14,6
Netherlands	46,4	36,4	17,2
Belgium	49,8	31,6	18,6
Slovenia	51,7	32,8	15,5
Sweden	52,2	40,4	7,4
UK	56,7	33,6	9,6
Finland	62,6	23,4	14,0
Ireland	64,3	19,0	16,7
Hungary	64,9	26,0	9,1

Source : DG Research Key Figures 2005
Data : OECD, Eurostat
Notes: (1) IE : 2001; CZ, DE, IT, FI, SE : 2003.
(2) EU-25 does not include : EE, EL, IE, LT, LU, AT, PT, SK.

SME's perform a relatively large part of business R&D in the EU

Small and medium sized firms account for a higher share of business R&D in the EU than in the US and Japan, performing 22% of business R&D in 2002. Countries that are characterised by a relatively high participation of SMEs in business R&D, such as the new Member States, Italy, Greece or Spain, also have low business R&D intensities. Conversely, countries with low concentrations of business R&D in SMEs - e.g. Sweden, France, Germany, Austria, Japan and the US - have also higher business R&D intensities. Countries with low R&D intensities and relatively less developed research systems often lack the minimum scale to host large R&D intensive companies, which in turn explains the predominance of SMEs in their total business R&D expenditure. This observable correlation between low R&D intensity and high participation of SMEs, however, does not apply to Denmark, where the high R&D intensity (the third highest in the EU) is largely driven by small and medium-sized enterprises.

Figure 2.3.11 Share of BERD performed by SMEs (%), 2002 (1)



Source: DG Research Key Figures 2005
Data: Eurostat, OECD (STI/EAS)
Notes: (1) AT : 1998; DE, EL : 1999; US : 2000; IE, IT, PL, PT, SE, UK, JP : 2001.
(2) EU-25 does not include : BE, DE, EL, IE, IT, LT, LU, AT, PL, PT, SI, SE, UK.
(3) DE : Institutes are not included.
(4) SE : Size class - 50-249 employees.
(5) JP : Size class - less than 300 employees.

The higher concentration of R&D expenditure in small and medium-sized companies should not be a problem if this supports company expansion. Empirical evidence, however, shows that, if some SMEs (particularly the high-tech ones, often labelled "New Technology-based firms" or NTBFs) can grow rapidly and become critical players in many industry sectors (e.g. Microsoft, Cisco, Sun Microsystems, Hewlett-Packard), the typical growth path of such an SME is more likely to be successful in the US than in Europe. According to figures on the growth paths of large companies in both the EU and the US, only 16% of the EU's current largest companies have been established after 1980 against 30% in the US. Out of these large companies created after 1980, only 37% were created from scratch (the remainder being the result of mergers and acquisitions) in the EU against 82% in the US[12].

It is therefore essential to support the creation and expansion of SMEs, especially in high and medium-high technology-intensive sectors and to ensure that the right conditions exist for SMEs to flourish and for Europe, as a consequence, to achieve its R&D potential.

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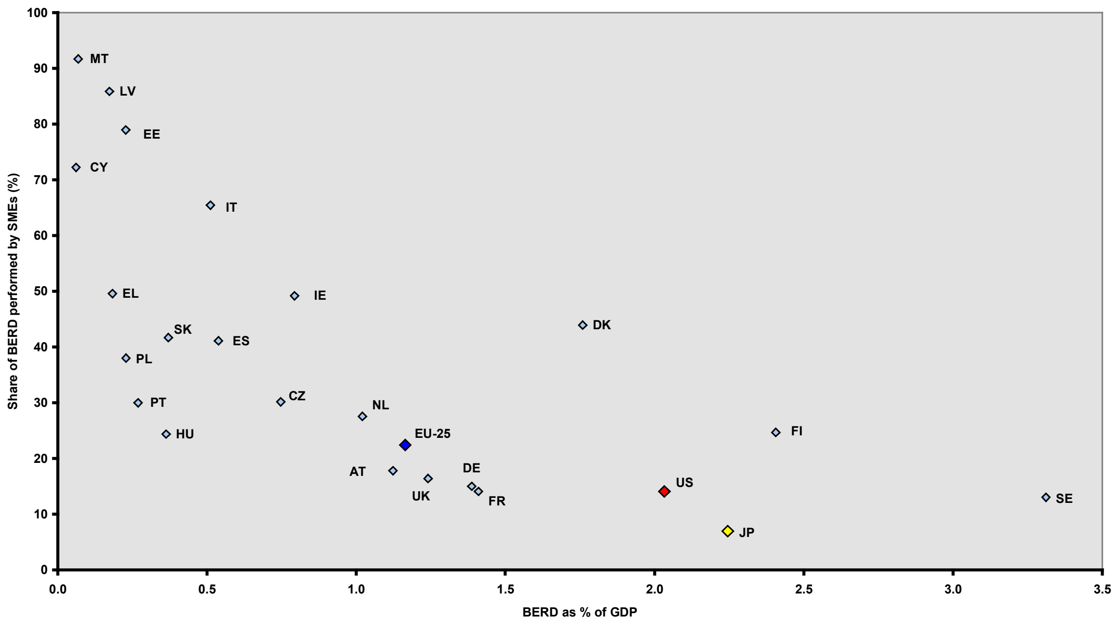
[12] COHEN, E. and LORENZI, J.-H. (2000), Politiques industrielles pour l'Europe, Conseil d'Analyse Économique

Figure 2.3.12 BERD as % of GDP and % share of BERD performed by SMEs, 2002 (1)

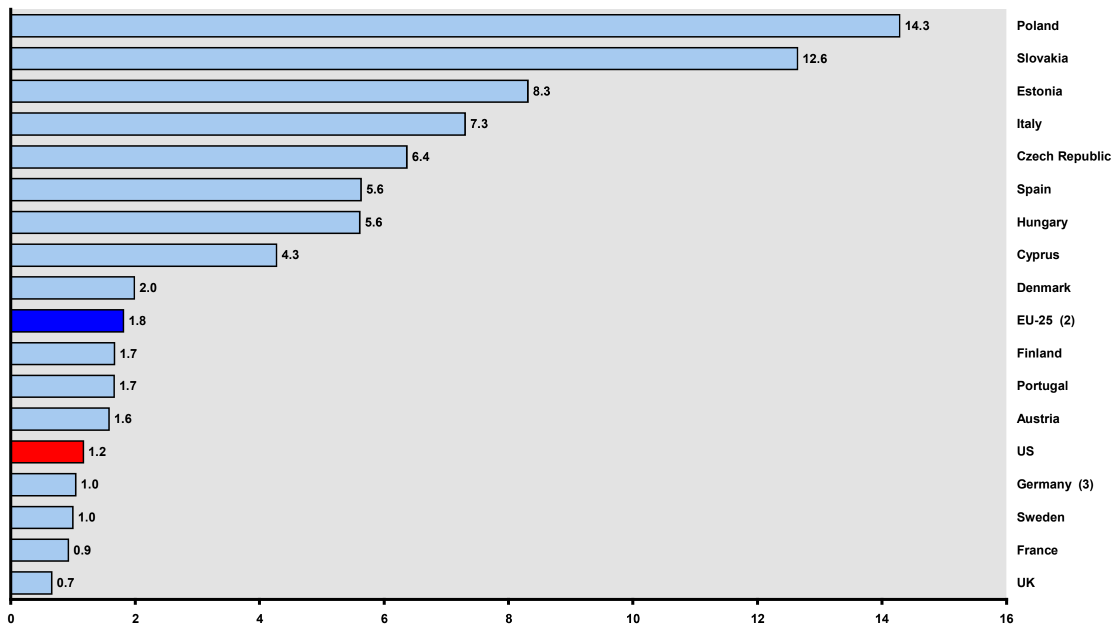


Source: DG Research — Key Figures 2005

Data: Eurostat, OECD (STI/EAS)

Notes: (1) AT : 1998; DE, EL : 1999; US : 2000; IE, IT, PL, PT, SE, UK, JP : 2001.
(2) EU-25 does not include : BE, DE, EL, IE, IT, LT, LU, AT, PL, PT, SI, SE, UK.
(3) DE : Institutes are not included.
(4) SE : Size class - 50-249 employees.
(5) JP : Size class - less than 300 employees.

Figure 2.3.13 Publicly funded R&D executed by SMEs in the business sector as % of total BERD, 2002 (1)



Source: DG Research — Key Figures 2005

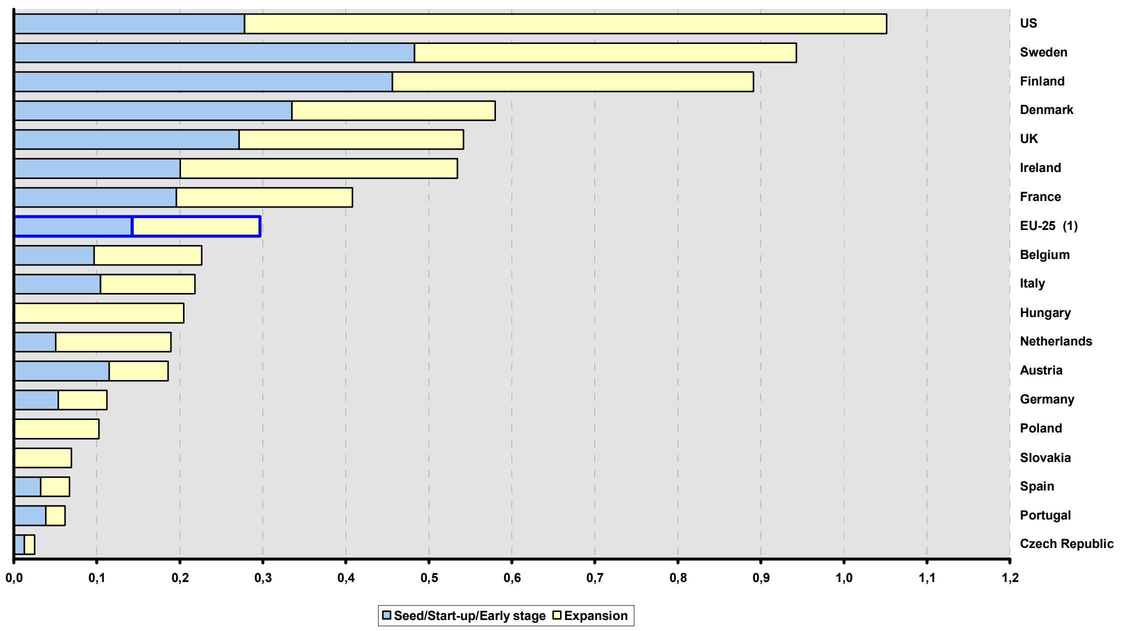
Data: Eurostat, OECD (STI/EAS).

Notes: (1) AT : 1998; DK, DE : 1999; US : 2000; IT, PL, PT, SE, UK : 2001.
(2) EU-25 does not include : BE, DK, DE, EL, IE, IT, LT, LV, LU, MT, NL, AT, PL, PT, SI, SE, UK.
(3) DE : Institutes are not included.

Less opportunities for technology 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. Therefore, venture capital investment creates and expands new business activities that generate additional business sector R&D and drive competitiveness and economic growth.

Figure 2.3.14 High-Tech venture capital by stage per 1000 GDP, 2003



Source: DG Research — Key Figures 2005
Data: PriceWaterhouseCoopers (Moneytree Survey, Money for Growth 2004)
Notes: (1) EU-25 does not include EE, LU, CY, LV, LT, LV, MT and SI.

In terms of venture capital investment relative to GDP in the high tech sectors, the EU is lagging behind the US. In 2003, the US's total investment in venture capital in these sectors was 1.05 euro per thousand GDP, which is about three times the amount invested in the EU. The EU countries with strongest high-tech venture capital investment rates also tend to be those with the highest R&D intensities. Sweden and Finland, for instance, show levels of high-tech venture capital investment comparable to the US's. US early stage venture capital investment in the high-tech sectors was much larger: in 2003, it was twice as high as in the EU-25. Moreover, three quarters of the high-tech venture capital investment within the US is made at the expansion stage, whereas only about half is invested at the expansion stage in Europe.

A recent study by the European Commission, based on comparable data, further analyses early-stage technology venture capital investment and points to three major differences between the EU and the US[13]. Firstly, the number of high-tech companies benefiting from early-stage venture capital investment is much larger in Europe (twice as much as in the US in 2003). It can realistically be assumed that Europe does not generate twice as much technological innovations as in the US, but that on average a larger proportion of new projects was financed by venture capital than in the US. Secondly, 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). A difference of this magnitude cannot be explained by cost level differentials (i.e. the cost of getting a new technology business on its way) at both sides of the Atlantic or by differences in the destination of venture capital investment (the sectoral breakdown being largely the same in the EU and in the US). Thirdly, there is a significant disparity between the US and the EU in the profitability of early stage venture investment: in 2003, average internal rates of return were about 30 to 50 times higher in the US. Since there is no reason to assume that European technological innovations would be of inferior quality, explanations for this poor investment performance should be sought elsewhere.

Examined against the backdrop of the low profitability rate and the dispersion of EU early stage investment, we can conclude that a large part of the small investments made by EU funds fail as a result of the technology having been too immature for venture financing. US venture capitalists appear to be more successful at concentrating their investment on more advanced projects / technologies that are generating better profits. From the point of view of the innovating companies, European research teams incorporate and seek venture capital at a too early stage, when clearly, on average, the uncertainties are still too high for both parties. 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 commercialisation of technological innovation cannot be solved solely through actions aimed at strengthening venture 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.

2.4. Public sector R&D and its relationship with the business enterprise sector

Public sector R&D can boost business R&D spending in several ways. It creates and expands the stock of knowledge that firms can build upon. The higher education sector trains highly-skilled graduates for industry; it develops new instruments and provides research infrastructures that can be fruitful for industrial R&D activity. Furthermore, a strong public research sector can attract investments from foreign-owned companies, especially via the concentration of resources in centres of excellence. Finally, through the formation of public-private research networks and the creation of new firms, the public research sector helps enhance the capacity for R&D problem solving.

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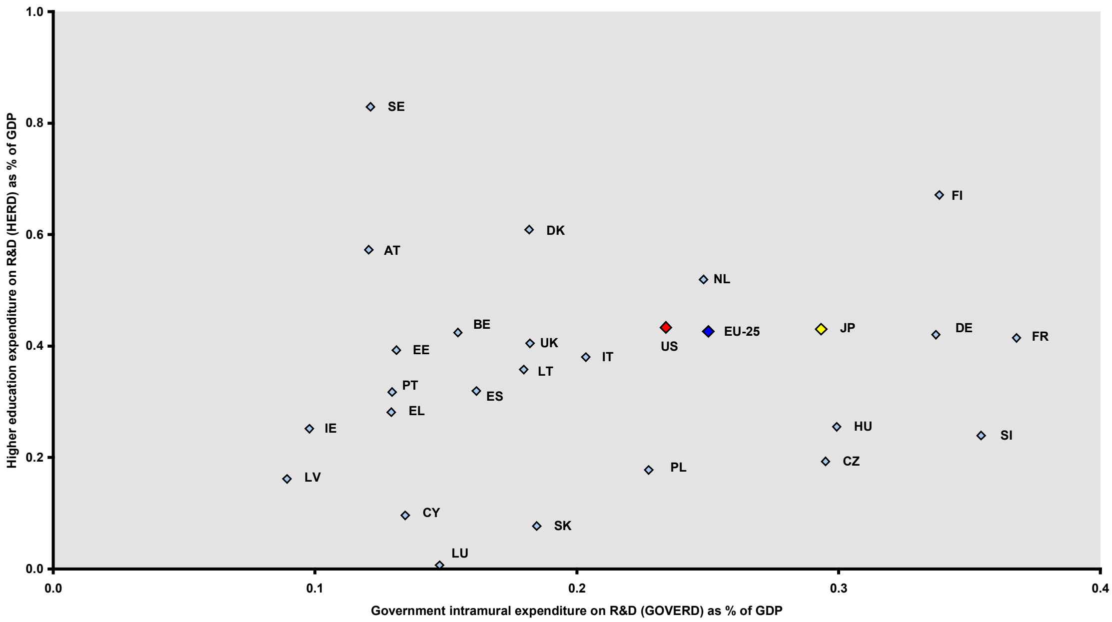
[13] European Commission (2005), "The shifting structure of private equity funding in Europe. What role for early stage investment ?", (ECFIN/L/6(2005)REP/51515-EN)

R&D expenditure in the higher education sector is on the rise in the EU …

R&D performed in the higher education sector is on the rise in Europe, Japan and the US. In 2003, higher education R&D expenditure as % of GDP amounted to 0.44% in the EU as a whole, well above its 1997 level (0.38%). Within the EU, the three Nordic countries Sweden, Finland and Denmark showed the highest intensity of higher education R&D in 2003, with values above 0.60%. Austria and the Netherlands were also above the EU average. On the other hand, most of the new Member States (except Lithuania and Estonia) were far below the EU average. In both the US and Japan, higher education R&D in relation to GDP amounted to 0.43% in 2003, compared to respectively 0.37% and 0.41% in 1997.

