

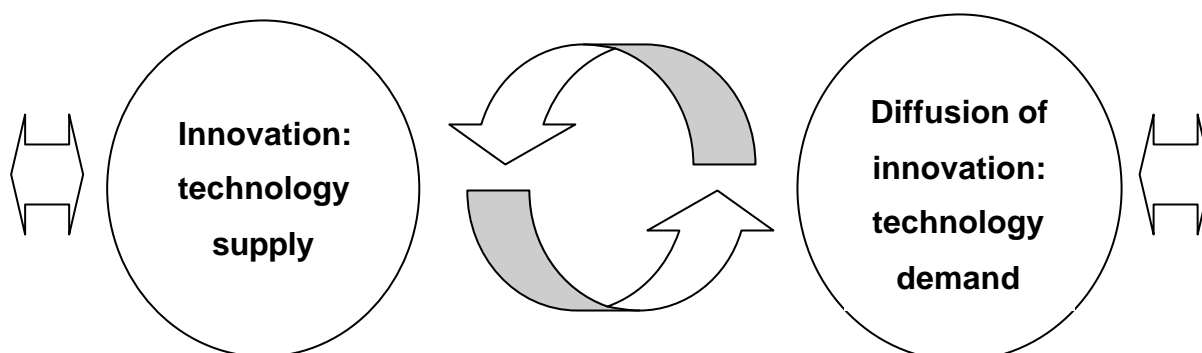
Annex C: Technology diffusion

Introduction

C1. This annex examines the role of technology diffusion in realising the full economic benefits of research and innovation. Technology diffusion is the process by which knowledge and technical expertise spread throughout the economy. It helps both raise individual firms' international competitiveness and drive aggregate productivity growth and job creation. It is now widely accepted that the degree of technology and knowledge flows across public and private sectors strongly affects the impact of technology on the economy (OECD 1998). A clear example of this is the computer – where productivity gains to business users adopting the new technology have greatly outweighed those to the computer industry itself (European Commission (EC) 1996).

C2. So as part of the report's attempt to understand the relationship between technology and productivity, we must look beyond the R&D efforts of the high-tech manufacturing sector to the diffusion of knowledge and new technologies. Where R&D innovation represent the supply side of technology, diffusion of innovation is determined by demand. Traditionally, it was seen as a distinct stage of technological development, following the innovation process in a linear fashion (Stoneman 1987) . In reality, the two are intertwined. Following the national innovation system framework of this work, it is more accurate to see research and innovation and diffusion of innovation as two elements in a network of innovative activities, with two-way interaction (Figure C1).

Figure C1: Supply and demand of technology



C3. As Figure C1 implies, technology diffusion involves more than just bringing new machinery or processes into a working environment. That process underlies the traditional linear model. Although obviously important, fully capturing the benefits of technology also requires significant training and organisational adaptation. And these are aspects of diffusion that affect future innovation. Promoting technology diffusion requires focusing on ways to increase investment in intangibles – human capital, training, R&D investment that produces ideas – as well as tangible investments in physical capital.

Knowledge spillovers

C4. The aspect of technology diffusion involving the transfer of knowledge and expertise, rather than physical capital, is known as *disembodied diffusion* (EC 1996). On the supply side, this results from the positive externalities – or ‘knowledge spillovers’ – arising from investment in R&D. Knowledge spillovers allow new technology or knowledge developed by one firm to potentially become available to others, domestically or abroad. The outputs of R&D investment are knowledge based, and knowledge exhibits some of the properties of a public good – in particular non-excludability (Stiglitz 1999). So the advance of knowledge resulting from research done in an enterprise often cannot be circumscribed to the firm in question and allows other firms of the sector to produce the same commodity without having to invest the same amount of money in R&D.

C5. This argues for the need for adequate intellectual property protection, to allow firms to appropriate sufficient returns from their R&D to ensure that such investment is profitable – see Annex F. But spillovers are essential to the development of the general stock of knowledge capital, since innovations that only benefited the originating firm, and were not widely diffused, would not enable the rapid and cumulative development of knowledge. And raising the stock of general knowledge capital itself provides stronger incentives to innovate, reducing the amount of R&D each subsequent firm must carry out to develop new technologies i.e. increasing returns to scale. So the role of policy here is to strike a careful balance, between providing incentives to invest in R&D (through sufficiently strong patent protection) and providing measures to ensure the rapid and wide diffusion of technology.

