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The diffusion of information technology in Europe



Harald Gruber

1. Introduction

Europe, as all modern economies, is shifting towards an information-based society, where Information Technology (IT) is dramatically modifying patterns of production and consumption and the modern way of life. Low-cost data processing and transmission technologies are leading the way not only in a technological revolution, but also in an economic and social revolution. The main drivers for these trends are technology and market liberalisation. Technological advances, in particular in microelectronics and optical fibres, have drastically reduced the cost of data processing and transmission. In parallel, reduction of trade barriers for IT equipment and the market liberalisation in key sectors adopting IT, such as telecommunications, mobilised huge amounts of private funding for the adoption of new products and services.

Information is the main good around which this revolution is built. Information as a good has some radically different feature compared to traditional goods produced in the economy: information is intangible; information can be shared in its use in an almost unlimited way and this makes it also very difficult to appropriate by the originator; while the production of information typically involves relatively large fixed cost, the diffusion of information is achieved at low cost. Hence traditional approaches to analysing markets for physical goods may not apply for certain sectors of the information economy (1). Because of pervasive “network effects”, i.e. the action of one agent has a feedback on others and vice versa, certain extreme features may occur, such as the “winner takes all” phenomenon. As a matter of fact, IT abounds with examples of innovative companies dominating, if not monopolising, markets such as Intel for microprocessor chips, and Microsoft for personal computer software. Another particular feature of IT production relates to the geographical clustering of production activities. The most illustrating example is Silicon Valley, which houses the world’s largest concentration of IT production, and generates most of the innovation in this field (Saxenian, 1994).

Because of so-called “externalities” in the production of IT, the sector has attracted the attention of policy makers. Moreover, as IT is a general purpose technology, it has pervaded all sectors of the economy, and the scope for innovation is widespread rather than restricted to a single sector of the economy. Significant productivity increases are expected as a result (Helpman, 1998).

One can distinguish the productivity increases generated within the IT producing sector from those generated by the IT using sectors. For Europe the view is forming that productivity growth has been lagging behind the US in both these dimensions (European Commission, 2000). Hence, the concern that the failure of Europe to participate in the IT revolution will doom the continent to playing a marginal role in the future of the global economy. This paper tries to unravel some of the main issues in this debate and indicate the policy options that would lead to an IT revolution. Sections 2 and 3

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1) For an excellent survey of these issues see Shapiro and Varian (1999).

briefly discuss the supply and demand aspects of IT, respectively. Section 4 indicates some broader policy options to stimulate the production and diffusion of IT within Europe. Section 5 concludes.

2. Production of IT hardware and software

Technical progress in hardware

We define the IT sector to be semiconductors, computers and related equipment, and software. This definition links IT to the information processing part of the “digital economy”, where different forms of information such as text, audio and picture are processed in the same way. There is a second leg in the digital economy that is related to telecommunications. In a world of technological convergence, the two sectors are becoming fully integrated, and thus very often they are jointly referred to as the “information and communications technology” (ICT) sector. Internet is the clearest example of this. However, the reason for treating the IT and communications sectors differently is that IT expenditure is predominantly an investment whereas telecommunications is mainly a consumption or intermediary good.

The whole IT sector is relatively young, starting with the invention of semiconductor devices in the late 1940s and with the additional boost received from the invention of microprocessors and memory chips at the beginning of the 1970s. All the basic inventions have been made the US, and the worldwide industry has been shaped by firms originating in that country (2).

The IT sector has an impressive track record in terms of speed of innovation and growth

The IT sector has an impressive track record in terms of speed of innovation and sector growth. Competition among producers has accelerated the pace of innovation and has shortened the life cycle of products. The technological progress in the industry is well described by “Moore’s Law”: because of the relentless downsizing of the chip size, performance of semiconductor chips doubles every 18 months. This prediction has proved to be remarkably accurate since it was first articulated in the late 1960s. Figure 1 shows the evolution of the information processing capacity of a microprocessor in terms of the number of transistors per chip (notice that the y-axis is logarithmic).