Figure 2.4.1 Public R&D in relation to GDP, 2003 (1)



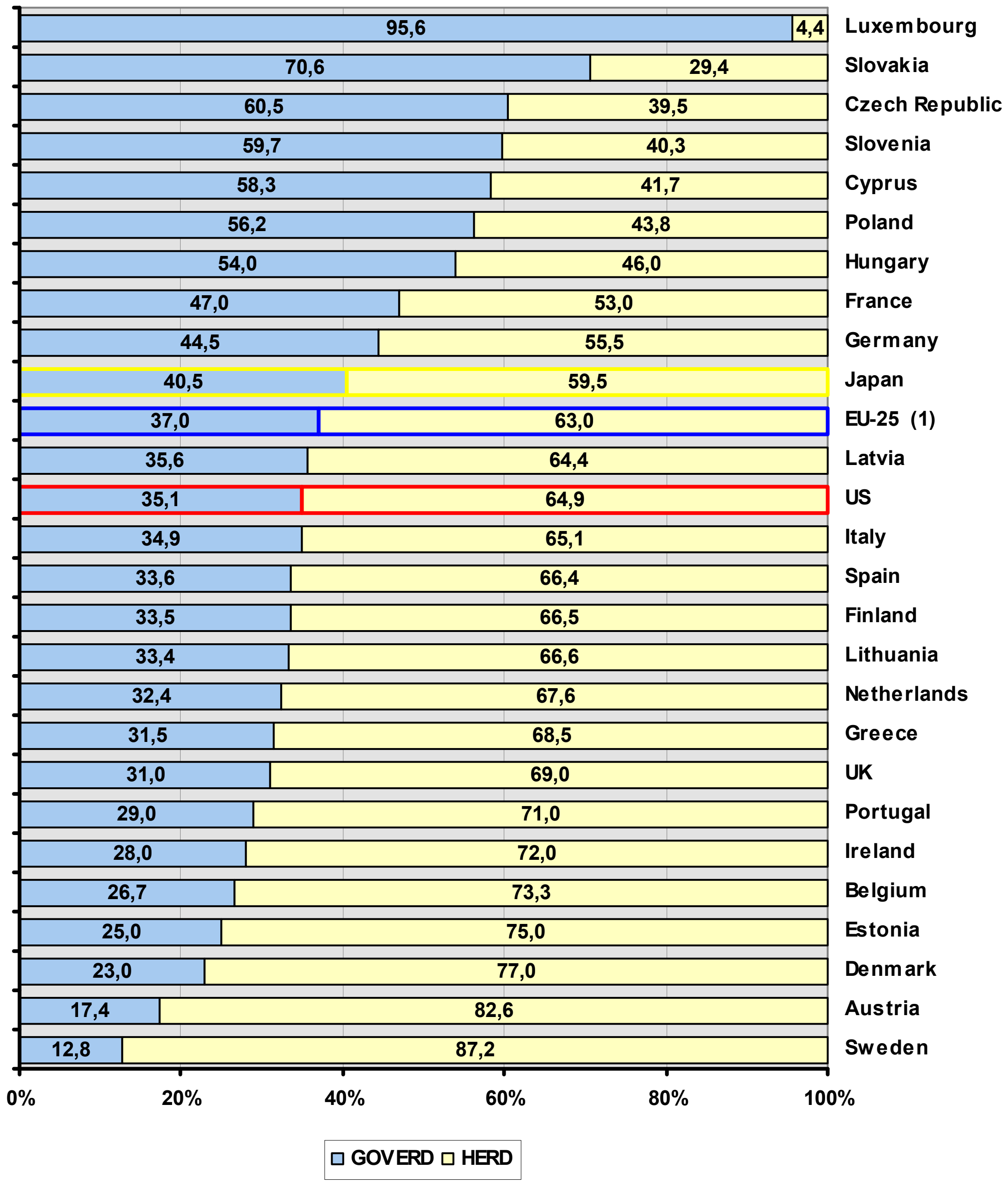
Source: DG Research — Key Figures 2005
Data: Eurostat, OECD
Notes: (1) LU, SE : 2001; AT, IE, IT, NL : 2002; BE : 2004.
(2) EU-25 was estimated by DG Research and does not include LU and MT.

In the EU, as well as in Japan and in the US, the intensity of R&D performed in the higher education sector is much higher than that of R&D executed in government institutions. In 2003 the latter reached 0.25% in the EU and 0.23% in the US, compared to 0.30% for Japan in 2002. In recent years, the intensity of government R&D has followed a downward trend in the EU while it has increased in the US and Japan from 1997 to 2003.

… But government R&D remains quite substantial in the new Member States

In the EU, there is a marked difference between the old and the new Member States where the organisation of public R&D is concerned. Whereas in the established EU Member States most public expenditure on R&D is executed by the higher education sector, in the new Member States (with the exceptions of Lithuania, Latvia and Estonia) a sizeable share of public R&D is performed in the government sector. An expansion of higher education R&D is required in these countries in order to facilitate more academic research and also to enable the training of more highly-skilled scientists and engineers for the business sector.

Figure 2.4.2 Shares of GOVERD and HERD in total public expenditure on R&D (%), 2003 (1)

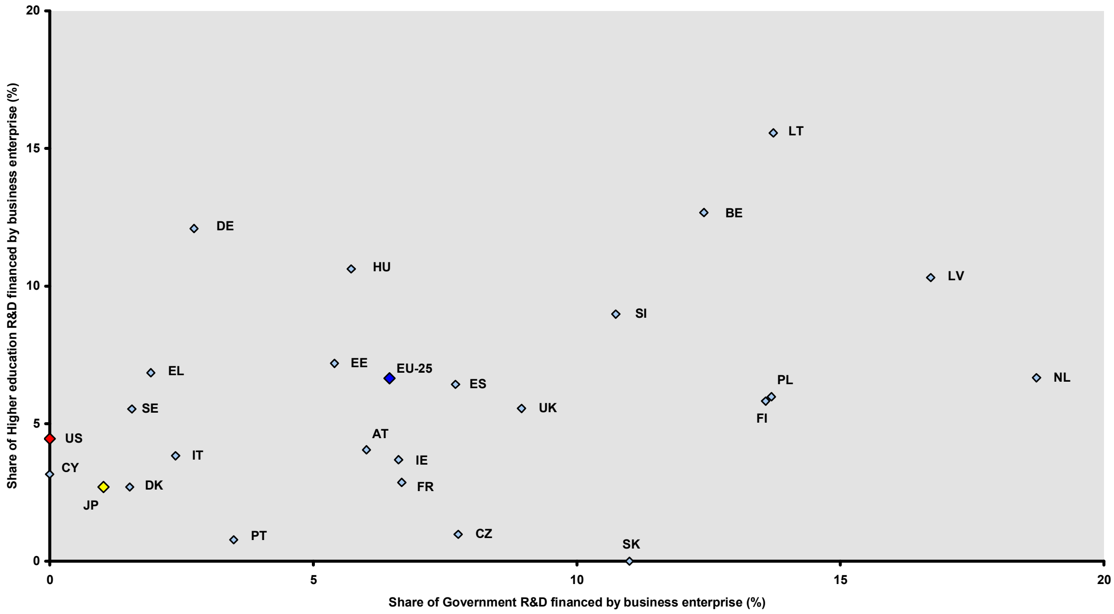


Source: DG Research Key Figures 2005
Data: Eurostat, OECD
Notes: (1) LU, SE : 2001; IE, IT, NL, AT : 2002; BE : 2004.
(2) EU-25 was estimated by DG Research and does not include LU and MT.

Firms are substantially financing public R&D

Business support for R&D in the higher education sector is substantially higher in the EU (6.6%) than in either the US (4.5%) or Japan (2.6%). In 2002, the differences between Europe and its competitors in the levels of government R&D funded by the business sector were even wider. In terms of growth rates, only Japan showed positive growth rates in the levels of the private funding in both public sectors. In Europe growth can only be witnessed in the level of higher education R&D financed by the business sector.

Figure 2.4.3 Shares of Goverment R&D and Higher education R&D financed by business enterprise (%), 2002 (1)



Source: DG Research Key Figures 2005
Data: Eurostat, OECD
Notes: (1) IT : 1996; BE, EL, PT, SE : 2001; CZ, DK, DE, ES, HU, PL, SK, FI, UK, US, JP : 2003.
(2) EU-25 was estimated by DG Research and does not include LU and MT.
(3) US : GOVERD refers to federal or central government only.

In Europe, the largest shares of government R&D financed by the business sector are found in the Netherlands and Latvia, in each case exceeding 15%. More than 10% of R&D performed in the higher education sector is funded by the business sector in Lithuania, Belgium, Germany, Hungary and Latvia. Hungary also enjoyed the highest growth rates between 1997 and 2002 with more than 30%. Among the most important R&D performing countries, France and the UK show a stronger business support for government R&D while Germany's business enterprise sector prefers to fund higher education R&D.

2.5. Human resources for science and technology

Neither R&D - nor other S&T activities - are possible without human resources. If the R&D expenditure target of 3% of GDP is to be achieved, ensuring that there are sufficient human resources for research is a preliminary step in the right direction. To this end, the European Commission advocates increasing the proportions of researchers in the labour force from six to eight per thousand[14]. This section first analyses the current level and growth of the EU's S&T labour force by examining recent developments in the numbers of researchers, and the size and age structure of the S&T workforce. It then looks at factors influencing the expansion of the stock of human resources, examining both the supply (investment in education, numbers of graduates, the participation of women) and demand (attractiveness of research careers) sides of the equation.

Box 5 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 a 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 a S&T field of study and are employed in a S&T occupation.

2.5.1. *The S&T labour force in the EU*

The pool of researchers is much smaller than in the US and Japan …

In 2003, the number of full-time equivalent (FTE) researchers per one thousand labour force was only 5.4 in the EU, compared to 10.1 in Japan and 9 in the US. Despite this gap between the EU and its main competitors, the number of researchers per one thousand labour force has been growing at an average annual rate of 2.8 % in the EU over recent years, much higher than the growth in R&D intensity.

Not surprisingly, Finland and Sweden - the countries with the highest R&D intensities - also have the highest numbers of researchers per one thousand labour force (more than 10) in Europe. The low R&D intensive countries such as the new Member States and the Southern European countries have smaller proportions of researchers. Many EU countries enjoyed a significant increase in the number of researchers in the labour force between 1997 and 2003, even though their R&D intensities increased only slowly or even declined in some cases. However, in Italy, Slovakia, Estonia and Lithuania, growth in the number of researchers per one thousand labour force has been either negative or relatively slow, especially when compared with their significant increases in R&D intensity in recent years.

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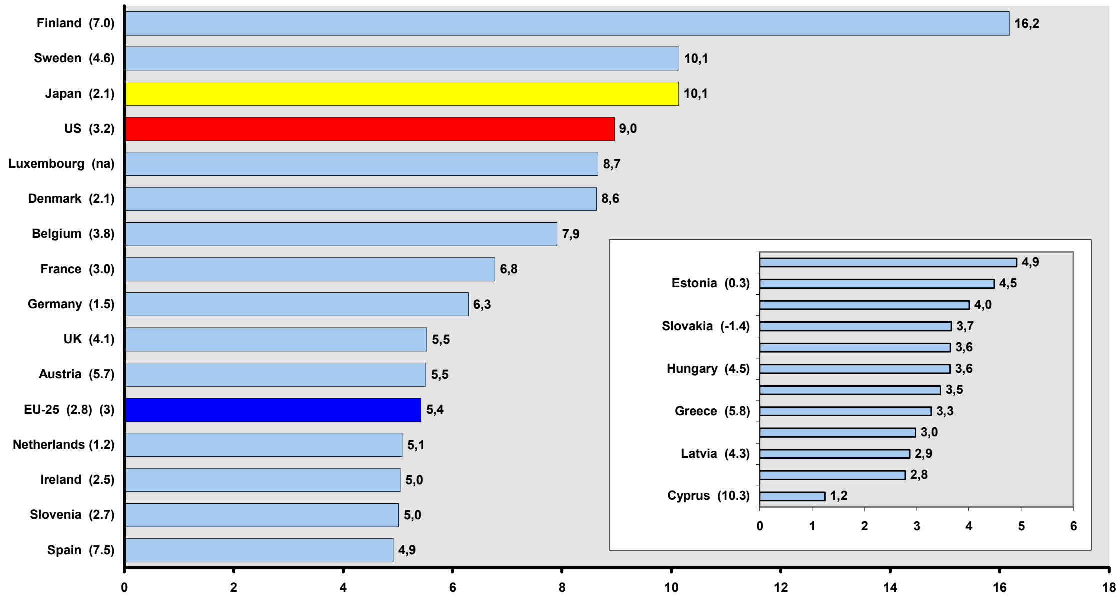
[14] European Commission (2004), "Science and Technology- The Key to Europe's Future"; COM(2004)353, Brussels

Figure 2.5.1.1 Number of researchers (FTE) per 1000 labour force, 2003 (1); in brackets : average annual growth rates (%), 1997-2003 (2)



Source: DG Research | Key Figures 2005

Data: Eurostat, OECD

Notes: (1) AT, UK : 1998; US : 1999; LU : 2000; EL, NL, SE : 2001; FR, IT, FI, JP : 2002; BE : 2004.
(2) AT : 1993-1998; UK : 1996-1998; US : 1997-1999; DK, EL, NL, SE : 1997-2001; FR, IT, FI, JP : 1997-2002; BE : 1997-2004; EE, CY : 1998-2003; IE : 2000-2003.
(3) EU-25 was estimated by DG Research and does not include LU and MT.

… Particularly in the business sector

Europe not only has a smaller pool of researchers than the US or Japan, the business sector, which accounts for the bulk of R&D performance, also has a lower share of researchers. In the US, four out of five researchers are working in the business sector as are two out of three researchers in Japan. In the EU, just under half of all researchers are working in the business sector, just over a third are working in higher education and most of the rest are working in government research institutions.

Within Europe, the share of researchers employed in enterprises varies between 6.7% in Lithuania and 85% in Luxembourg. Among the countries with high levels of expenditure on R&D, Germany has the highest share of business sector researchers (58.1%), followed by the UK (57.9%). Countries with low shares of R&D expenditure performed by the business sector - namely the new Member States and the Southern European countries - also have low proportions of business researchers. However, these countries have generally experienced higher than average increases in the proportions of business sector researchers since 1997.