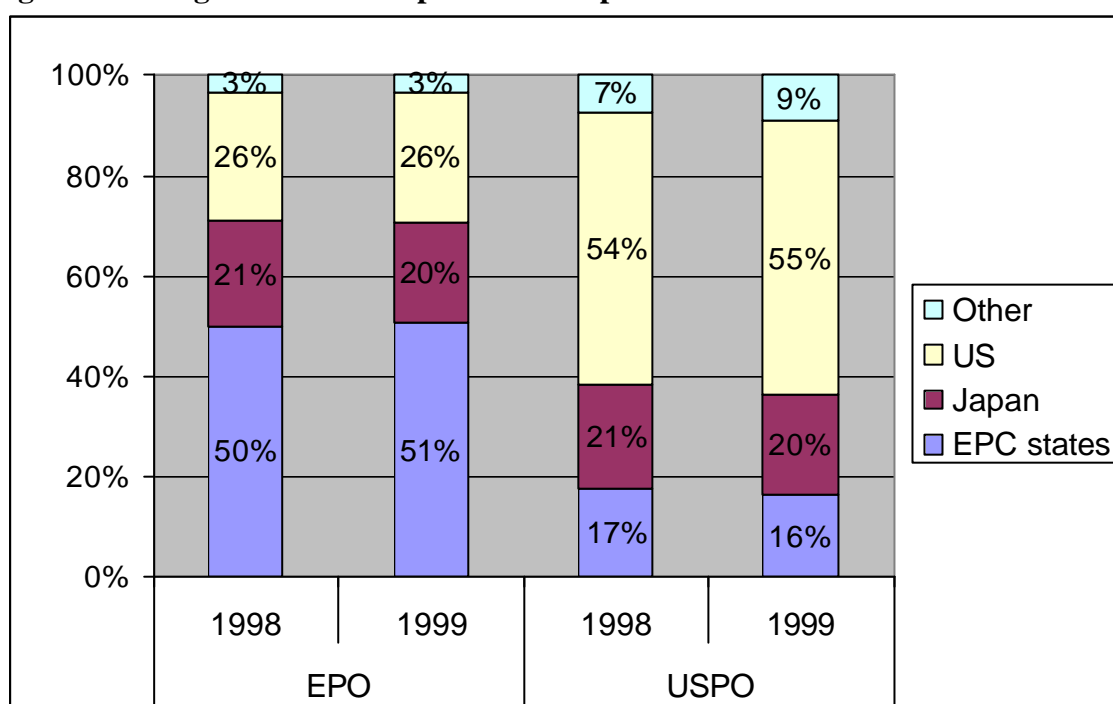
Cooperation and networks

C6. The importance of knowledge spillovers to innovation is at the heart of the formation of informal or formal ‘networks’. The public good aspects to knowledge creation mean that the knowledge created by one firm does not depend solely on its own research efforts, but draws on the efforts of others as well. And as knowledge now draws on a wide variety of sources, and innovation uses a broad range of technologies and ideas, the need for cooperation is strong. This can be informal – through patent citations or purchasing embodied technologies and consultant services. Or it can be formal – collaborations through mergers and acquisitions or strategic alliances.

C7. Empirical studies bear out the importance of collaboration and networks in the invention, development and diffusion of technologies (Table 1, chapter II). The incentives to collaborate are even stronger in a global economy, because the costs and risks of innovation are higher when competing on the global market, and because they allow groups of firms to mutually benefit from exploiting ‘network effects’, which rely on scale factors to deliver higher returns to all. A notable example is the development of the GSM standard, which has facilitated extremely rapid growth in the use of mobile phones in Europe, and the current leadership of Nokia and Ericsson in this market (OECD 2000d).

C8. The trend towards greater international cooperation can be seen in recent patenting data: cross-border ownership of patents – where the applicant resides in a different country than the inventor – has increased considerably in the 1990s (OECD 2000d). But the internationalisation of patenting has not been equally rapidly in all countries – US patents have a larger and more rapidly growing proportion of foreign co-inventors than those of Europe or Japan (OECD 2000d). Figure C2 also shows that US and Japanese innovators have achieved a higher level of penetration into foreign markets than Europeans (EPC states), which shows that they are more successful at international diffusion than the EU.

Figure C2: Origination of European and US patents



Source: EPO and USPTO

C9. There is strong evidence from patent citations of geographical localisation of knowledge flows – for the US, Japan, UK, France and Germany, the frequency of domestic citations is higher than citations *received from* other countries, or citations *made to* other countries (Jaffe 1998). No country has as strong external knowledge flows as it does internally. But patent citations also show that inter-country knowledge flows are typically bi-directional, so higher flows are generally seen in both directions or not at all. This indicates that a greater ability to ‘absorb’ new technology accompanies stronger innovative capacity. Also, Jaffe (1998) finds that, with the exception of the UK, the US is ‘closer’ in terms of knowledge flows, to Japan than to any of the EU Member States – possibly illustrating a comparative ‘diffusion gap’ between EU and US.

