HIGHLIGHTS

Creation, diffusion and use of knowledge are increasingly important to OECD economies

Structural changes in OECD economies reflect the growing weight of the production, diffusion and use of knowledge.

A range of indicators show the growing importance of knowledge to OECD economies. Investment in information and communication technologies (ICT), which are crucial to the knowledge-based economy, has increased considerably in recent years and in 1997, represented 4% of OECD GDP. In the second half of the 1990s, the diffusion of ICT accelerated with the emergence of the Internet, although considerable differences among countries remain. Investment in intangible assets – education, R&D, software – is also strong. Education is important, as the new technologies require skilled workers. Over the past generation, the proportion of adults with at least a secondary education level rose from 44% to 72% of the total OECD population and the share of adults with at least a tertiary education level doubled, from 22% to 41%. The share of knowledge-based sectors in value added and employment also continues to rise. In 1997, they accounted for around 50% of total value added in Australia, the European Union and the United States, considerably above their share in 1985.

OECD economies devote more resources to generating and diffusing knowledge, as measured by R&D.

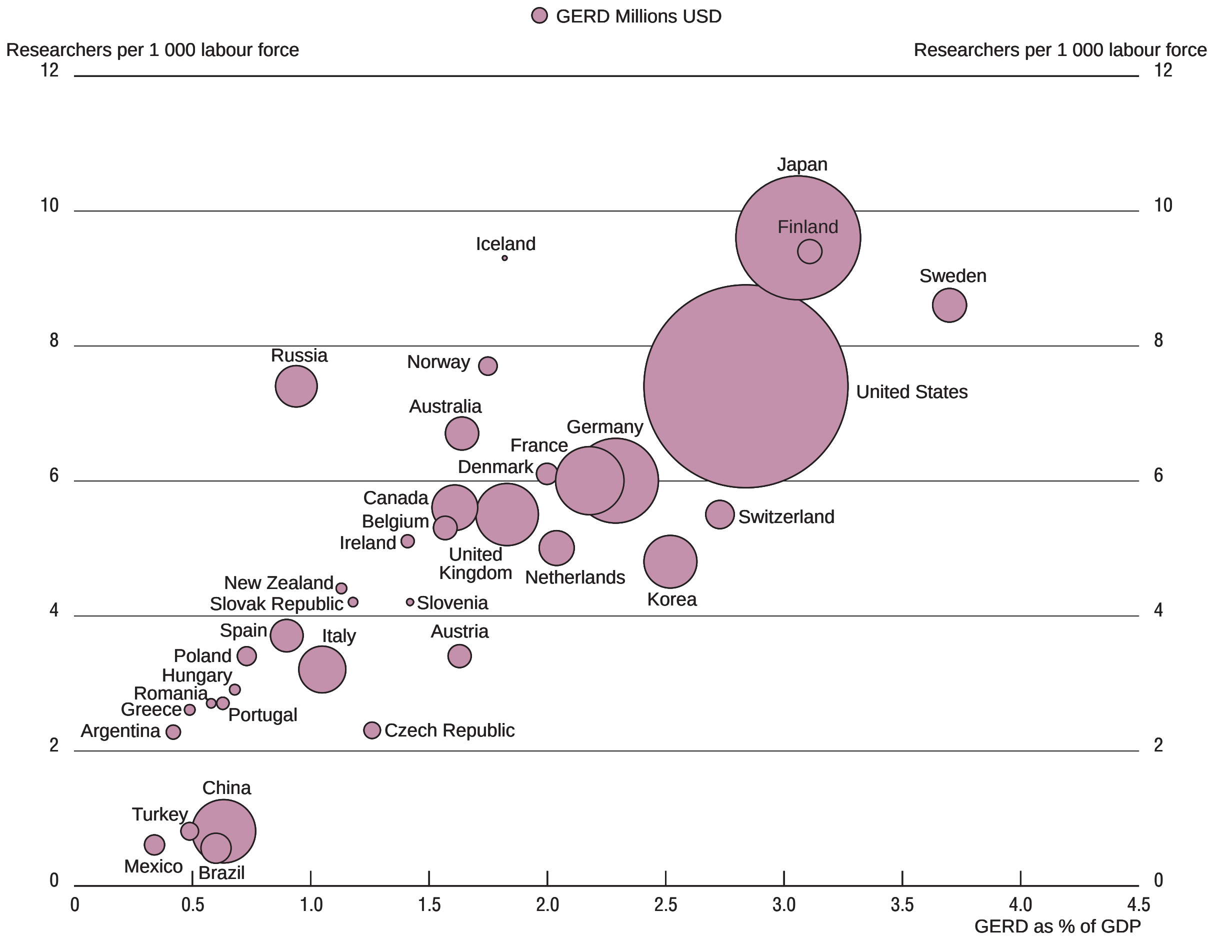
Expenditure on R&D differs considerably; the richer the country, the more R&D-intensive it is. The United States spent almost USD 250 billion on R&D in 1999 and accounts for 48% of total OECD expenditure on R&D, followed at a considerable distance by Japan (18%), Germany (about 8%) and France (about 5.5%). The volume of US R&D reflects its central role in world scientific and technological progress (Figure 1). Relative R&D efforts also differ considerably; Finland, Japan, Korea, Sweden and the United States invest the largest shares of GDP in R&D. The balance between the public and private sectors in funding R&D also differs considerably. At one extreme are countries such as Ireland, Japan and Korea, where 70% of R&D is funded by business and 20% by the government. At the other are countries such as Mexico and Portugal where the proportions are reversed.