Table 2.5.1.1 Researchers (FTE) by institutional sector

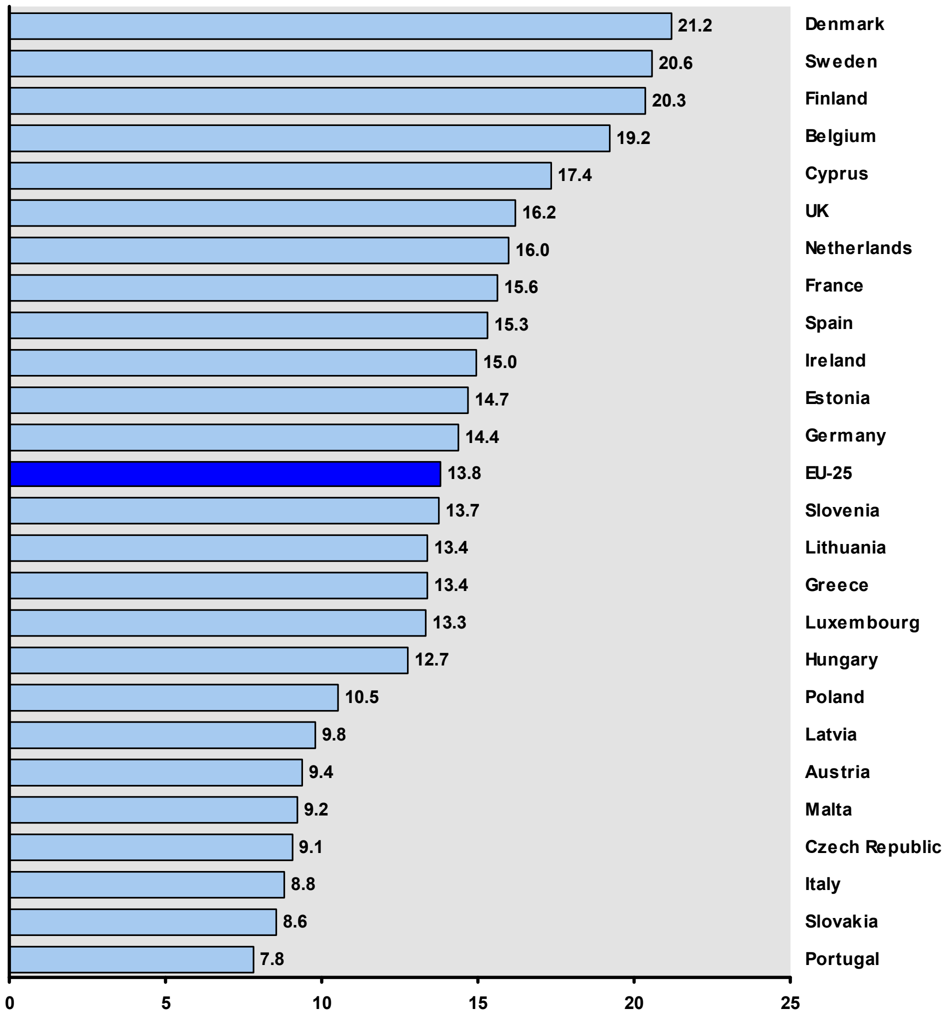
	Total Researchers 2003 (1)	in % by sector, 2003 (1)			Average annual growth rates of sectoral shares (%), 1997-2003 (2)		
		Business enterprise	Government	Higher education	Business enterprise	Government	Higher education
Belgium	36167	57.2	7.4	34.6	0.8	4.1	-1.8
Czech Republic	15809	41.5	30.6	27.3	0.3	-2.9	3.2
Denmark	25130	59.7	9.3	30.5	3.7	-3.4	-3.1
Germany	264721	58.1	14.7	27.2	0.5	-1.2	-0.4
Estonia	2976	15.6	16.1	66.3	9.8	-5.4	-0.7
Greece	14371	26.4	13.8	59.5	12.4	-6.6	-2.2
Spain	92523	29.8	16.7	53.2	1.5	-3.8	0.8
France	186420	51.1	12.9	34.1	1.6	-0.4	-1.9
Ireland	9386	63.8	6.4	29.8	4.7	-5.7	-4.6
Italy	71242	39.3	19.0	39.7	-1.3	-1.8	1.4
Cyprus	460	27.2	23.9	44.6	9.4	-7.0	0.2
Latvia	3203	14.5	16.1	69.4	8.3	-13.9	5.1
Lithuania	6606	6.7	25.5	67.8	26.4	-6.6	2.2
Luxembourg	1646	85.0	13.6	1.3	:	:	:
Hungary	15180	29.5	31.2	39.2	1.3	-1.9	0.7
Netherlands	43539	46.9	15.6	36.4	2.7	-1.5	-2.7
Austria	24124	66.3	4.1	28.9	1.5	-5.1	-2.4
Poland	58595	11.7	22.6	65.6	-8.5	1.2	1.8
Portugal	19766	19.4	16.2	51.4	14.2	-4.5	-1.1
Slovenia	4789	36.2	32.0	28.3	1.0	-1.4	-0.1
Slovakia	9626	19.9	25.3	54.8	-8.5	0.4	4.8
Finland	41724	56.6	11.3	31.2	1.4	-4.6	-0.6
Sweden	45995	60.6	4.9	34.5	1.7	-7.2	-1.5
UK	157662	57.9	9.1	31.1	1.0	0.6	-2.1
EU-25 (3)	1178237	49.0	13.4	36.5	0.9	-2.5	-0.2
US	1261227	80.5	3.8	14.7	0.8	-6.1	-2.1
Japan	675330	67.9	5.0	25.5	-0.4	0.8	1.6

Source: DG Research — Key Figures 2005
Data: Eurostat, OECD
Notes: (1) UK : 1998; US : 1999; LU : 2000; EL, SE : 2001; FR, IE, IT, NL, AT : 2002; BE : 2004.
(2) UK : 1996-1998; IE, NL, US : 1997-1999; DK, EL, ES, SE, JP : 1997-2001; FR, IT : 1997-2002; AT : 1998-2002; CY : 1998-2003, BE 1998-2004.
(3) EU-25 was estimated by DG Research and does not include LU and MT.

The ageing of the S&T labour force is becoming a concern in many Member States

The role of human resources educated *and* employed in S&T occupations (the 'highly-qualified S&T workers') in knowledge-driven economies is fundamental because they contribute directly to the expansion of R&D activities and to the development of technological innovations. The importance of this S&T labour force varies across Europe from more than one fifth of the labour force in Denmark, Sweden and Finland to less than one twelfth in Portugal. As one might expect, high R&D-intensive countries have the largest shares of core S&T workers in the total labour force.

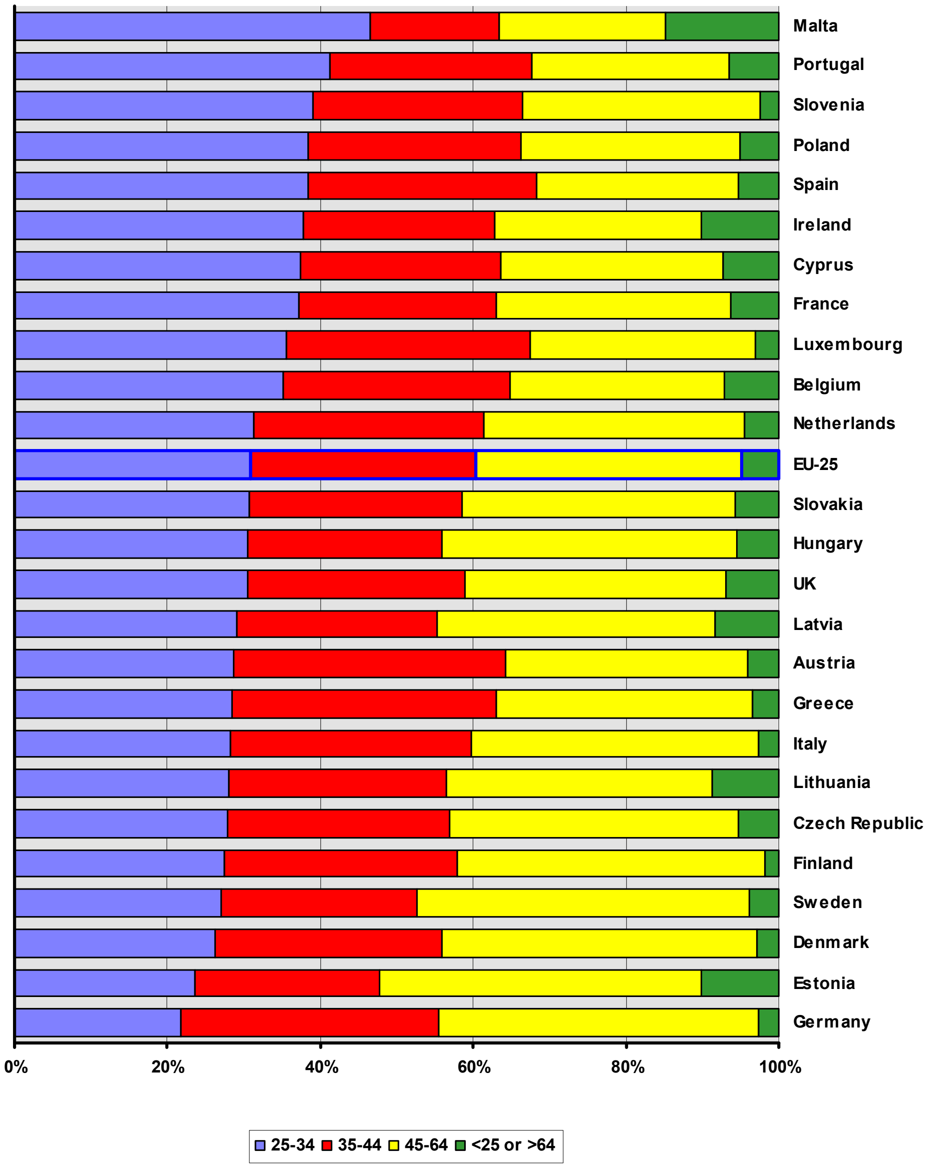
Figure 2.5.1.2 Highly-qualified scientific and technical workers (1) as % of total labour force, 2003 (2)



Source: DG Research Key Figures 2005
Data: Eurostat
Notes: (1) Highly-qualified scientific and technical workers refer here to the group of people educated AND employed in Science and Technology (HRSTC; see Box 5).
(2) NL : 2002

In several countries, concerns are rising about the ageing of the S&T labour force. In the EU-25 as a whole, about 35% of S&T workers were in the 45-64 year old age group in 2003, compared to 31% in the 25-34 age group. In Germany, Estonia, Denmark, Sweden and Finland the age distribution of the S&T workforce is skewed towards the older age groups. In these countries, more than 35% of the S&T workforce is aged between 45 and 64, while the youngest group represents only about 25% of the S&T workforce (only slightly above 20% in Germany). The situation is of particular concern in Estonia and Sweden because of the relatively low proportions of the 35-44 age group. These countries may face significant difficulties concerning the replacement of the retiring S&T labour force in the coming years. On the other hand, Belgium, Luxembourg, Portugal and Spain have the lower proportions of scientists and engineers in the 45-64 age group and the largest shares of scientists and engineers in the 25-34 age group.

Figure 2.5.1.3 Highly-qualified scientific and technical workers (1) - % distribution by age group, 2003 (2)



Source: DG Research — Key Figures 2005
Data: Eurostat
Notes: (1) Highly-qualified scientific and technical workers refer here to the group of people educated AND employed in Science and Technology (HRSTC).
(2) NL : 2002

2.5.2. Expanding the stock of human resources for science and technology

The global financial commitment to tertiary education is low in the EU ...

Investment in education, especially in tertiary education, is seen as a crucial factor for Europe's transition towards the knowledge-based economy since it impacts on the supply of new graduates. The enlarged EU, however, devotes a much lower share of its wealth to the financing of tertiary education than the US. In 2001, the EU spent 1.3% of its GDP on the financing of tertiary education compared to 3.3% in the US and 1.2% in Japan.

Although public funding of tertiary education is also higher in the US than in the EU, the most striking difference between the two regions concerns private expenditure. In relative terms, private expenditure on higher education is nines times higher in the US than in the EU. The difference between the EU and the US is less marked when one considers all levels of education and is entirely due to the private expenditure.

Within the EU-25, the level of private expenditure on tertiary education remains below 0.5% of GDP for all Member States with the exceptions of Cyprus (0.8%) and Latvia (0.5%). In terms of public expenditure, there are wide differences between the EU Member States. In 2001, the highest-spending countries were the Nordic countries, whose governments spent more than 2% of GDP on tertiary education, while amongst the lowest-spending countries – Czech Republic, Italy, Malta, Slovakia and UK – the percentage was between 0.8% and 0.9%.

Table 2.5.2.1 Public and private expenditure on education as % of GDP, 2001

	Tertiary education		All levels of education	
	Public expenditure	Private expenditure	Public expenditure	Private expenditure
Belgium	1.36	0.21	6.11	0.44
Czech Republic	0.80	0.13	4.16	0.41
Denmark	2.73	0.04	8.50	0.28
Germany	1.12	0.09	4.57	0.98
Estonia	1.07	:	5.48	:
Greece	1.19	0.00	3.90	0.23
Spain	1.01	0.30	4.41	0.59
France	1.02	0.16	5.76	0.48
Ireland	1.24	0.20	4.35	0.35
Italy	0.81	0.20	4.98	0.32
Cyprus	1.21	0.79	6.28	1.31
Latvia	0.90	0.54	5.75	0.70
Lithuania	1.34	:	5.92	:
Luxembourg	:	:	3.84	0.001
Hungary	1.11	0.26	5.15	0.57
Malta	0.88	0.02	4.47	0.85
Netherlands	1.32	0.28	4.99	0.45
Austria	1.35	0.06	5.70	0.32
Poland	1.07	:	5.56	:
Portugal	1.09	0.09	5.91	0.09
Slovenia	1.33	0.45	6.13	0.85
Slovakia	0.83	0.05	4.03	0.12
Finland	2.05	0.06	6.24	0.13
Sweden	2.05	0.20	7.31	0.21
UK	0.81	0.30	4.69	0.81
EU-25 (1)	1.08	0.20	5.10	0.60
US	1.48	1.77	5.08	2.22
Japan	0.54	0.61	3.57	1.17

Source: DG Research Key Figures 2005

Data: Eurostat

Note: (1) The values for EU-25 are estimations.

High public spending on education does not necessarily translate into a high level of public spending at the tertiary level. The EU allocated around 21.2% of total public expenditure on education to tertiary education in 2001 while this share amounted to 29.1% and 15.1% in the US and Japan, respectively. Among the EU countries, Finland, Denmark and Greece, with figures above 30%, had the highest share of total public expenditure on education allocated to tertiary education. Conversely, Italy, Latvia the UK and France, showed relatively low public support for tertiary education.

... But inflows of S&E graduates remain relatively high

The supply of human resources is best reflected in the numbers of new university graduates, particularly the graduates in Science and Engineering (S&E) and their share in the total number of graduates. In 2003, 24.2% of all degrees awarded in the EU were in S&E fields of study, a slight decrease from 1998. The corresponding figures for Japan and the US were 23.1% and 18.5% respectively. Absolute numbers of graduates are increasing in the EU and the US, particularly in science, but there have been fewer engineering graduates every year in Japan since 1999. Nonetheless, in comparison to the EU and the US, Japan produces a disproportionately high share of engineering graduates (20.1%) and a remarkably low share of science degrees (3.0%).