Science-innovation links

C10. Innovation increasingly draws on basic scientific research, in particular in new technologies such as biotechnology and information technology (OECD 2000d). Apart from playing a major role in developing the stock of general knowledge, the public science system also provides skilled graduates that are essential to a firm's ability to adopt and develop new technologies, as well as new instruments and methods for industrial research. Scientific institutions are at the heart of the world's research and innovation networks, essential to the global diffusion of new knowledge, and play a role in the formation of new firms or spinoffs, placing them increasingly at the heart of industry clusters.

C11. But the growth in science-innovation links has not been equally rapid in all OECD countries (OECD 1998). This is partly a feature of the different structures of different national innovation systems, which vary according to the country's industrial specialisation and the strength of the interaction between science and enterprise. In some systems, for example the US, Canada, Denmark and the UK, the science-innovation link is strong. In others, such as Germany, Japan and Korea, but also to a lesser extent in Austria and Italy, the focus of innovation has been more towards engineering excellence and rapid adoption and adaptation of technological innovation (OECD 2000d).

The role of EU R&D Framework Programmes

C12. Some of the underlying causes of the EU's relatively weak innovation performance comparative to the US and Japan need to be tackled at Community level. In particular this involves integrating European research efforts and capacities and enhancing intra-EU cooperation and networks, as well as researcher mobility. At Lisbon European Council, Heads of State recognised this need by fully endorsing the Commission's proposal to create a *European Research Area*.

“The aim is to create conditions making it possible to increase the impact of European research efforts by strengthening the coherence of research activities and policies conducted in Europe.” (EC 2000)

C13. In terms of expenditure, the main lever that the EU has to influence technology development in Europe is the R&D Framework Programme, whose budget is set every four years. It is aimed at stimulating co-operation, building up scientific and technological excellence and raising industrial competitiveness in the Union. The current (5th) RTD Framework Programme, running from 1998 to 2002 has a budget of €14.96bn to be spent on key research themes and on horizontal measures such as promoting innovation, international co-operation and SMEs. Negotiations on the budget of the 6th Framework Programme, which is due to run from 2002 to 2006, are currently underway with a proposed budget of €17.5bn. The areas to be supported range from integrated research on selected scientific and technological themes to co-ordination of national research activities and policy developments. It includes networking of national innovation systems, support for researcher mobility and access to research infrastructures

among activities designed to better structure the European Research Area integrate scientific institutions. As in the past, funding for specific research areas, such as information technologies, aeronautics and life sciences, will represent the bulk of the Community financial support.

C14. The overall evolution of the framework programme over time shows a very substantial shift in the pattern of expenditure from straightforward research activities to more horizontal ‘structuring’ activities including human resources, infrastructures and co-ordination of national activities and policy developments.

C15. To help bring about the European Research Area, the Community funding will be carried out by means of a range of instruments among which “Networks of excellence” and “Integrated projects” are designed to strengthen European scientific and technological excellence and competitiveness by mobilising a critical mass of skills and resources. The participants will administer these instruments with a high level of autonomy.

Absorptive capacity – skills and training

C16. The demand side of disembodied diffusion is determined by the ‘absorptive capacities’ of firms, that is, their ability to incorporate innovations developed elsewhere into their production process. To increase its capacity to absorb new knowledge, a firm must raise the skill level of its staff while also investing more in R&D. Although firms traditionally invest in R&D to invent new technologies, this also helps enable the firm to absorb new technologies and knowledge. The ability to imitate and profit from technology developed elsewhere may in fact depend crucially on own R&D expenditures (EC 1996). Adoption of new technology depends on absorptive capacity: the latter depends in large measure on the capacity to innovate.

C17. Much of the knowledge generated by R&D remains tacit, even after publication of research in patents. This is embodied in people’s skills, experience and education. Transferring this knowledge depends on the skills level of other staff, as well as on networks and researcher mobility. Indeed, innovation surveys indicate that a lack of skilled personnel is one of the greatest barriers to technology (OECD 2000d). In the services sector this is particularly true, where innovation is not always related to technology, and where people and the skills they embody help drive innovation (OECD 2000e). Eaton *et al* 1998 try to quantify the effects of increased schooling on absorptive capacity: they estimate that raising the average level of schooling in the EU by a little over half a year would deliver a 10% permanent increase in its average income level. Important changes to human capital requirements in the last decade include:

- Initial levels of education are no longer sufficient to meet continuously changing demands: lifelong learning is increasingly important.
- Skills needed for innovation and technological change – creativity, cognitive skills – were less needed in the past (Stiglitz, 1999).
- Some countries face shortages of specific categories of high-skilled personnel.