More R&D is now funded by business and more is oriented towards civilian needs.

R&D funding has fluctuated considerably over the past years. With the end of the cold war, defence R&D has declined. Moreover, government R&D fell relative to GDP during much of the first half of the 1990s, as depressed cyclical conditions and large budget deficits limited public spending, and the economic slowdown of the early 1990s led to a sharp drop in total OECD R&D intensity.

Figure 1. **R&D expenditure in the OECD and non-OECD area, 1999**[1]

GERD in billion USD PPP and as a percentage of GDP, researchers per 1 000 labour force[2]



1. Or latest available year.
2. The size of the circles is proportional to the absolute volume of R&D expenditure.

Source: OECD, *Main Science and Technology Indicators*, May 2000 and OECD estimates.

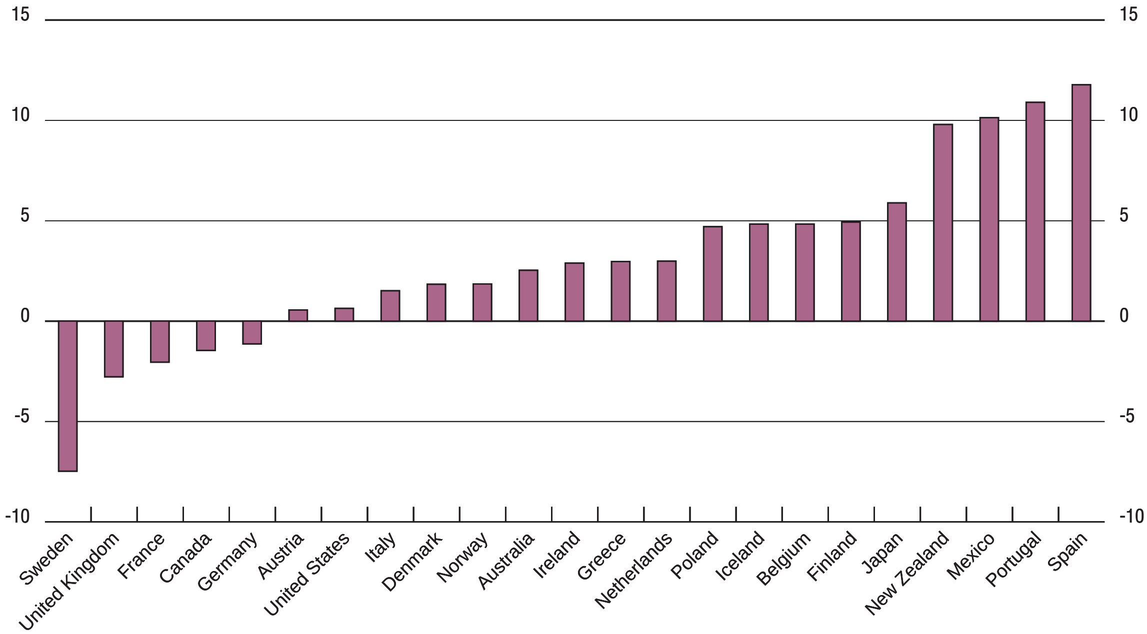
Investment in R&D has mounted over recent years…

In recent years, investment in R&D has risen. Government budget deficits have improved, and countries such as Finland and Japan have strengthened their public funding (Figure 2). Macroeconomic conditions have improved in many countries and have contributed to a considerable pick-up in business R&D, in particular in Denmark, Finland, Japan, Sweden and the United States.

… and is complemented by venture capital.

Funding for innovation goes considerably beyond R&D. Venture capital has become a major source of funding for new technology-based firms and thus contributes to innovation. In 1999, IT-related companies attracted more than two-thirds of all US venture capital funds. Venture capital markets have boomed in recent years, doubling in North America and more than tripling in Europe.