Table 2.5.2.2 S&E graduates (ISCED 5 and 6) as % of new degrees, 2003 (1)

	Share of new degrees (%)			
	Science	Engineering	Total S&E	Total S&E average annual growth rate (%) 1998-2003 (2)
Belgium	9,1	10,2	19,3	0,6
Czech Republic	7,9	16,6	24,5	-0,1
Denmark	8,5	11,3	19,8	0,3
Germany	9,4	17,0	26,4	-1,6
Estonia	7,9	9,3	17,1	-0,9
Greece	:	:	:	:
Spain	11,2	16,9	28,1	5,1
France	13,0	16,4	29,4	-0,9
Ireland	18,0	11,9	29,9	-1,4
Italy	7,6	15,3	22,9	-1,4
Cyprus	9,0	3,1	12,0	-3,8
Latvia	6,3	7,1	13,4	-7,0
Lithuania	5,0	17,4	22,4	-1,9
Luxembourg	10,7	3,8	14,6	-16,8
Hungary	2,9	8,3	11,2	-9,1
Malta	4,1	4,8	8,9	12,5
Netherlands	5,6	10,7	16,3	-0,8
Austria	7,0	21,4	28,4	-3,3
Poland	5,1	9,6	14,6	-0,6
Portugal	6,0	13,0	19,0	1,1
Slovenia	3,4	15,2	18,6	-4,8
Slovakia	8,8	15,3	24,1	2,7
Finland	7,4	21,4	28,7	2,4
Sweden	9,6	20,9	30,5	3,3
UK	17,0	8,8	25,8	-2,9
EU-25 (3)	11,0	13,2	24,2	-0,8
US	10,6	7,9	18,5	1,7
Japan	3,0	20,1	23,1	-1,5

Source: DG Research Key Figures 2005
Data: Eurostat
Notes: (1) LU : 2000; IT, FI : 2002.
(2) LU : 1998-2000; IT, FI : 1998-2002; CY : 1999-2003; BE : 2000-2003; UK : 2001-2003.
(3) EU-25 does not include EL, IT, LU and FI.

Within the EU, Sweden, France and Ireland generate the highest shares of S&E graduates. In these countries, S&E degrees account for around one-third of all degrees awarded. Conversely, the proportion of S&E degrees in relation to total degrees is rather low in Malta, Hungary and Cyprus. Since 1998, the proportion of all S&E degrees awarded has declined in no less than 16 Member States and there were only marginal increases in Belgium, Denmark and Portugal. Spain, Sweden, Slovakia and Finland had steady increase and the high rates of growth in Malta and Estonia are largely due to the small size of the graduate populations.

Women are under-represented in research

Although women constitute nearly half of the S&T labour force in the EU, they represent only between 17% and 35% of the researchers' population (depending on the sector in which they are employed). As researchers, women are particularly under-represented in the business sector. They are therefore an obvious resource to enlarge the pool of researchers in Europe. Because women have a huge potential for the future of R&D in Europe, many countries - including Finland, Germany and the Netherlands - have undertaken considerable effort to address this issue.

Table 2.5.2.3 Female researchers as % of all researchers (HC (1)), 2002 (2)

	Business Enterprise	Government	Higher Education
Belgium	18.1	29.9	37.2
Czech Republic	19.7	32.9	34.9
Germany	11.7	23.7	22.4
Denmark	21.3	33.8	32.0
Estonia	23.4	60.0	43.4
Greece	23.9	38.5	38.1
Spain	24.8	42.4	37.0
France	20.9	31.9	33.0
Ireland	20.4	32.1	:
Italy	19.0	38.4	29.8
Cyprus	24.1	32.9	30.5
Latvia	48.2	54.8	52.2
Lithuania	32.7	49.2	48.0
Luxembourg	:	33.5	20.4
Hungary	23.7	38.2	35.3
Malta	:	51.5	:
Netherlands	9.3	:	27.3
Austria	:	:	:
Poland	28.2	42.9	38.9
Portugal	27.7	56.1	45.1
Slovenia	28.7	43.3	34.3
Slovakia	29.9	44.1	40.8
Finland	18.4	40.7	44.2
Sweden	25.1	:	39.9
UK	:	31.8	36.6
EU-25 (3)	17.5	34.8	34.9
US	:	:	:
Japan	6.0	11.5	20.0

Source: DG Research — Key Figures 2005

Data: Eurostat, WIS database

Notes: (1) FTE instead of HC : BE - Government, Higher Education; DE - All sectors; IE : Government.
(2) Business Enterprise - PL : 2000; BE, DE, EL, IE, IT, LU, NL, PT, SE : 2001. Government - BE, EL, PT : 2001.
Higher Education - IE : 2000; BE, DE, EL, IT, LU, NL, PL, PT, SE : 2001.
(3) The values for EU-25 were calculated by DG Research.

In almost all countries for which data are available, the share of women (in head count - HC) among all researchers was below 50% in 2002. The absence of women in R&D activity is particularly remarkable in Germany, where the female share of the population of researchers is about one third below average, and, to a lesser extent, in the Netherlands. This under-representation results from both exogenous (e.g. women-unfriendly working environments, in particular as regards the attractiveness of research careers) and endogenous factors (gender differences in study and career choices, especially vis-à-vis scientific fields).

Table 2.5.2.4 Female graduates (ISCED 5 and 6) as % of all graduates in S&E fields of study, 2003 (1)

	Science	Engineering
Belgium	31.7	19.3
Czech Republic	38.7	24.7
Denmark	30.6	30.1
Germany	34.9	17.2
Estonia	44.6	40.8
Greece	:	:
Spain	37.7	25.6
France	41.0	21.7
Ireland	45.3	18.7
Italy	52.9	27.2
Cyprus	47.2	26.5
Latvia	46.8	29.9
Lithuania	47.8	32.2
Luxembourg	4.2	1.9
Hungary	33.2	24.3
Malta	35.7	18.4
Netherlands	29.3	12.8
Austria	33.8	16.9
Poland	51.0	23.8
Portugal	58.2	33.9
Slovenia	39.3	22.4
Slovakia	41.2	30.5
Finland	48.5	20.5
Sweden	46.4	28.6
UK	42.2	19.2
EU-25 (2)	41.0	22.1
US	41.4	19.2
Japan	25.6	12.7

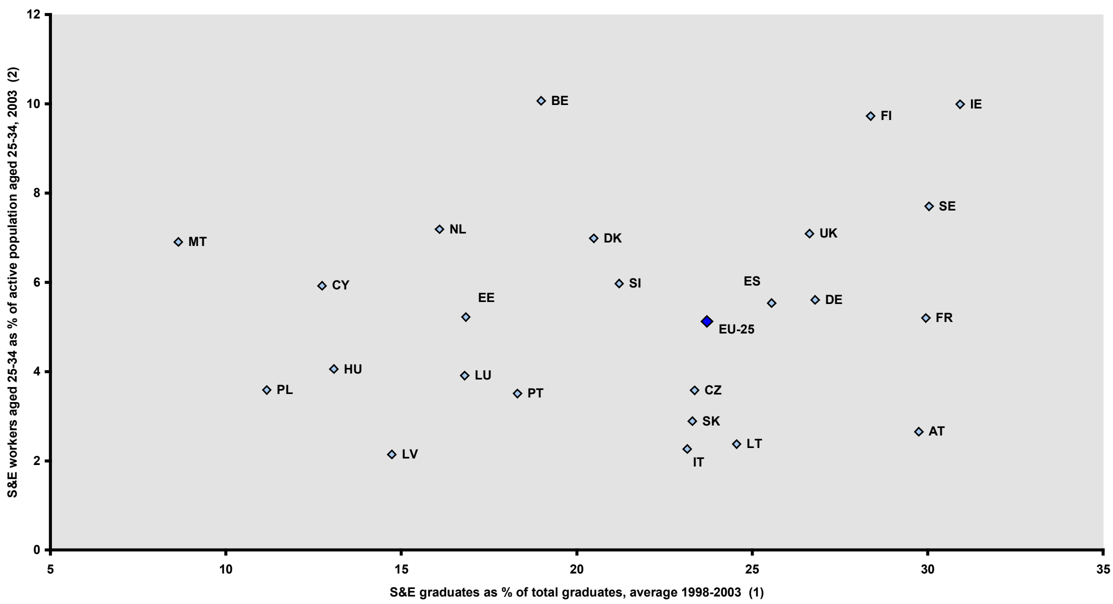
Source: DG Research — Key Figures 2005
Data: Eurostat
Notes: (1) LU : 1998; IT, FI : 2002.
(2) EU-25 does not include EL, IT, LU and FI.

In the EU, women remain seriously under-represented in the S&E fields of study, especially in engineering where they represent only 22% of all graduates. The situation in the US is comparable to the EU, whereas in Japan the under-representation is even more dramatic. Among EU Member States, the extent of this under-representation varies greatly. Estonia, Cyprus, Latvia, Lithuania and Poland, Italy and Portugal, as well as the high R&D intensive Sweden, award relatively more S&E degrees to women.

Improving the attractiveness of research careers

Making research careers more attractive is crucial to increasing the inflow of S&E educated people into research positions and S&E occupations. Comparing the proportion of S&E graduates in the total number of graduates (supply side) with the number of Scientists and Engineers (S&E workers) aged 25-34 as proportion of the active population of the same age (demand side) therefore helps to examine to what extent S&E educated people actually enter an S&E career in their country.

Figure 2.5.2.1 S&E graduates as % of total graduates in relation to S&E workers aged 25-34 as % of active population aged 25-34



Source: DG Research — Key Figures 2005
Data: Eurostat
Notes: (1) LU : 1998-2000; DK : 1998-2001; IT, NL, FI : 1998-2002; CY : 1999-2003; BE : 2000-2003; UK : 2001-2003.
(2) LU : 2000; DK : 2001; IT, NL, FI : 2002.
(3) EU-25 was estimated by DG Research and does not include DK, EL, LU and MT.

Most of the new Member States, as well as Italy, Portugal and Austria produce average to high shares of S&E graduates, but have relatively low levels of Scientists and Engineers in their active population, indicating that a non-negligible part of their S&E graduates opt for a non S&E career or for a job outside the country. These countries are characterised by relatively low R&D intensities and a relatively weak contribution by the business sector to R&D funding. Conversely, Finland, Ireland, Belgium, and to a lesser extent Sweden, are able to combine an average to high level of S&E graduates with a high level of S&E workers in their active population. Particularly Belgium seems quite successful at attracting S&E educated people into S&E positions. These countries generally combine high overall R&D intensities with a higher involvement of the business sector in the funding of R&D.

Beyond the characteristics and structure of the domestic economy, another factor is international migration flows. About 11% of the doctorates in Science and Engineering awarded to non-US citizens in the US, are awarded to European PhD-students, and this share has been growing since the late nineties. Nearly 60% of this group have firm plans to stay in the US after their PhD instead of returning to their country of origin. Moreover, that proportion has increased significantly over the past decade: from 44.5% at the beginning of the 1990s to 57.5% at the turn of the millennium. This increase is particularly striking for French recipients of US S&E doctorates: almost half of them now accept a post-doctoral research appointment or academic, industrial or other employment in the US after their PhD instead of returning home, against around 30% ten years ago.

Table 2.5.2.5 Non-U.S. citizens awarded doctorates in the sciences and in engineering, by country of citizenship and year of doctorate, 1997-2002

Country	Percentage of total foreign citizenship		Average annual growth rates 1997-2002 (%)
	1997	2002	
Total foreign citizenship	**100**	**100**	**-2.0**
Europe, total	**13.0**	**17.5**	**6.1**
EU-25	**9.3**	**10.7**	**2.8**
Belgium	0.2	0.2	0.8
UK	0.9	1.5	10.5
France	0.7	1.0	6.7
Germany	1.8	2.2	4.2
Europe, other	9.4	12.5	6.0
North America	**4.7**	**6.5**	**6.5**
South America	**4.0**	**4.7**	**3.3**
East Asia	**46.6**	**48.4**	**0.8**
West Asia	**19.6**	**16.8**	**-3.0**
Pacific/Australasia	**2.0**	**1.7**	**-2.7**
Africa	**3.4**	**3.3**	**-0.5**
Country unknown	**6.7**	**1.0**	**-31.0**

Source: DG Research   Key Figures 2005
Data: National Science Foundation, Division of Science Resources Statistics, Survey of Earned Doctorates

Europe does not succeed at retaining the best researchers. At the same time, Europe appears to hold much less of an attraction notably to US researchers while being a popular destination for scientists from the developing countries[15].

Table 2.5.2.6 Firm plans of foreign recipients of United States S&E doctorates to stay in the United States, by place of origin

Place of origin	Firm plans to stay		
	% share of foreign S&E doctorate recipients		
	1990–93	1994–97	1998–2001
All non-U.S. citizens	**40.9**	**43.3**	**54.1**
Europe	**44.5**	**47.9**	**57.5**
Greece	45.8	40.8	56.5
UK	57.7	59.5	62.4
Germany	43.0	44.6	52.4
Italy	36.5	31.9	49.8
France	29.4	32.0	48.4
Spain	38.5	45.7	40.8
Other	45.4	53.0	61.1
East / South Asia	**44.1**	**46.2**	**58.5**
Pacifica / Australasia	**33.1**	**28.7**	**43.1**
North / South America	**36.0**	**36.1**	**42.4**
Africa	**24.5**	**25.8**	**40.7**

Source: DG Research   Key Figures 2005
Data: NSF
Notes: (1) Data include foreign doctoral recipients who are either permanent or temporary residents. Recipients with firm plans to stay have a post-doctoral research appointment or academic, industrial or other firm employment in the United States.

15 Third European Report on Science and Technology Indicators 2003, p. 224.

3. PERFORMANCE OF THE KNOWLEDGE-BASED ECONOMY

3.1. Introduction

The aim of countries to maintain and develop their scientific and technological knowledge-bases, has led to an increasing focus on a number of indicators. These indicators relate to important questions such as: What is the share of knowledge-based industries in country x? What is the importance of a country in the overall production of scientific publications? What is the country's share of patents? These, among other indicators, capture the changing relationships between science and technology.

A country's performance in the knowledge-based economy is not measured simply by outputs of science and technology, but must also be judged in relation to the important goal of increasing its competitiveness. Indeed these different aspects of performance are closely linked. A competitive economy is increasingly understood as an economy able to achieve sustained rises in standards of living for its population at low levels of unemployment. The key determinant of competitiveness is labour productivity. Gains in labour productivity are the result of increasing human capital, capital deepening and technical progress or innovation as measured by total factor productivity. The degree of innovativeness is determined by firms' own R&D activities leading to new products or processes and by spill-over effects that magnify the benefits of own R&D efforts, but also by diffusion effects associated with imported technology and the presence of multinational firms.

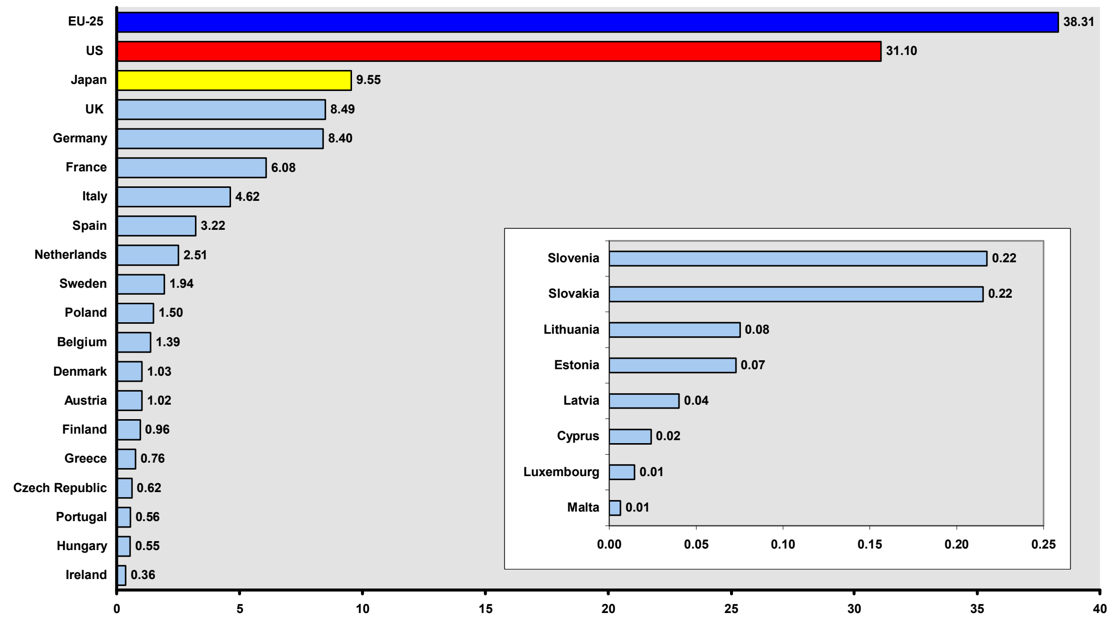
This part analyses the performance of European economies in their transition towards a knowledge-based economy from two perspectives. First, the performance of individual countries in terms of S&T output is examined. Second, the performance of the EU economies in terms of their ability to produce and sell high-tech products and in term of labour productivity growth is analysed. The analysis will mainly focus on the contribution of each sector to the productivity growth in both the EU and the US, taking into account the distribution of R&D investment across sectors and the specific industry structure in both economies.