- Barriers to mobility may be reducing knowledge flows within an economy.

Technology embodied in capital

C18. The most linear aspect of the diffusion process is the transfer of new technology in goods. There is strong evidence of the importance of technology intensive capital investment to services – embodied R&D has a significant positive impact on TFP growth in the services sector (EC 1996). The relation between capital investment and productivity growth in services gives one of the most robust results of this Commission study (EC 1996): the rate of return of capital embodied R&D exceeds 200 % in this sector in the 1980s. An OECD study (1996b) similarly finds that: (i) technology diffusion has contributed substantially to TFP growth, often accounting for more than half of productivity growth in a given period; (ii) its contribution typically exceeds that of direct R&D efforts.

C19. To maximise the benefits of embodied technology investment, governments need to ensure that their countries are open to the trade of new technologies, and that their firms have the absorptive capacities to make use of these new technologies. However, it would be undesirable for countries to focus on absorption to the extent that the overall stock of R&D is reduced. Furthermore, because countries that spend more on R&D take more advantage of foreign technology, free riding (waiting for other countries to develop the new technology and just trying to imitate when it is ready) would be ineffective (OECD 2001a). In addition, there is evidence that countries that are further behind the technology frontier have more to gain from increasing their R&D efforts since these efforts are more likely to result in capturing international spillovers from technologically advanced countries (Bernstein and Mohnen, 1994; Coe and Helpman, 1993).

C20. Nevertheless, if technology suppliers are allowed to charge high, monopolistic prices for their technology embodied goods, they will capture most of the social benefits from them. Only if there is adequate competitive pressure on suppliers to drive prices downwards can buyers increase their productivity as a result of their technology expenditures. So the market structure of the supplying industries strongly affects the impact of equipment-embodied diffusion on the productivity of user firms (EC 1996).

Policy implications

C21. This Annex has shown the crucial role diffusion plays in realising the full economic benefits of innovation. To increase the benefits from knowledge spillovers created by R&D and innovation, firms need to develop their own R&D and technology absorption capacity, co-operate more closely with one another and the science base, use more skilled and mobile workers, and open themselves more to external trade. But firms cannot do this alone. Governments, by setting the framework conditions under which innovators operate and providing incentives for private R&D, and as the major provider of education and skills, play a central role: policies directed towards promoting diffusion can have significant effects on increasing innovation, productivity and growth (Eaton *et al* 1999). The analysis above suggests the following factors are particularly important.

- **Networking** – knowledge has a wider variety of sources and innovation requires a broader range of technologies and ideas so that there is a greater need for cooperation (OECD 2000d). The US has achieved a higher level of co-operation between firms and public institutions, to facilitate knowledge transfer from public to private sector. (OECD 2000f). The EU needs to focus policies here if it is to enjoy similar productivity gains from innovation. Funding to support R&D collaboration and technology transfer at European level, university-industry spin-offs, clusters and incubators is particularly important. The new instruments and measures put in place in the Sixth Framework Programme are intended to enhance networking and diffusion of knowledge in Europe.
- **Human capital** – many innovation surveys suggest that the lack of skilled research and technical personnel is a principal barrier to innovation. Lifelong learning is especially important in enabling citizens to adapt to a rapidly changing society. Government's role in providing certain types of education and skills is important, but individuals and firms must invest themselves as well.
- **Researcher mobility** – this is essential to breaking down geographical barriers to knowledge flows and maximising the returns from tacit knowledge embodied in the researchers' skills and expertise. At present, mobility is low for most countries, but especially so for the EU. The EU Sixth R&D Framework Programme is well positioned to add value by funding mobility – as the high spillover benefits provide greater incentives for action at Community rather than national level.
- **Trade** – openness to trade is important for economies to have access to new technology through acquiring technology embodied in capital. The two-dimensional relationship of knowledge flows indicates that greater imports of knowledge will also yield greater export. One study estimates that increasing intra-EU trade volumes by 70% would cause a permanent 10% average income gain in the EU (Eaton *et al* 1999).
- **Competition** – competition policy can play an important role in promoting innovation through allowing networking and collaboration at pre-competitive stages, while banning co-operation at the competitive stage to increase adoption, imitation and diffusion of new technologies. Evidence from the diffusion of the Internet clearly shows that Internet penetration is highest in those countries with the lowest Internet access costs (OECD 2000d).
- **Intellectual property** – nevertheless, Government's must provide sufficiently strong incentives to firms to innovate through adequate intellectual property rights. Policy can also be used to promote science-innovation links, as in the US, where the extension of patent protection to publicly funded research has

helped strengthen the role of science in innovation. This is covered more fully in Annex H.