Figure 2. **Average annual growth of government appropriations to R&D, 1995-99**[1]



1. Or latest available year, *i.e.* 1997 for New Zealand; 1998 for Australia, Belgium, Canada, France, Germany, Ireland, Italy, Mexico, Poland and the United Kingdom; 2000 for Denmark, Finland, Japan, Norway and the United States.

Source: OECD, *Main Science and Technology Indicators*, May 2000; series deflated by the producer price index.

The growing role of knowledge has led to greater networking and co-operation.

ICT has enabled the codification of large amounts of knowledge and has led to easier and cheaper diffusion of such knowledge. Firms now tend to focus on maintaining control of their tacit knowledge – their experience and skills – and externalise activities that do not lie within their core competencies. They have become integrated into networks that provide them with knowledge or acquire knowledge by buying other firms or through mergers. Between 1991 and 1999, the value of global cross-border mergers and acquisitions grew more than six-fold, from USD 85 billion to USD 558 billion. Strategic alliances also developed rapidly over the decade, and grew by 40% in 1999. The number of new co-operative deals increased from just over 1 000 in 1989 to more than 7 000 ten years later. Recent alliances are far larger in scale than earlier partnerships.

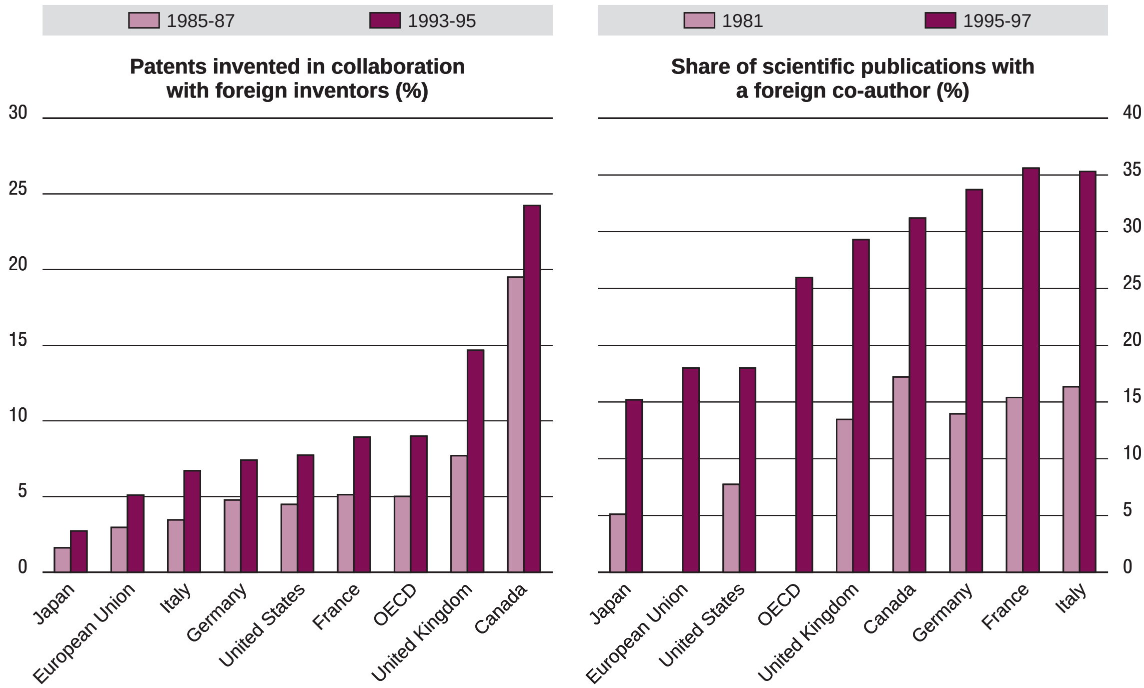
R&D and scientific efforts have become more international.

The importance of networking is also evident in the rising cross-border ownership of inventions. Across the OECD area, the share of foreign co-inventors in total patenting rose from 5% in the mid-1980s to 9% eight years later. Already in 1995, 26% of all scientific publications in the OECD area involved international collaboration (Figure 3).

Differences in income and productivity persist in the OECD area, …

Both income and productivity reflect differences in the transition to a knowledge-based economy. Over the past decade, a number of European countries (Norway, West Germany, Belgium and

Figure 3. **International co-operation in science and technology**



1. OECD and EU averages are for 1995.

Source: OECD (1999) and National Science Foundation (2000).