3.2. S&T output

The EU leads in scientific output

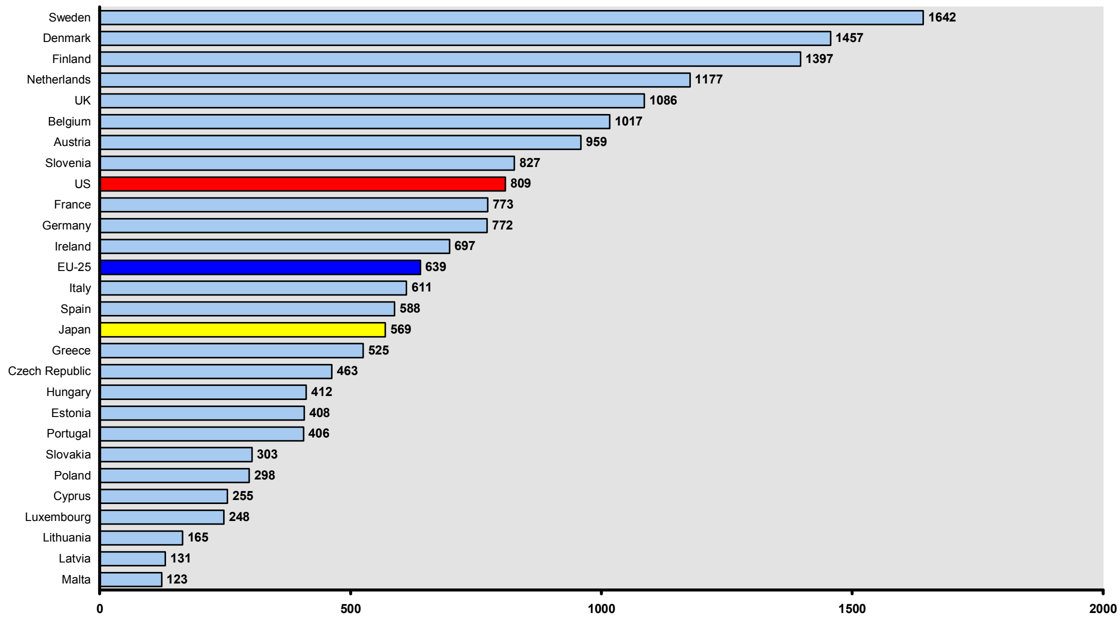
In terms of total number of publications as well as world share, the EU maintained a comfortable lead. Its world share in 2003 was 38.3% (showing a slight decline compared to 1997) whereas the US was responsible for 31.1% of the world scientific publication output. Japan, for its part, accounted for 9.6% of world scientific publications. Among individual EU Member States, the UK, Germany, France and Italy were the largest producers of scientific publications, with an aggregated world share amounting to 27.6%. These four countries accounted for more than 70% of the EU's scientific publication output in 2003.

Figure 3.2.1 World shares of scientific publications (%), 2003



Source: DG Research Key Figures 2005
Data: Thomson Scientific/CWTS, Leiden University

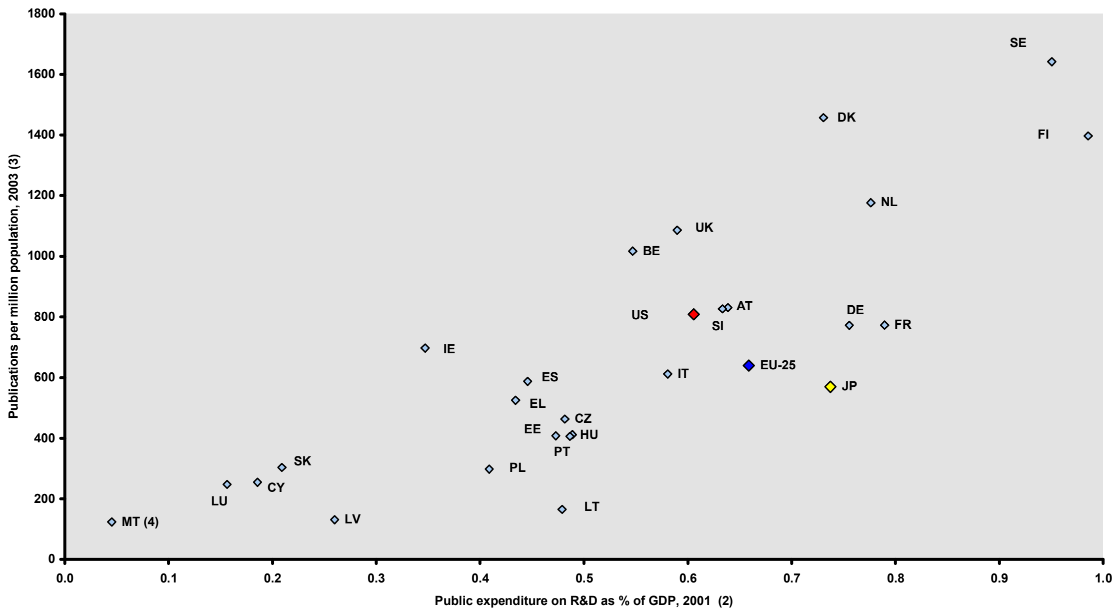
Figure 3.2.2 Number of scientific publications per million population, 2003



Source: DG Research Key Figures 2005
Data: Thomson Scientific/CWTS, Leiden University; OECD, Eurostat
Note : Population for US and JP was estimated.

Comparing Europe, the US and Japan in terms of the number of scientific publications per million population, the US leads with 809, followed by Europe with 639 and Japan with 569. Within Europe, the ratio was particularly high in the three Nordic countries. The new Member States can be found at the lowest end of the scale, except for Slovenia which performs well above the EU average.

Figure 3.2.3 Publications in relation to public expenditure on R&D (1)



Source: DG Research | Key Figures 2005

Data: Eurostat, OECD, Thomson Scientific/CWTS, Leiden University

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 publications per million population has been applied.

(2) MT : 2002; AT : 1998.

(3) AT : 2000.

(4) MT : Public expenditure on R&D does not include higher education expenditure on R&D.

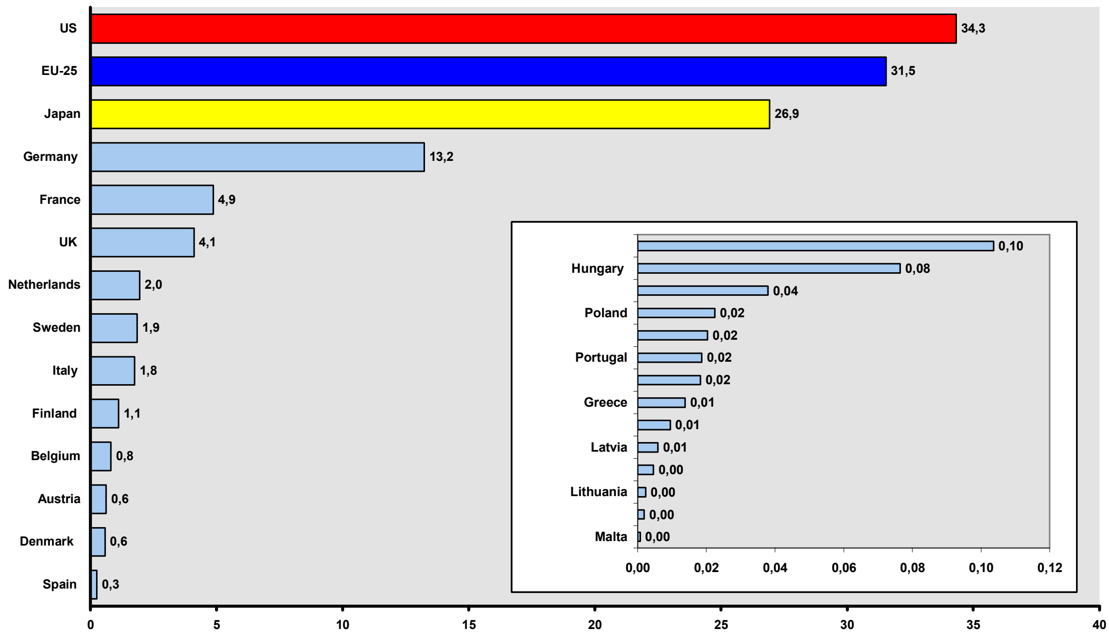
There is a strong positive relationship between the level of public expenditure on R&D relative to GDP and the number of scientific publications per million population across the EU countries, the US and Japan.

But the EU is failing in fully exploiting its scientific base

Triadic patent families refer to patent inventions for which protection has been sought at the three major patent offices: the European Patent Office (EPO), the US Patent and Trademark Office (USPTO) and the Japanese patent office (JPO). The extra protection is generally assumed to imply higher commercial returns. Furthermore, this measure irons out any bias in the output indicators introduced by patents that are only sought in their own region or by double-counting at the global level. They therefore provide a useful proxy for global technological output.

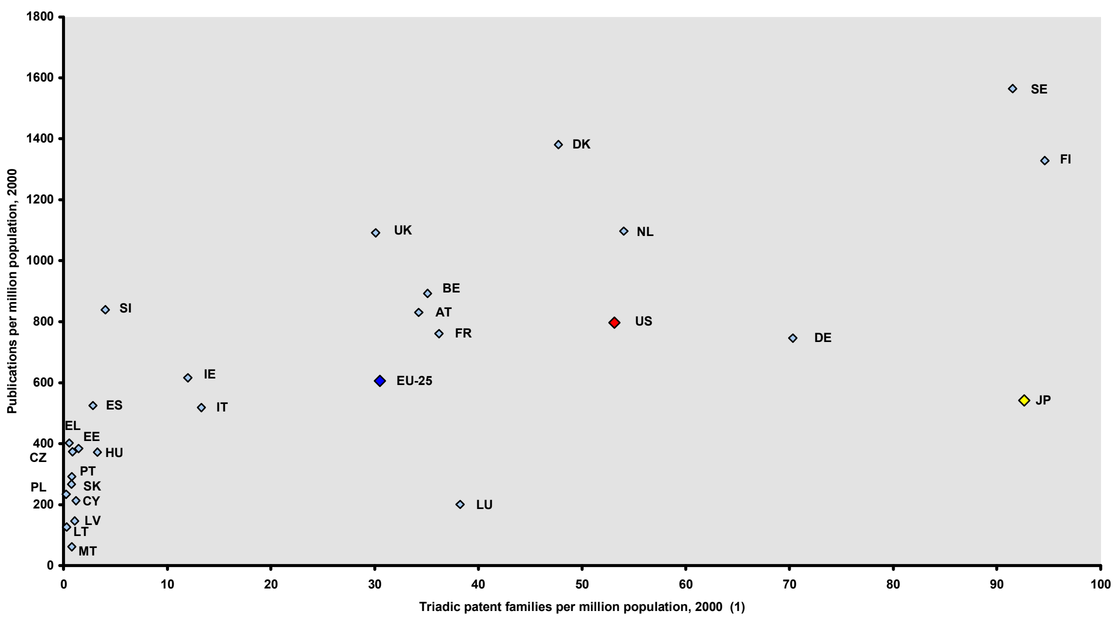
The US (34.3%) and the EU-25 (31.5%) accounted for nearly two thirds of triadic patent families in 2000. Japan accounted for a further 26.9%, implying that Europe and its two main competitors really dominate global technological output. However, only Japan increased its world share in technological output during the period 1997-2000. Within the EU, Germany enjoys a world share of 13.2% of triadic patent families, more than the shares jointly held by France, the UK, Sweden and Italy, but nevertheless a slight decline on its share in 1997. France and Sweden's world shares have also decreased over the same period, but the UK, Italy and Finland experienced increases.

Figure 3.2.4 World shares in total triadic patent families (%), 2000 (1)



Source: DG Research Key Figures 2005
Data: OECD
Notes: (1) Data by earliest priority date and country of residence of the inventors.

Figure 3.2.5 Triadic patent families and publications per million population, 2000

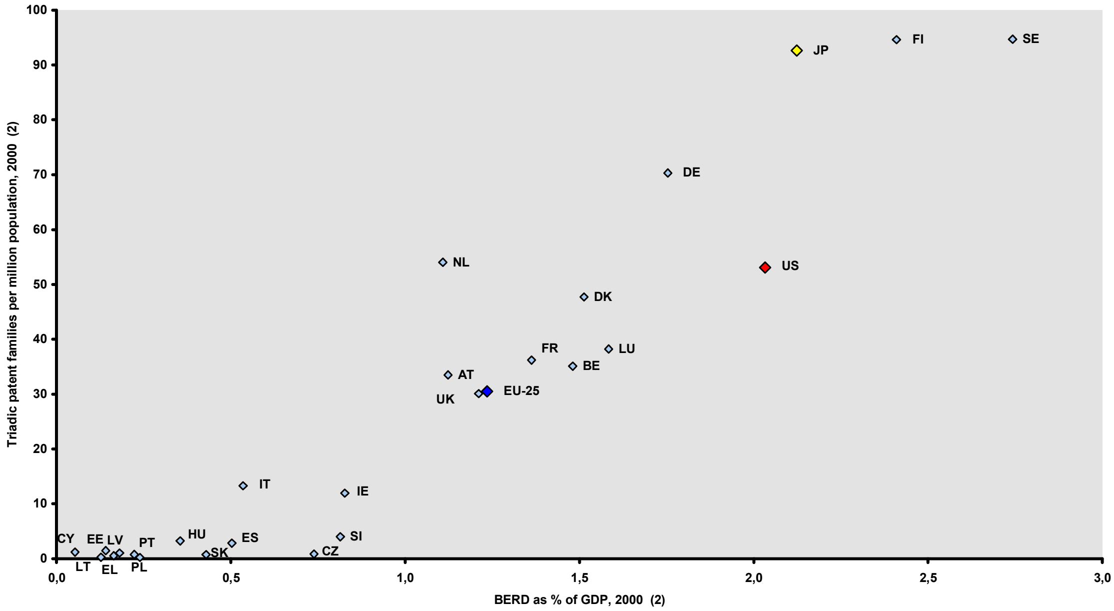


Source: DG Research Key Figures 2005
Data: Eurostat, OECD, Thomson Scientific/CWTS, Leiden University
Notes: (1) Data by earliest priority date and country of residence of the inventors.

When technological output is standardised by population size, a different picture emerges. Japan has the highest number of patents in total triadic patent families per million population (93) followed by the US (53) and EU-25 (31). In Europe, only Finland

and Sweden can keep pace with Japan. Germany and the Netherlands outperform the US. In contrast, no less than 13 Member States were producing less than 5 triadic patents per million population in 2000.

Figure 3.2.6 Triadic patent families (1) in relation to BERD as % of GDP



Source: DG Research Key Figures 2005
Data: Eurostat, OECD
Notes: (1) Data by earliest priority date and country of residence of the inventors.
(2) AT : 1998; SE : 1999.
(3) EU-25 does not include MT.

Countries with high levels of business R&D expenditure relative to GDP such as Finland, Sweden and Japan also have large numbers of triadic patent families per million population. In contrast, countries such as the new Member States show both low business R&D intensities and low numbers of triadic patent families per million population.