France) have surpassed the United States in terms of GDP per hour worked. However, their GDP per capita remains considerably below that in the United States, as their labour utilisation is lower. In recent years, trend productivity growth has improved in a small number of OECD countries, apparently partly as a result of increased technological change.

… partly owing to differences in levels of technological change and innovation.

Both scientific output and patenting rose substantially across the OECD area in the 1990s. In 1995, more than 38% of all OECD scientific publications originated in European Union countries, and another 38% in the United States. Japan contributed about 10%. The United States accounts for almost 35% of all major patents in the OECD area, Japan for 29% and Germany for 12%, followed at a considerable distance by France and the United Kingdom. The increase in scientific and technological output is also affecting international competition. A growing share of manufacturing exports consists of high- and medium-high-technology goods, particularly in Ireland, Japan and the United States. Technology also plays a direct role in international competition. The United States is the main net exporter of disembodied technology, such as licenses, patents and know-how. Japan has been a net exporter since 1993, but only three EU countries (Belgium, the Netherlands, Sweden) are net exporters of technology.

Government policies are adjusting to the emergence of a knowledge-based economy

Recent science, technology and innovation policies in the OECD area focus on funding for science, university reform and the establishment of centres of excellence.

Countries such as Austria, France, Japan, Korea, Mexico, Portugal and Spain have undertaken large-scale initiatives to reform their science, technology and innovation (STI) policies in recent years. Others, including Belgium, Canada, the Czech Republic, Finland, Germany, Ireland, New Zealand, Norway, Portugal, Turkey, the United Kingdom and the United States, are increasing their support to the science base. In the United States, support for basic research was increased by more than 10% in the 2000 budget. These efforts often aim to increase the contribution of science to economic growth and to address challenges such as the environment. Many countries are also undertaking university reform with a view to greater autonomy, more competitive and performance-based funding and the commercialisation of the results of public research. Rules governing science-industry relations are also undergoing reform. In a break with the egalitarian treatment of universities, many countries are establishing centres of excellence. These help to create and diffuse knowledge and can act as the core of innovation networks.

Greater attention is also paid to new growth areas such as biotechnology, to the role of networks in innovation and to that of human resources in innovation.

Other STI policies seem broadly shared across the OECD area. Attention is given to new growth areas such as biotechnology and to the promotion of start-up firms, for example through support for venture capital markets and regulatory reform. The role of networking is increasingly recognised: funding for R&D is more closely linked to collaboration in research groups, science-industry interactions are a key policy focus and several countries emphasise the formation of clusters. Attention is also given to incentive structures for researchers, and to policies to increase the mobility of personnel within the science system and between science and industry. International mobility of highly skilled workers and concerns about the brain drain affect policy in several countries.

Policy evaluation has gained in importance and greater attention is given to science, technology and innovation policies at the highest level of government.

Countries are also making greater efforts to evaluate the outcomes of policy. More attention is given to STI issues at the highest levels of government, often through the establishment of a high-level ministerial council for STI policy or through greater co-ordination in the area of STI. Many countries are also increasing their efforts to involve society in developing STI policies. Foresight programmes and consultative procedures to develop long-term plans have become common across the OECD area. Australia and the United States, for instance, held large innovation summits in the past year.

Throughout the OECD area, there is scope for learning more about successful approaches to scientific progress, innovation and economic growth.

Even countries for which the OECD has made few policy recommendations in the past (*e.g.* Australia, Finland, the United States) are making substantial policy changes, proof that this is an area in need of regular attention. Many governments work with business, researchers and other partners to design and implement policy, as the active involvement of stakeholders fosters lasting change. It is difficult to assess whether the changes now being made will be effective enough. Best practices will continue to evolve, as will the need to review policies. Countries that have recently engaged in reform have taken only a first step towards making their innovation systems more effective.

Some countries' strong economic growth is linked to innovation and technological change

Science and technology play a significant role in OECD economic performance.

Disparities in economic growth in the OECD area have increased in the 1990s. In a few countries (Australia, Denmark, Finland, Ireland, Norway, the United States) multi-factor productivity (MFP) has increased, apparently as a result of a higher rate of innovation. The increase in MFP and improvements in the quality of capital and labour indicate that innovation and technological change are important drivers of economic growth. Information technology, in particular, is a key factor, and has had strong impacts on productivity, particularly when accompanied by organisational change and better worker skills. It has also helped to improve performance in previously stagnant services sectors, reduced transaction costs and enabled more extensive networking among firms.

Changes in the innovation process have affected the role of innovation and technological change in growth.

The growing role of innovation and technological change seems linked to changes in the innovation process. Innovation has become more market-driven, and innovation surveys for 12 European countries suggest that over 30% of manufacturing turnover derives from new or improved products. More of the financing of innovation is directed towards new firms and risky projects. Innovation also relies much more on networking and co-operation, including between science and industry. A recent analysis of US patent citations found that more than 70% of biotechnology citations were to papers originating solely at public science institutions. Innovation is more global, arises from many sources and is spread more widely across sectors, including services, thus broadening the basis for economic growth (Figure 4).

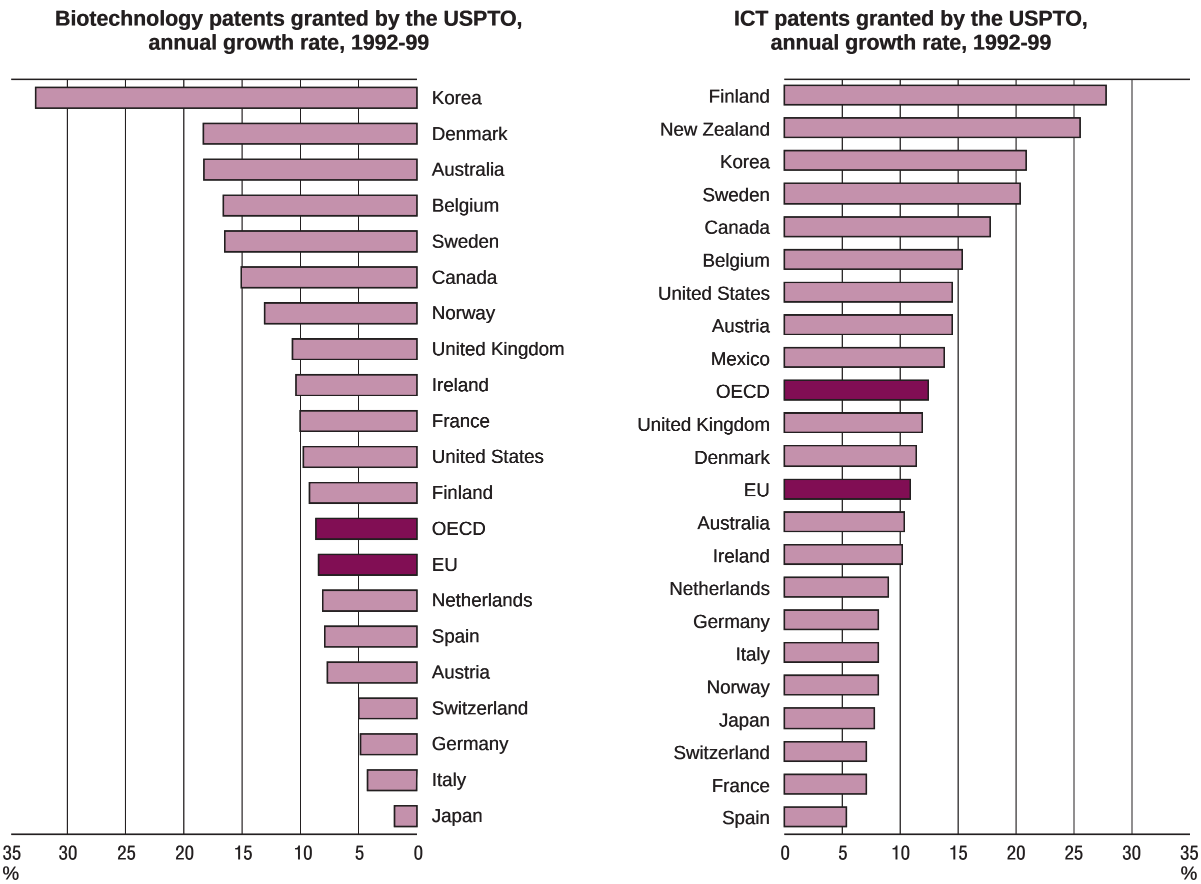
The United States seems to have adapted the most successfully to the new requirements for innovation.

Not all countries have adapted equally to these changes. The United States appears to have done so most effectively. Over the past two decades, it has introduced a series of measures to strengthen competition, facilitate networking and co-operation, strengthen links between science and industry and increase returns to investment in R&D. The extension of patent protection to publicly funded research (the Bayh-Dole Act of 1980) has had a significant impact on the rate of technology transfer from science. Federal funding has contributed to scientific and technological breakthroughs that now support economic growth.

Small successful OECD economies have all undertaken a programme of structural reform.