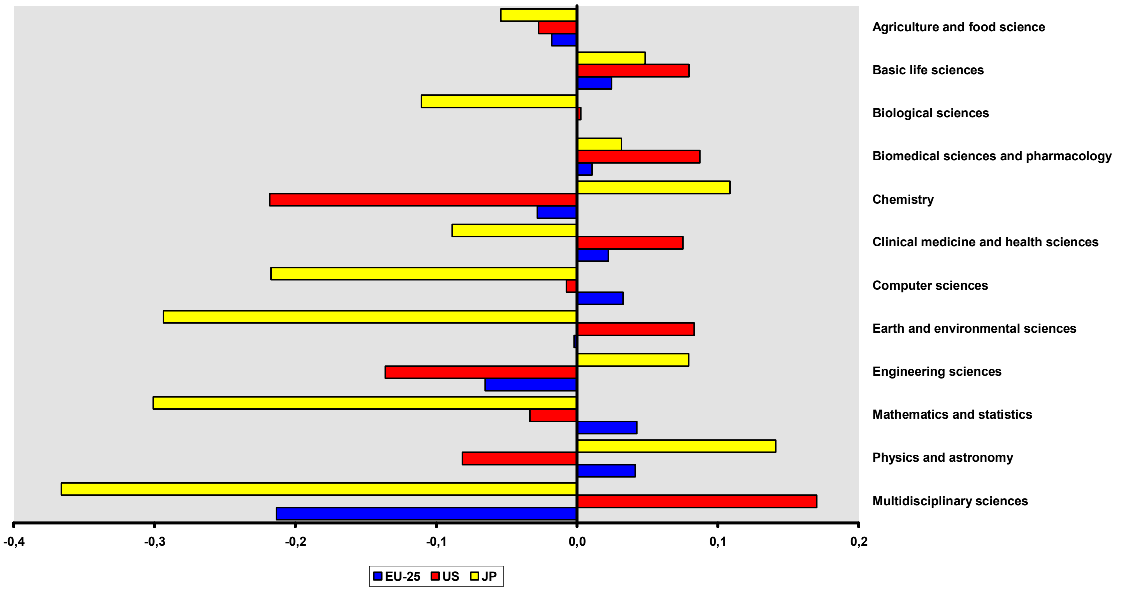
S&T knowledge bases are too diversified in several EU countries

In order to assess the relative scientific and technological strengths and weaknesses of regions and countries, it is useful to examine their scientific and technological specialisations. A region/country's level of specialisation in a given field of science or technology is measured by comparing the world share of the region/country in the particular field to the world share of the region/country for all fields combined (we refer to the 'share of scientific publications' for scientific specialisation patterns, and to the 'share of patents' for technological specialisation). The EU's scientific and technological output appears to be more diversified 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.

Compared to the US and Japan, the scientific capabilities of the EU are distributed evenly across all fields of science. 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.

Figure 3.2.7 Scientific publications - relative specialisation index, 2000-2003

EU-25, US, Japan

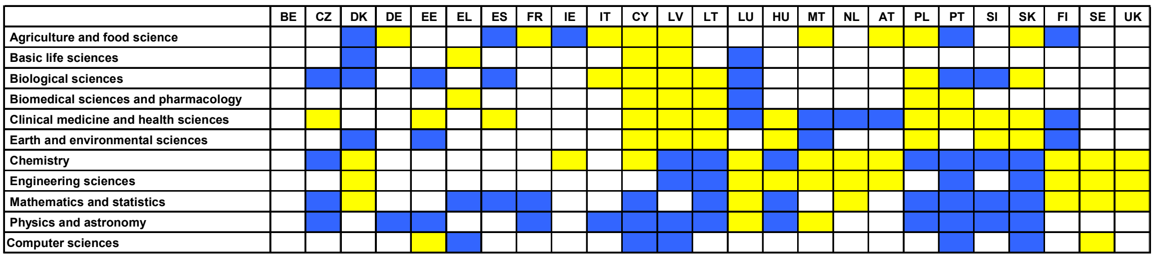


Source: DG Research

Key Figures 2005

Data: Thomson Scientific/CWTS, Leiden University

Figure 3.2.8 Scientific publications - relative specialisation index, 2000-2003



Yellow = under-specialised **Blue = specialised** **White = no specialisation**

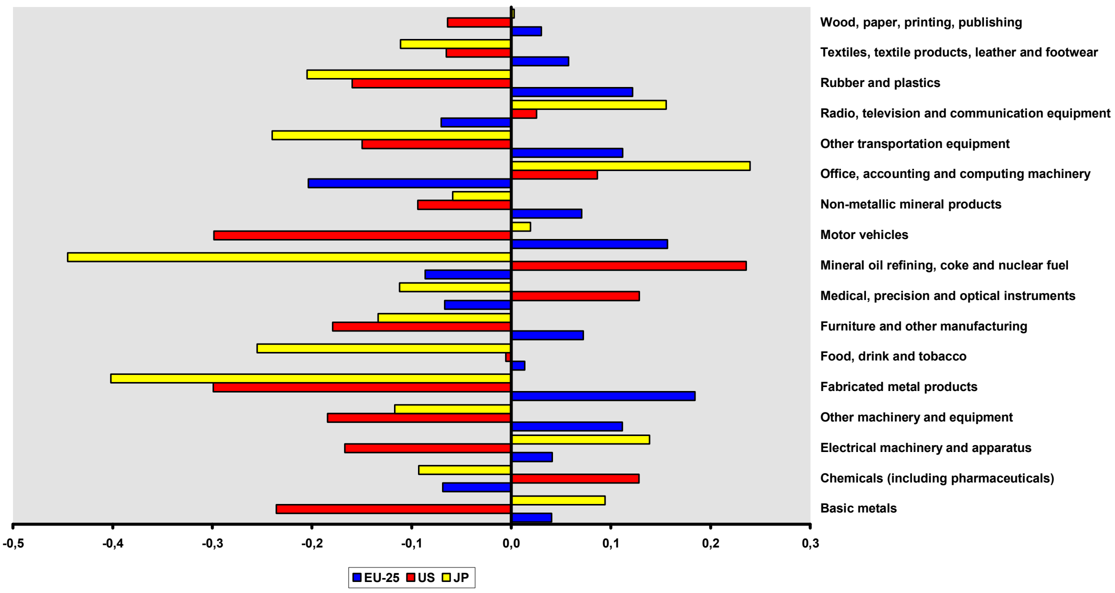
Source: DG Research
Data: Thomson Scientific/CWTS, Leiden University

The EU countries show diversity with regards to their scientific capabilities. Among the most active publishing EU countries, Germany is strong in physics and astronomy but is less involved in agriculture and food science; the UK is relatively under-specialised in chemistry, engineering sciences, and mathematics and statistics; France is active in mathematics and statistics as well as in physics and astronomy but is weak in agriculture and food science; finally, Italy shows under-specialisation in agriculture and food science and in biological sciences. With regard to the smaller (in terms of publications) EU countries such as Portugal and Slovakia, concerns may arise about the broad scope of their scientific efforts given the constraints imposed by their limited financial and human resources.

Compared to the US and Japan, the EU shows a technological specialisation in traditional manufacturing industries. Over the period 1997-2000, the EU specialised mostly in rubber & plastics, transportation equipment and motor vehicles, fabricated metal products and in other machinery equipment, whereas an under-specialisation in ICT manufacturing industries is revealed[16]. The US specialised mainly in ICT manufacturing industries and chemical-related industries. Japan primarily focused on electrical machinery & apparatus and ICT manufacturing.

Figure 3.2.9 EPO patent applications in the manufacturing sector - relative specialisation index, 1997-2000

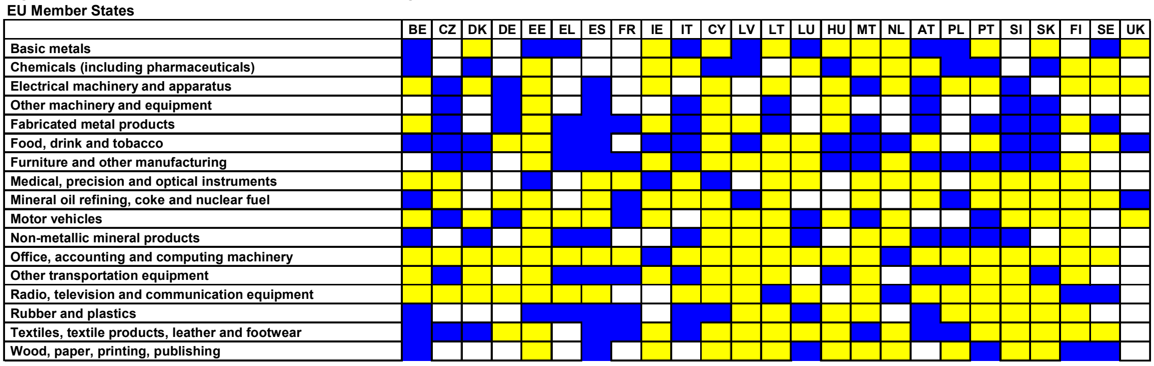
EU-25, US, Japan



Source: DG Research
Data: OECD

Key Figures 2005

Figure 3.2.10 EPO patent applications in the manufacturing sector - relative specialisation index, 1997-2000
EU Member States



Yellow = underspecialised **Blue = specialised** **White = no specialisation**

Source: DG Research
Data: OECD
Notes: (1) Data by earliest priority date and country of residence of the inventors.

Key Figures 2005

[16] "ICT manufacturing industries" refer to the following sectors: radio, television, and communication equipment; office, accounting, and computing machinery; medical, precision and optical instruments.

Technological specialisation is very diverse within the EU pointing to fragmented R&D efforts in Europe. Most of the new Member States have highly dissimilar specialisation profiles *vis-à-vis* the other EU countries. These country-divergences reveal in part substantial differences in industry structure.

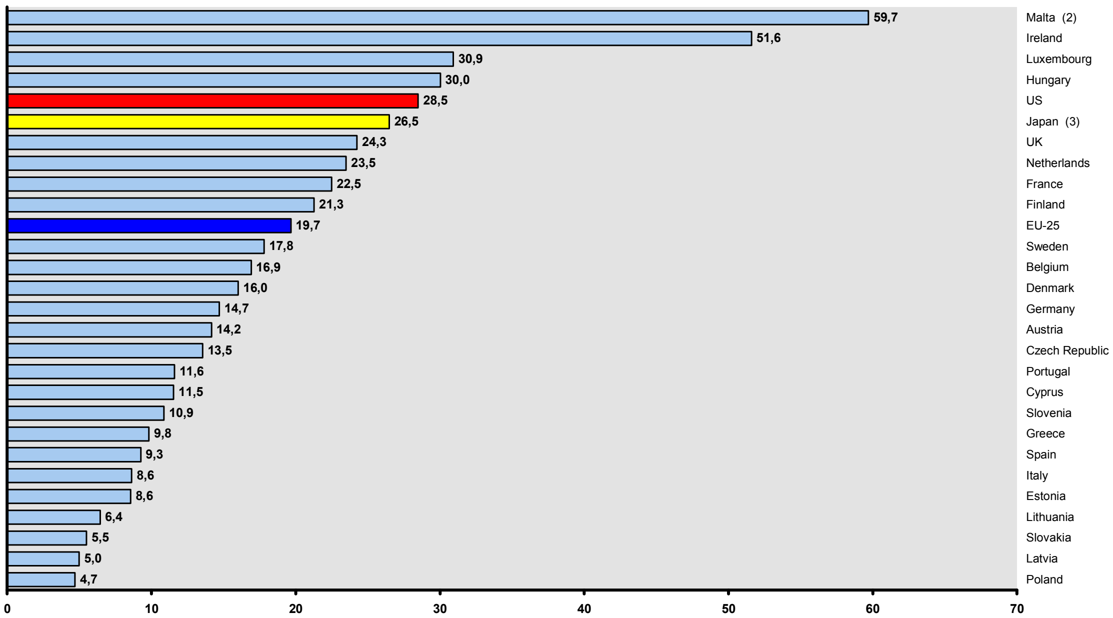
The degree of technological diversification varies sharply across the EU Member States and does not seem too dependent on their levels of R&D effort. Some low R&D spending EU countries – including Czech Republic, Greece, Poland, and Spain – exhibit high diversification which may impede their performance.

3.3. Industry, technology and competitiveness

Manufacturing exports are less technology-intensive in the EU than in the US and Japan

The relative strengths of European industry can be assessed by its ability to produce goods that find demand in the global marketplace. European competitiveness can therefore be gauged by examining trends in the market shares of EU high-tech industries in international trade.

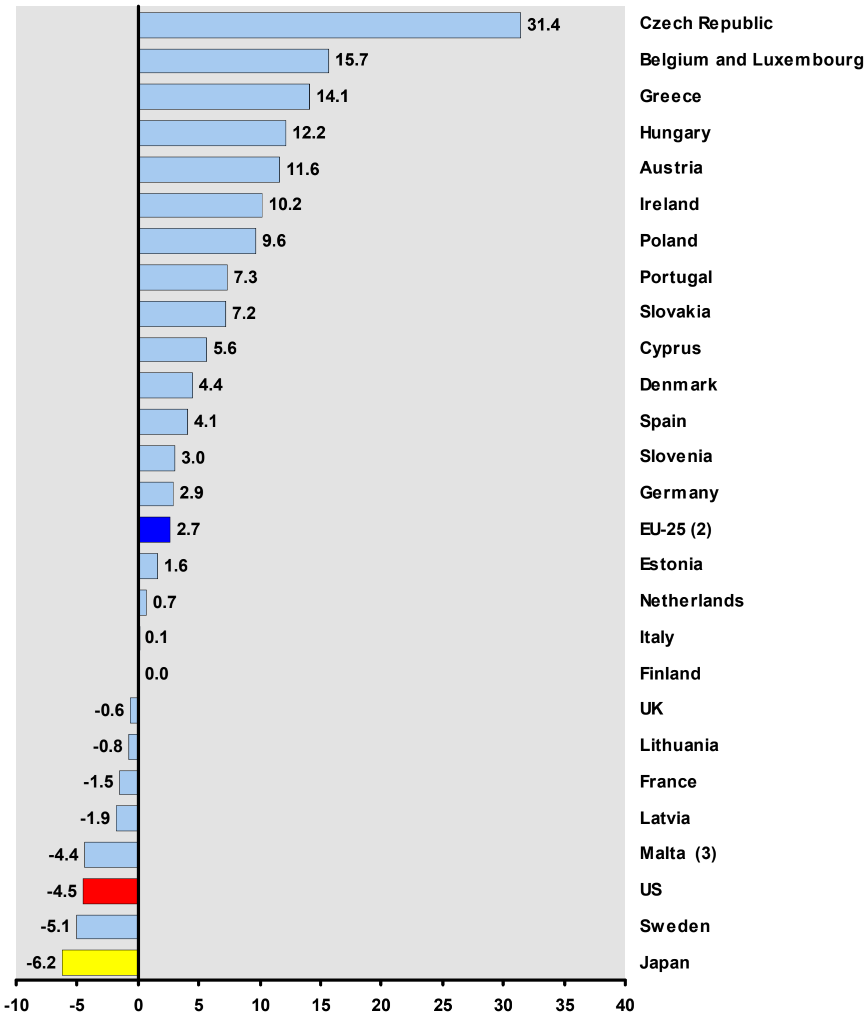
Figure 3.3.1 High-Tech manufacturing industries - exports as % of total manufacturing exports, 2003 (1)



Source: DG Research Key Figures 2005
Data: Eurostat (Comext), UN (Comtrade)
Notes: (1) The value for EU-25 does not inlcude intra-EU-25 exports.
(2) Data for MT refer to 2001.
(3) Data for JP refer to 2002.