Other OECD countries with strong economic performance, such as Australia, Denmark, Finland, Ireland, the Netherlands and Norway, are much smaller than the United States. In their case, openness to technologies from abroad is crucial. However, for countries specialised in certain technological fields, a strong knowledge base in certain fields is essential. More generally, these small OECD countries have all undertaken a broad programme of structural reform which has improved the business climate, strengthened

Figure 4. **Innovation in biotechnology and ICT**



Source: OECD calculations based on data from the US Patent and Trademark Office.

competition, pushed firms to improve performance, and enabled innovation and growth to flourish.

Policy requirements have changed.

Changes in the innovation process require changes in policy. Policies to strengthen competition are important, but not sufficient. The improvement of knowledge flows both within the economy and internationally are crucial areas for policy consideration. To benefit from knowledge produced throughout the world and strengthen the national foundations of growth, a country's investment in knowledge is of growing importance.

Services have gained in importance for innovation and growth and policies need modification

Services are an increasingly dynamic sector of the economy and of increasing importance for innovation.

The traditional view is that services are not very dynamic, that new service jobs are poorly paid, that they have little or no productivity growth and that they do not innovate. Recent work does not support this view. Many services experience rapid productivity growth, several are innovative and new service jobs increasingly require skilled personnel. Between 1985 and 1997, around two-thirds of GDP growth in the OECD business sector resulted from growth in the services sector.

Investment in ICT is an important driver of change in services…

ICT is enabling productivity improvements in many sectors, including transport, communications, wholesale and retail trade, and finance and business services, although official productivity estimates often still obscure their impact because of measurement problems. Proper measurement of output in services may show rapid growth. A study for the US banking industry showed output growth of 7.4% a year between 1977 and 1994, well above the previous official measure of 1.3% a year. ICT is important for industries that process information, such as financial services, but also for areas such as logistics because it makes more efficient transport possible. To be effective, however, investment in ICT needs to be accompanied by upskilling of workers, organisational change and a competitive business climate.

… and has helped to make them more innovative.

Services have become more innovative. The Italian innovation survey suggests that 31% of service firms innovate, compared with 33% in manufacturing. Across the OECD area, services sector R&D has risen from less than 5% of total business enterprise R&D in 1980 to more than 15% in 1995. Sectors such as communication and transport are more technology-intensive than many manufacturing industries. Knowledge-intensive services, such as R&D, computing and consultant services, have experienced very rapid growth and are important sources of innovation. Many other services have become more innovative following the implementation of ICT in service delivery, the competition-enhancing effects of regulatory reform and the increased role of networking and co-operation in the innovation process.

Obstacles to innovation in services are similar to those in manufacturing…

Innovation surveys suggest that most of the obstacles to growth and innovation in services are the same as in manufacturing. Insufficient access to finance and risk capital, lack of internal capacity to innovate, insufficient expertise in applying ICT and high risk are typically the main barriers to innovation in both sectors. This may suggest that there is no need for specific policy for innovation in services.

... although some policies may need adjustment to promote innovation in services.

However, some aspects of policy must take better account of the needs and characteristics of the services sector. Regulatory reform is needed to ease access to and reduce the costs of service-relevant ICT and to promote competition and innovation throughout the economy. The reduction of barriers to trade and foreign investment in services can also help to strengthen competition and should promote the diffusion of innovative ideas and concepts across countries. Policies promoting R&D in the business sector may require modification if they are biased against service innovation. Better and more comprehensive data on the services sector will improve the understanding of innovation in services.

Interaction between universities and industry is crucial to innovation

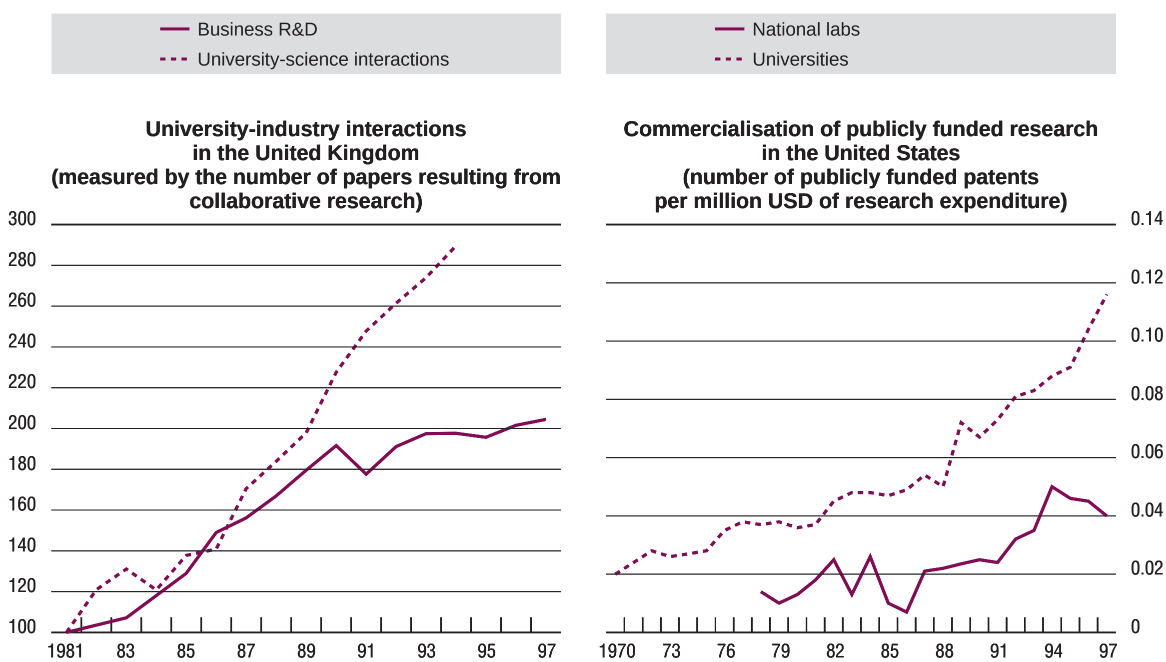
The performance of an innovation system depends more than in the past on the intensity and effectiveness of interaction between science and industry.

Industry-science linkages have become a central concern of government policy in recent years. Technical progress has accelerated in areas where innovation is directly rooted in science (biotechnology, information technology, new materials) and firms' demand for links to the science base has increased (Figure 5). Innovation now requires more external and more multidisciplinary knowledge. In addition, owing to increased competition and a more short-term orientation, firms have been forced to save on R&D costs and to search for alternative sources of knowledge. Financial, regulatory and organisational changes have boosted the development of a market for knowledge. Restrictions on public financing have encouraged universities and other publicly funded research organisations to enter this market, especially when they can build on established linkages with industry.

Both firms and universities benefit from such interaction.

Such links are beneficial to both universities and firms. Universities seek industry contacts to ensure good job prospects for students, to keep curricula up to date and to obtain research support. Leading research universities seek strategic alliances with firms in order to consolidate their position in innovation networks and to establish their place in the market for knowledge. The main benefit for firms is often improved access to

Figure 5. **The increasing intensity of science-industry interaction**



Source: Katz and Hicks (1998) [United Kingdom]; Jaffe (1999) [United States].

well-trained human resources. Other benefits include access to new scientific knowledge, established networks and problem-solving capabilities.

Science-industry links differ considerably across OECD countries.

Interaction between science and industry takes various forms in different countries, owing to differences in institutions, regulatory frameworks, research financing, intellectual property rights and the status and mobility of researchers. Thus, policy challenges may differ. In countries with large public involvement in R&D, such as Italy and Mexico, the technological absorption capacity of the business sector is often not very well developed. In countries with average public involvement in R&D, such as France and the United Kingdom, R&D efforts are often duplicated and science is not always sufficiently responsive to business needs. In countries with low public involvement in R&D, such as Japan and the United States, improving the leverage of public research and its quality is often a key concern.

Spin-off firms from public research are a valuable channel for interaction.

While modest in number, university spin-off firms are a vital component of networks and play an increasingly valuable role in most countries. Preliminary OECD data suggest that spin-off formation is about three to four times higher in North America than in other OECD areas. Most spin-offs are concentrated in ICT and biotechnology. Governments can help lower certain obstacles to spin-off formation by providing seed capital to help finance early-stage investment or by improving incentive structures for researchers and would-be entrepreneurs.

Low mobility of scientists remains a major obstacle to industry-science linkages in some OECD countries.

Data on the mobility of scientists, while scarce, show large differences across the OECD area. In the United States, scientists and engineers change jobs every four years, and even more frequently in areas such as software and IT. In Japan, only 20% of engineers change jobs in their career. Employment rules and labour market conditions set the overall situation for mobility. The lack of transferability of pensions between the public and private sectors is a major barrier to the mobility of researchers in many countries. More specific constraints include public employment legislation, regulations on temporary mobility and secondary employment and regulations on academic entrepreneurship.

Incentive structures also affect the links between science and industry.

Other barriers also affect the link between science and industry. For instance, the granting of intellectual property rights varies significantly. Some countries grant ownership of publicly funded research to the performing institution, others to the inventor. Granting licenses to institutions tends to make the research less exclusive. In addition, public researchers are traditionally evaluated on their research, not on their contribution to industry.