In 2003, manufacturing exports were less technology-intensive in the EU than in the US and Japan. High-tech industries accounted for about 20% of total EU manufacturing exports, while they represented more than 25% of total manufacturing exports in Japan and the US. Within the EU, manufacturing exports are largely technology-intensive for Malta, Ireland, Luxembourg and Hungary

Figure 3.3.2 High-Tech manufacturing industries - world market shares of exports - average annual growth (%), 1997-2002 (1)



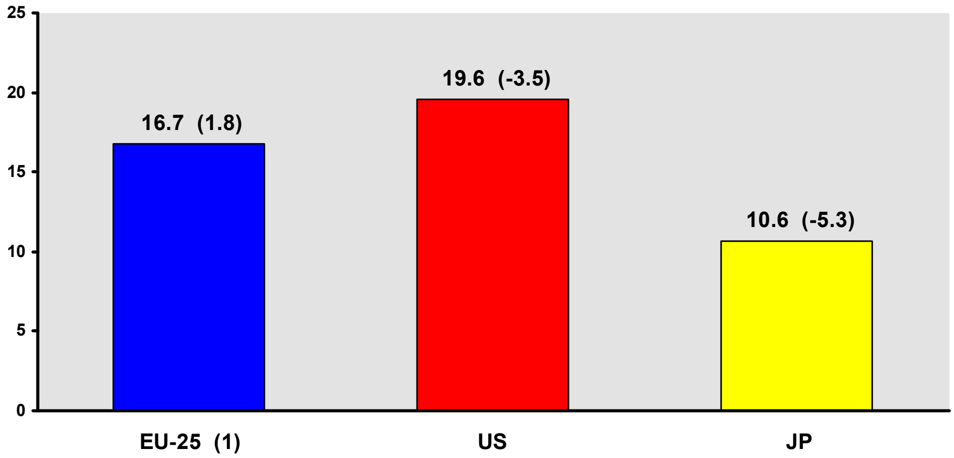
Source: DG Research Key Figures 2005

Data: Eurostat (Comext), UN (Comtrade)

Notes: (1) All data include intra-EU-25 high-tech exports and the world market refers to total world high-tech exports including intra-EU-25 exports.
(2) EU-25 does not include MT.
(3) Data for MT refer to 1996-2001.

In 2002, US high-tech industries accounted for more exports at world level than the EU or Japan, *i.e.* nearly 20% in comparison to 16.7% and 10.6%, respectively. However, the world export share of EU high-tech industries increased by 1.8% annually from 1997 to 2002, whereas the shares of Japan and the US followed downward trends. The positive trend in Europe seems primarily due to the development of high-tech production in the new Member States: a positive effect of enlargement, with also positive spill-overs on older Member States, which are all out-performing the US apart for the case of Sweden. Not surprisingly, the largest EU R&D spending countries - namely the UK, Germany and France - had high world export shares for their high-tech sectors. Nonetheless, a few smaller European countries such as the Netherlands, Ireland and Belgium also accounted for a healthy share in world high-tech exports. Moreover, over the period 1997-2002, the most significant growth in high-tech manufacturing exports was enjoyed by several medium-sized countries with average R&D intensity.

Figure 3.3.3 High-Tech manufacturing industries - world market shares of exports excluding intra-EU-25 trade (%), 2002; in brackets : average annual growth rates, 1997-2002



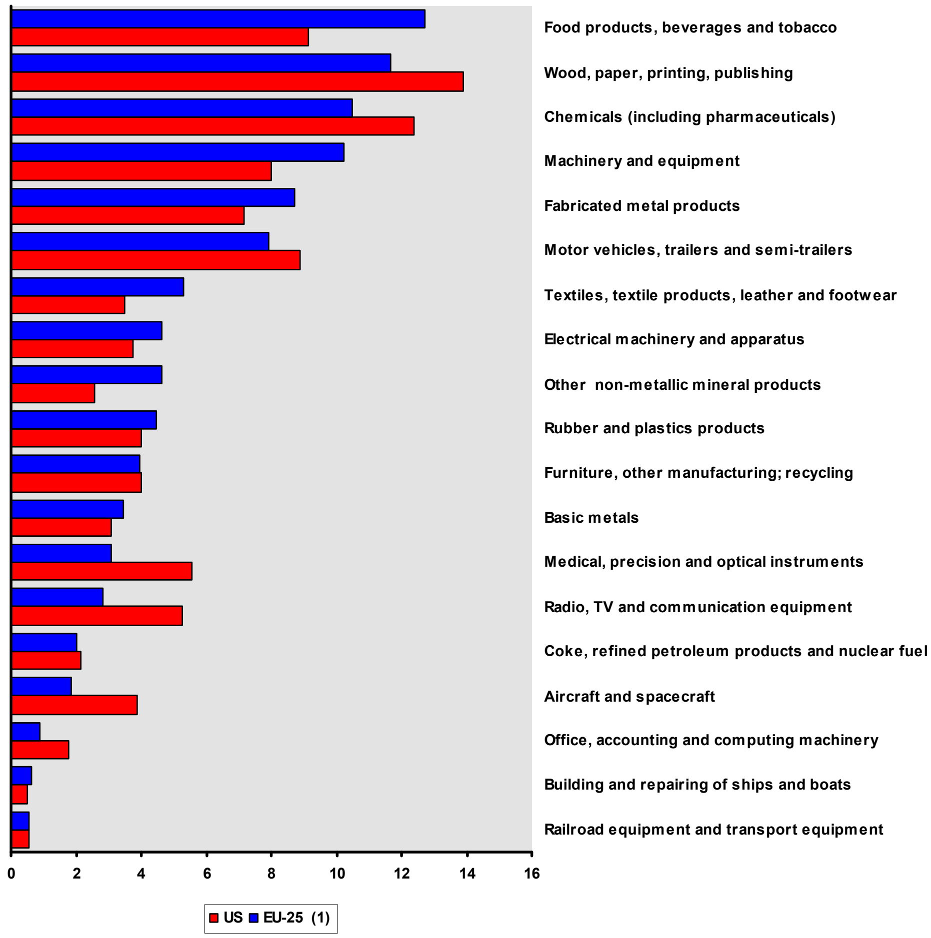
Source: DG Research — Key Figures 2005
Data: Eurostat (Comext), UN (Comtrade)
Notes: (1) EU-25 does not include MT.

While the US and Japan have a structural trade surplus in high-tech manufacturing industries, the EU is characterized by a structural trade deficit in these industries. Within the EU, only Malta, Ireland, Finland, the UK, Sweden, Slovenia and to a lesser extent France have a structural trade surplus in high-tech manufactures in 2003. However, the situation in most of the other Member States has improved since 1997.

The EU-US R&D investment gap at the sectoral level

There is an R&D investment gap between the EU-25 and the US. In 2003, total business R&D intensity amounted to 1.23% in the EU compared to 1.78% in the US. The business sector accounts for more than half of the R&D activity in the EU and the US economies and is responsible for about 80% of the R&D investment gap between the two regions. This difference in aggregated business R&D intensity between the EU and the US can be explained by two major factors: 1) the weight of the sectors in total value added (industry structure) and 2) the sector-specific business R&D intensities.

Figure 3.3.4 Manufacturing value added - % distribution by sector, 2002



Source : DG Research — Key Figures 2005
Data : Groningen Growth and Development Centre
Notes: (1) EU-25 does not include EE, CY, LV, LT, MT, SI.

In terms of industry structure, the service industries as a whole[17] contribute to around three quarters of total output in the US and the EU. In 2002, their share in total value added amounted to 76.7% in the US and 70.7% in the EU compared to 73.1% and 68.3%, respectively, in 1997. The share of ICT manufacturing industries[18] in manufacturing output is much bigger in the US than in the EU. These industries contributed to 12.6% of manufacturing value added in the US in 2002, while their share amounted to only 6.8% in the EU.

The total services sector accounts for one third of total business R&D in the US, in contrast to less than one fifth in the EU. The share of services in total business R&D was 34.4% in the US in 2000, a substantial increase on its level of 19.7% in 1997. The corresponding share for the EU was 15.7% in 2002 compared to 11.5% in 1997. The

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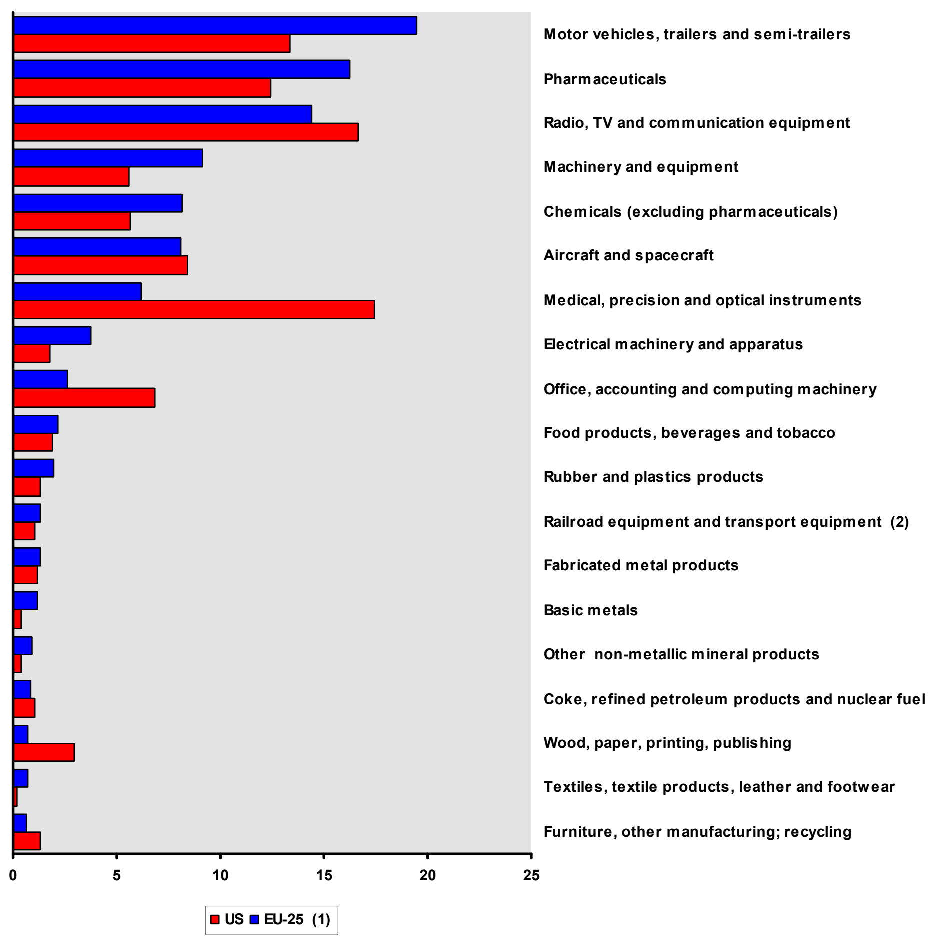
[17] Services cover the following activities: wholesale and retail trade, restaurants and hotels; transport and storage and communication; finance, insurance, real estate and business services; community social and personal services.

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

large and increasing share of business R&D expenditure on services, especially in the US and the EU, is mainly due to three factors:

1. an improvement of the measurement of services sector R&D[19];
2. a growth in R&D intensity in the services sector;
3. a strengthening of R&D outsourcing in both the business and government sectors[20].

Figure 3.3.5 Manufacturing BERD - % distribution by sector, 2002



Source : DG Research | Key Figures 2005
Data : OECD, Eurostat
Notes: (1) EU-25 does not include EE, EL, IE, LT, LU, AT, PT, SK.
(2) Building and repairing of ships and boats is included in railroad equipment and transport equipment.

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19 It is important to note that R&D at industry level in general is difficult to measure because R&D surveys are conducted at enterprise level and large R&D intensive firms such as IBM are classified according to their "primary activity", which is based on employment. IBM switched from being a manufacturing company in 1992 to being a services company. Thus, the share of services in total business R&D is overestimated in the case of US. Many more services in the EU than the US are provided by the public sector.

20 Services sector R&D, which for some countries can be significant, is for some other countries in reality, outsourced manufacturing R&D.

In comparison to the EU, R&D performed by the manufacturing sector in the US is heavily concentrated in ICT manufacturing industries. The share of these industries in US manufacturing R&D was 40.9% in 2002, well above the 23.2% level in the EU. This gap was mainly due to the 'medical, precision and optical instruments' industry, which in 2002 had a share of 6.2% of total manufacturing R&D in the EU compared to 17.4% in the US. The US also performed, in relative terms, more R&D than the EU in the 'wood, paper, printing, and publishing' industries. On the other hand, the EU had significantly higher shares of manufacturing R&D than the US in the 'chemicals', 'pharmaceuticals', 'machinery and equipment', and 'motor vehicles, trailers and semi-trailers' industries.

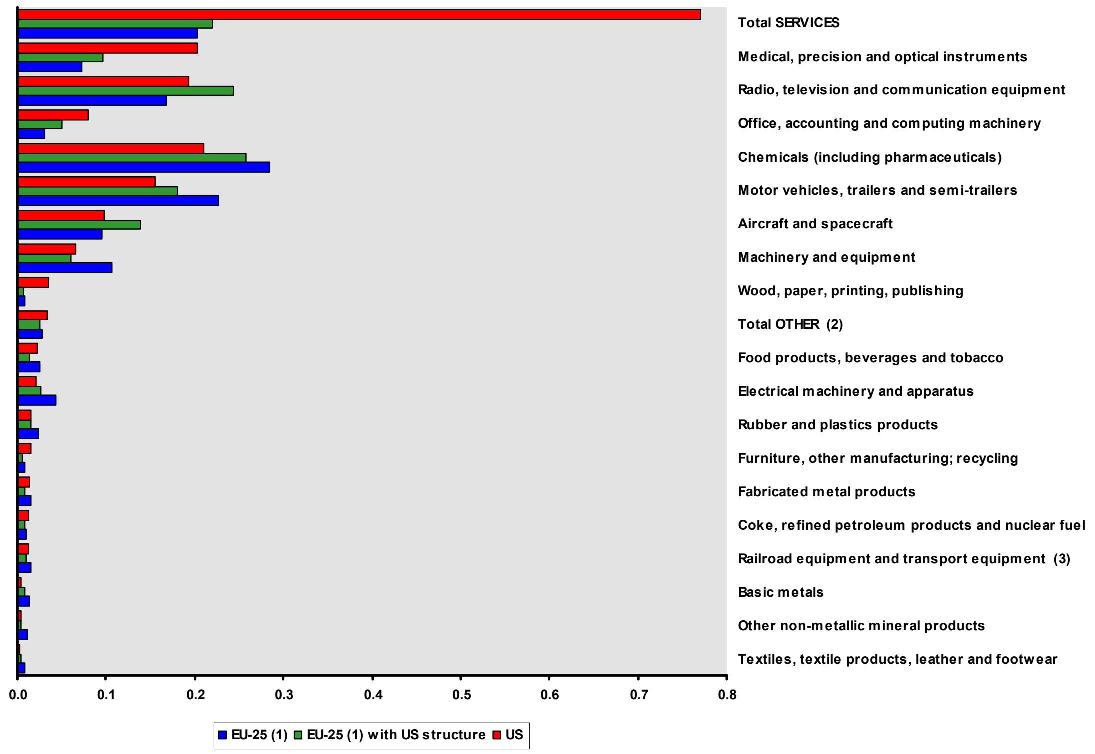
In order to investigate to what extent industry structure is likely to impact on total business R&D intensity, we have re-calculated, by means of a basic simulation exercise, the latter at EU level using the US industrial structure. Assuming that the EU[21] had the same industrial structure as the US in 2002 (the latest year available for such a comparison) and keeping the EU business R&D intensities unchanged at sector level, the total business R&D intensity (aggregated business R&D as a percentage of aggregated value added in each sector) at EU level would decrease slightly from 1.40% to 1.39%, well below the US value of 1.97%.

Admittedly, the conclusion of this basic simulation exercise should be interpreted with caution since it supposes, notably, that: *i)* the US industrial structure is not correlated to the distribution of R&D expenditure across the business sector; *ii)* the interactions between the manufacturing and services with respect to R&D activity are the same in the EU and in the US; and *iii)* measurement problems in the services sector in the EU and the US are not considered. However, such exercise has the advantage to stress the critical importance of R&D in the service sector and its contribution to overall business R&D intensity.

Assuming that the EU had the same industrial structure as the US, the most significant increase in the contribution of industries to total business R&D intensity in the EU would originate from the following sectors (in decreasing order of importance): 'radio, television and communication equipment'; 'aircraft and spacecraft'; 'medical, precision and optical instruments'; 'office, accounting and computing machinery'; and 'total services'. In particular, the contribution of the ICT manufacturing industries would rise from 0.27 to 0.39 percentage points, which would compare to 0.48 percentage points in the US. On the other hand, the contributions of several industries – especially, machinery and equipment, motor vehicles, and chemicals - to total business R&D intensity in the EU would decline.

21 In order to ensure comparability between the EU and the US in terms of value added and R&D expenditure at industry level, the EU refers to the following Member States: BE, CZ, DK, DE, ES, FR, IT, HU, NL, PL, FI, SE and UK. These countries account for the bulk of R&D effort in EU-25.

Figure 3.3.6 Industry contributions to total business R&D intensity in the US and EU-25 (1), 2002
in percentage points



Source : DG Research | Key Figures 2005

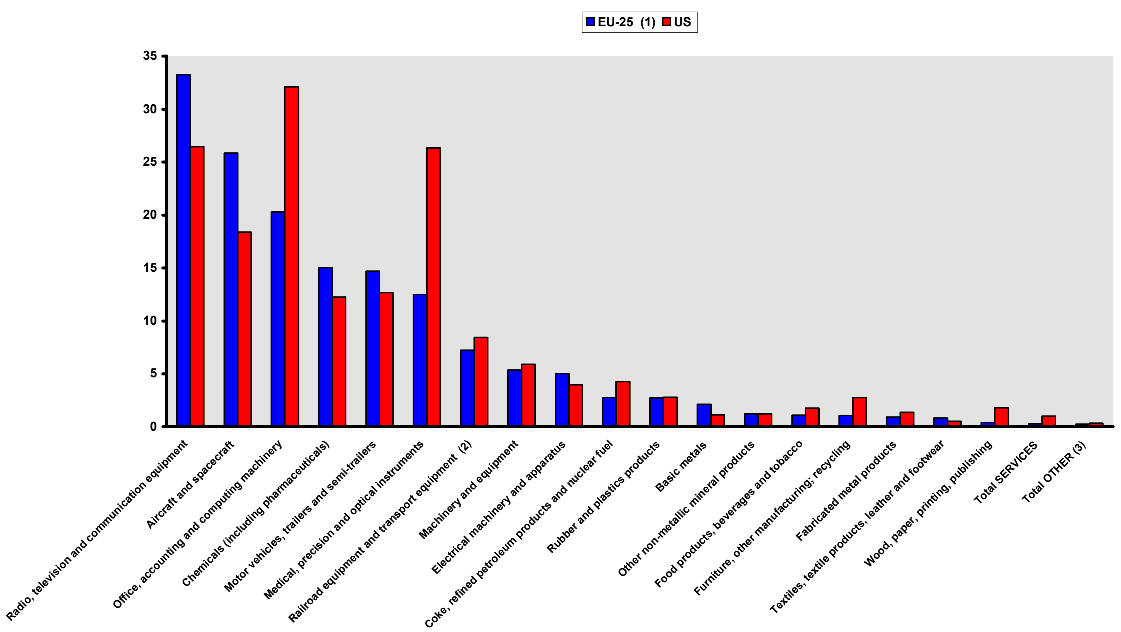
Data : Eurostat, OECD, Groningen Growth and Development Centre

Notes: (1) EU-25 does not include EE, EL, IE, CY, LT, LV, LU, MT, AT, PT, SI, SK.

(2) OTHER consists of the following sectors : Agriculture; Forestry; Fishing; Mining and quarrying; Electricity, gas and water supply; Construction.

(3) Building and repairing of ships and boats is included in Railroad equipment and transport equipment.

Figure 3.3.7 Business R&D intensity by sector, 2002



Source : DG Research | Key Figures 2005

Data : Eurostat, OECD, Groningen Growth and Development Centre

Notes: (1) EU-25 does not include EE, EL, IE, CY, LT, LV, LU, MT, AT, PT, SI, SK.

(2) Building and repairing of ships and boats is included in Railroad equipment and transport equipment.

(3) OTHER consists of the following sectors : Agriculture; Forestry; Fishing; Mining and quarrying; Electricity, gas and water supply; Construction.

Most of the EU-US R&D gap, therefore, stems from a low R&D intensive services sector, as well as, to a lesser extent, a smaller size and lower R&D intensity in the ICT manufacturing sector. In the US, the services sector contributes approximately 0.8 percentage points of total business R&D intensity, which is much higher than in the EU (where it accounts for 0.2 percentage points of total business R&D intensity).

Although both the interactions between manufacturing and services and the measurement of R&D activity in those sectors may differ in the US and the EU, these results tend to show, in line with other studies, the huge potential of the services in contribution to overall business R&D intensity and sub consequently the need to adapt R&D policy to the growing importance of services R&D[22]. Further studies on R&D in the services are nonetheless required to custom R&D policy to such sector.

ICT diffusion in Europe and the United States: explanation of the productivity growth gap?

The remarkable acceleration in labour productivity growth and multifactor productivity growth in the United States since the mid 1990s has been largely discussed over recent years. A general consensus has emerged that this acceleration can be attributabed to information and communication technology (ICT), suggesting that the "Solow paradox" ("we see computers everywhere but in the productivity statistics") has largely been resolved.

Empirical studies at aggregate, industry, and firm-level indeed stress three effects of ICT on economic growth and productivity.

Capital deepening

Investment in ICT can contribute to capital deepening by adding to the stock of capital that is available for workers and consequently helps raise labour productivity and growth.

ICT investment accounted for between 0.3 and 1.0 percentage points contribution to annual average GDP growth during 1995-2002 in the EU countries (for which data are available) and the United States. Sweden, the United States, Denmark and Belgium received the largest contribution of ICT investment to GDP growth while France, Germany and Italy were lagging behind.

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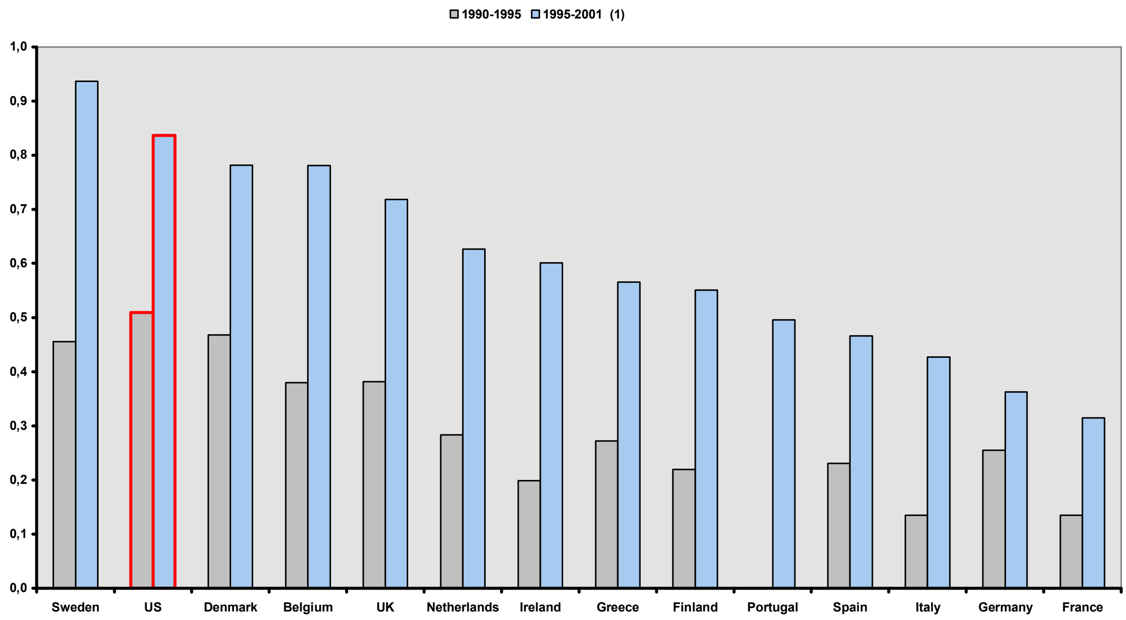
[22] OECD (2005), Enhancing the Performance of the Services sector, Paris: OECD; OECD (2004), Science, Technology and Industry Outlook, Paris: OECD; OECD (2001), Innovation and Productivity in Services, Paris: OECD.

Figure 3.3.8 Contribution of ICT investment to GDP growth in selected EU countries and the US (in percentage points)



Source: OECD Key Figures 2005

Data: OECD

Notes: (1) DE, FR, US, JP : 1995-2002.

Increased productivity in the ICT-producing sector

Rapid technical change in the production of ICT goods and services can contribute to acceleration in labour productivity growth in ICT-producing sector since a decline in the prices of these goods can lead to higher growth in real volumes. Moreover, since ICT goods are part of output, rapid technical change in the production of ICT goods can raise the growth rate of multifactor productivity, thus boosting the growth rate of labour productivity.

The contribution of ICT-producing manufacturing to labour productivity growth rose substantially in the 1990s. This reflects in part the growing share of the ICT manufacturing sector in total manufacturing but also acceleration in technical change in the production of some ICT goods. ICT-producing manufacturing made the largest contributions to labour productivity growth in Ireland, Finland, Sweden and the United States over 1996-2002. It role was nevertheless much more modest in Luxembourg, Spain, Italy and the Netherlands.

ICT-producing services contributed to labour productivity growth in the 1990s, although to a lesser extent than ICT-producing manufacturing. ICT-producing services boosted labour productivity growth in several countries such as Germany, Finland and Luxembourg. Such rising contribution is partly due to an increase in productivity growth thanks to both the liberalisation of telecommunications and acceleration in technical change and to the expansion of the computer services in several economies.

Table 3.3.1 Sectoral contribution to labour productivity growth in selected EU countries and the US, 1990-1995 (1) and 1996-2002 (2)
(total economy, value added per person employed, contribution in percentage points)

	Total economy		ICT - producing manufacturing (3)		ICT - producing services (4)		ICT - using services (5)	
	1990-1995	1996-2002	1990-1995	1996-2002	1990-1995	1996-2002	1990-1995	1996-2002
Belgium	1,90	0,78	0,03	0,13	0,12	0,05	0,47	0,17
Denmark	1,99	1,45	0,09	0,09	0,27	0,13	0,18	0,37
Germany	2,11	1,38	0,17	0,09	0,18	0,46	0,17	0,12
Spain	1,22	0,28	0,14	0,01	0,09	0,16	-0,17	-0,03
France	1,13	1,00	0,20	0,21	0,02	0,14	0,01	-0,17
Ireland	2,39	3,76	0,43	0,89	0,10	0,28	0,15	0,73
Italy	2,83	0,56	0,09	0,02	0,12	0,20	0,88	0,14
Luxembourg	2,08	0,51	-0,03	-0,01	0,74	0,32	1,13	-0,20
Netherlands	0,63	0,77	0,10	0,03	0,09	0,17	0,25	0,28
Austria	2,32	1,73	0,12	0,11	0,15	0,13	0,59	0,51
Finland	2,65	2,02	0,20	0,82	0,13	0,36	0,10	0,22
Sweden	2,95	2,67	0,27	0,51	0,24	0,22	0,45	0,60
UK	2,20	1,08	0,19	0,12	0,18	0,24	0,37	0,85
US	1,12	1,74	0,33	0,45	0,14	0,16	0,24	1,29

Source: Pilat D. and A. Wölfl (2004), "ICT production and ICT use: what role in aggregate productivity growth", in OECD, The Economic Impact of ICT, Paris

Key Figures 2005

Data: OECD

Notes: (1) DE : 1991-95; FR, IT : 1992-96.
(2) SE : 1996-98; ES : 1996-99; IE : 1996-2000; FR, UK, US : 1996-2001.
(3) ISIC Rev 3 30-33.
(4) ISIC Rev 3 64&72.
(5) ISIC Rev 3 71-74.

Increased productivity in the ICT-using sector

The impact of ICT is not limited to the ICT-producing sector but extend to the ICT-using sector.

The use of ICT effectively enables firms to increase their market share, expand their product range, customise the services offered, respond better to demand, reduce transaction costs and inefficiency in the use of capital and labour, or establish networks. A more intensive use of ICT can thus help firms enhance their overall efficiency and performance. In that respect, an increase in labour productivity growth in the ICT-using sector may be caused not only by a greater use of capital but also an increase in multifactor productivity.

Estimates emphasize the dramatic increase in the contribution of the ICT-using sector to labour productivity growth in the United States over the 1990s while its contribution remained quite limited in many EU countries such as Luxembourg, France, Spain, Germany and Italy.

The preceding developments show that Europe lags behind the United States in experiencing an increase in labour productivity growth especially in ICT-using services. The performance of the United States in the ICT-using services seems mainly due to major acceleration in labour productivity and output growth in distribution (retail and wholesale trade) and financial services. Moreover, evidence shows that the surge in multifactor productivity in the second half of the past decade does not only reflect acceleration in technical change in the production of ICT goods and services but also a major contribution of the ICT-using sector, primarily in retail trade and wholesale trade.

According to Triplett and Bosworth[23], "IT in services industries accounted for 80 percent of total IT contribution to US labour productivity growth between 1995 and 2001. As with labour productivity growth and multifactor productivity growth, the IT revolution in the United States is a services industry story".

Table 3.3.2 Average annual growth of labour productivity per hour worked of ICT and non-ICT industries in EU-15 and the US

	1979-1995		1995-2002	
	EU-15	US	EU-15	US
Total Economy	2,3	1,2	1,8	2,5
ICT Producing Industries	6,8	7,2	8,6	9,3
ICT Producing Manufacturing	11,6	15,1	16,2	23,5
ICT Producing Services	4,4	2,4	5,9	2,7
ICT Using Industries	2,3	1,6	1,8	4,9
ICT Using Manufacturing	2,7	0,8	2	2,6
ICT Using Services	2	1,9	1,7	5,3
of which :				
Wholesale Trade	2,4	3,5	1,5	8,1
Retail Trade	1,7	2,4	1,5	7,1
Financial Services	1,9	1,5	2,3	5
ICT-intensive Business Services	0,8	-0,9	0,6	0,7
Non-ICT Industries	1,9	0,4	1,1	0,2
Non-ICT Manufacturing	3,2	2,3	2,1	1,2
Non-ICT Services	0,8	-0,3	0,5	0,2
Non-ICT Other	3,4	1,4	2,1	0,4

Source: Van Ark B. (2005), "Does the Europan Union Need to Reive Productivity Growth?", Research Memorandum, GD-75, Groningen Growth and Development Centre Key Figures 2005
Data: Groningen Growth and Development Centre

Although there are marked differences between EU countries, several factors can explain why the European Union has not fully benefited from ICT such as the US: high costs of ICT investments, regulatory environments (e.g. product market competition) and lower capacity of absorption and propensity to innovate of firms (e.g. organizational change and skills). Such factors are key determinants for influencing ICT diffusion[24]. In other words, ICT *alone* is not the answer to elevate productivity growth. ICT use requires complementary investments, in particular investment in intangible assets, and more generally, adequate framework conditions.

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[23] Triplett J. and B. Bosworth (2004), Productivity in the US Services Sector: New Sources of Economic Growth, Brooking Institution Press, Washington DC

[24] In addition, measurement problems in services and productivity may underestimate the impacts of ICT.