Policies to support private R&D are not equally effective

To increase business funding of R&D, direct support is preferable to indirect support.

Because firms may underinvest in R&D, governments typically stimulate private R&D. They can do this in several ways, but not all are equally effective. Both fiscal incentives and direct public support stimulate R&D funded by business, but research performed by government and universities may crowd out private R&D. Publicly funded research may lead to technology that is used by business, however, even if it does not affect private R&D. Defence R&D has a negative impact on business funding of R&D, while civilian R&D has a neutral impact. More targeted government funding of business R&D may reduce barriers to the transfer of knowledge from universities and may thus limit the crowding-out effect. Whereas crowding out is often immediate, spillovers may take some time to materialise.

Countries that provide too little or too much direct funding to business stimulate private R&D less than those with a moderate level of public funding.

The effectiveness of such policies varies. First, countries that provide a level of direct funding to business that is too low or too high stimulate private R&D less than those with an intermediate level of public funding. The effectiveness of government funding of business R&D seems to have an inverted-U shape, increasing up to an average subsidisation rate of about 13% and decreasing beyond. Over a subsidisation level of 25%, additional public money appears to substitute for private funding. These figures are mainly illustrative, as actual thresholds depend on the precise policies used and on economic conditions, which differ across countries and change over time. Second, stable policies are more effective than volatile policies. Third, the effectiveness of policy tools depends on the mix of policy instruments. In particular, government funding of business R&D and tax incentives are substitutes; greater use of the one reduces the effectiveness of the other.

Government support to business R&D is more likely to be effective if it is part of a long-term framework.

Some broad policy conclusions can be drawn. First, any type of government support to business R&D is more likely to be effective if it is integrated within a long-term framework, as this reduces uncertainty. Second, as policy instruments should be consistent, the various agencies involved in their design and management need to be co-ordinated. Third, if government wishes to stimulate business R&D, it should avoid providing too little or too much funding. Fourth, while funding of defence-related R&D is not explicitly aimed at stimulating private R&D expenditure, it has a crowding-out effect on civilian business R&D. Fifth, research performed in universities has potential uses for business and targeted government funding appears to increase technology transfer from universities.

Networking is essential to innovation and requires greater attention from policy makers

Networking is now a significant factor in innovation.

It has been widely recognised in recent years that innovation processes are characterised by a considerable degree of interaction and division of labour. In stimulating co-operation among actors in the innovation system, policy makers expect that synergy will occur and that the innovation potential will be better exploited in existing and in new firms, in research and in society as a whole. Partners in networks can obtain benefits that they could not get independently through the increased scale and scope of activities, cost and risk sharing, improved ability to deal with complexity, enhanced learning effects, greater flexibility and efficiency and greater speed.

Technology alliances have gained ground and have changed in character.

One sign that networking has become more important is the sharp increase in international technology alliances in biotechnology and ICT in the early 1990s, which accelerated as the decade continued. New technologies have become more knowledge-intensive and thus require more co-operation. Countries differ substantially in this respect, however, apparently as a result of their level of technological sophistication and their economic structure. Large firms are more involved in technological alliances than small ones. Collaboration is now often considered as a first-best option, rather than a solution of last resort. In addition, firms increasingly collaborate on R&D, an activity which firms traditionally did not share with other firms. Firms are also increasingly engaging in R&D collaboration with overseas partners.

Firms increasingly co-operate with foreign partners.

Firms rarely innovate alone. In Austria, 61% of product-innovating firms collaborated with one or more partners, 83% in Spain and as high as 97% in Denmark. The available evidence suggests that inter-firm collaboration still predominantly takes place among domestic firms. However, foreign firms, especially suppliers of materials and components and private customers, play a significant and growing role in national innovation networks.

Co-operation between firms requires trust.

Intensive inter-firm links and learning between partners depend on high levels of trust because the knowledge transferred is often tacit, uncodified, specific and commercially sensitive. Trust helps to build long-term relationships between firms and reduces the costs of co-operation.

The role of government may vary depending on the amount of networking already in place.

Governments have recognised the growing importance of co-operative networks. Governments and non-profit organisations can promote firms' awareness of networking, notably by distributing information. Governments can also assist firms in their search for network partners by furnishing them with information, brokerage and matching services. Experience suggests that governments cannot create networks from scratch, however. They can sometimes reduce firms' reservations about inter-firm co-operation, although building trust takes time. The establishment of long-term network facilitation programmes and foresight programmes may be helpful. The success of networks may also depend on other resources, such as access to a key technology or to important foreign markets. In some cases, governments can help to address systemic failures in these areas. In others, private alternatives may be more efficient.