Table 1. The evolution of the cost of data processing (in nominal USD)

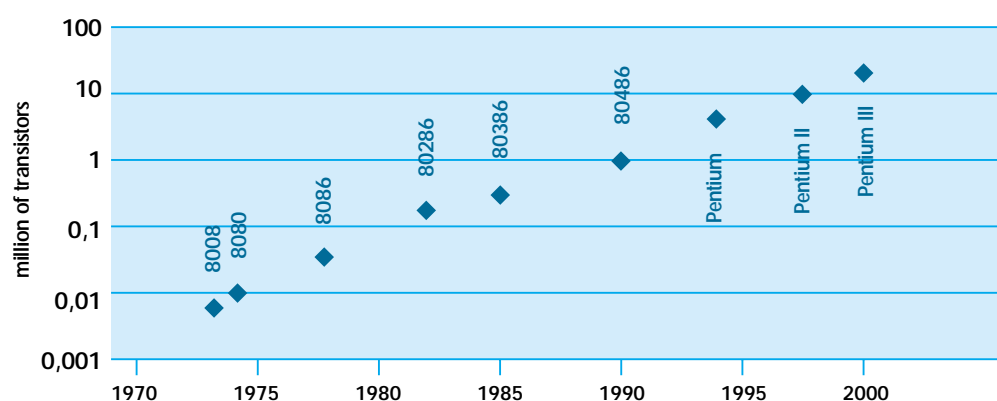
Cost of:	1970	1999	Annual growth rate
1 MHz processing power	7 600	0.17	-31%
1 M bit storage	5 260	0.17	-30%
1 trillion bits sent	150 000	0.12	-38%

Source: The Economist magazine

This strong performance has translated into dramatic declines for the price of processing information. As indicated in Table 1, the average cost of microprocessor computing power, in terms of instructions per second, has fallen by 30% annually, as has the price of data storage per bit. The performance in transmission capacity for information has increased even more impressively thanks to the invention of optical fibre cables. The cost of sending information is falling at rates close to 40% per year.

2) For interesting accounts see Cortada (1987), and Scherer (1999).

Figure 1. The evolution of processing capacity of microprocessors (logarithmic scale)



Source: Intel

The position of European companies

A comparison of IT production among the major economic regions indicates the relatively small role the EU plays in the world production of IT hardware (see Table 2). The most striking difference is with electronic components, where the EU produces only about half that of the US or Japan. A similar difference exists in the production of computers. There appears to be a strong relationship between the production of semiconductors, personal computers, and the location of invention; moreover, technological leadership tends to persist.

Table 2 also lists the value of production of telecommunications equipment. Even though this is not IT in the strict sense, the point here is that Europe scores much better with telecommunications equipment production. Moreover, Europe is particularly well placed in new and rapidly growing sub-sectors of the telecommunications equipment industry, such as mobile. The strength of production in telecommunications is concomitant with the fact that expenditure for telecommunications services accounts for a higher share of GDP in Europe than in the US.

Table 2. Value of production of selected IT products in 1997 in USD billion

	Electronic components	Computers	Telecom equipment
EU	40.1	53.5	28.3
US	79.2	82.4	36.2
Japan	84.4	67.7	21.8

Source: OECD

For many countries, IT hardware production has lost its ability to create a significant number of new jobs. Labour productivity growth in the IT hardware production sector is outpacing the growth in total production. Hence the employment level in the hardware sector is stable or even declining. New IT related jobs are typically created in the software sector and sectors using IT. The IT hardware production sector nevertheless has an important role as it supports high paying jobs. For

US and Japanese firms emerge as the main suppliers in the IT hardware market. European firms are virtually absent from the top ranks.

example, in the US, the average annual salary in the IT sector was USD 46 000 in 1996, compared to an average of USD 28 000 for the private sector on average (US-DOC, 1998).

Table 3 lists the world's most important IT equipment manufacturing companies. In line with the aggregate data in Table 2, US and Japanese firms emerge as the main suppliers in the IT hardware market. Indeed, European firms are virtually absent from the top ranks, with the exception of Siemens. The technologically leading computer hardware producers such as IBM and Compaq, as well as the leading software and services producers such as Microsoft and EDS, are all based in the US.

There is also the undisputed technological and market leadership of Intel in the development and production of microprocessors, the key component of a computer (Intel has a market share of more than 15 percent of total world semiconductors sales, with a 90 percent share of the market for microprocessors). The only competitor in this field is another US firm, AMD (Gruber, 2000).

Table 3. The world's top IT companies in 1998

	Headquarters	Revenues (USD billion)	Employees (thousands)
IBM	US	81.7	350
Siemens	EU	66.9	416
Hitachi	Japan	64.3	331
Matsushita	Japan	60.3	276
Hewlett-Packard	US	47.0	125
Toshiba	Japan	41.7	186
Fujitsu	Japan	38.1	180
NEC	Japan	38.0	152
Compaq	US	31.2	90
Motorola	US	29.4	133

Source: OECD (1999)

Japanese firms, such as NEC and Toshiba, have specialised in memory chips. These are considered commodities, where production efficiency and economies of scale are important. The worldwide dynamic random access memory (DRAM) chip market is dominated by these firms along with the South Korean company, Samsung.

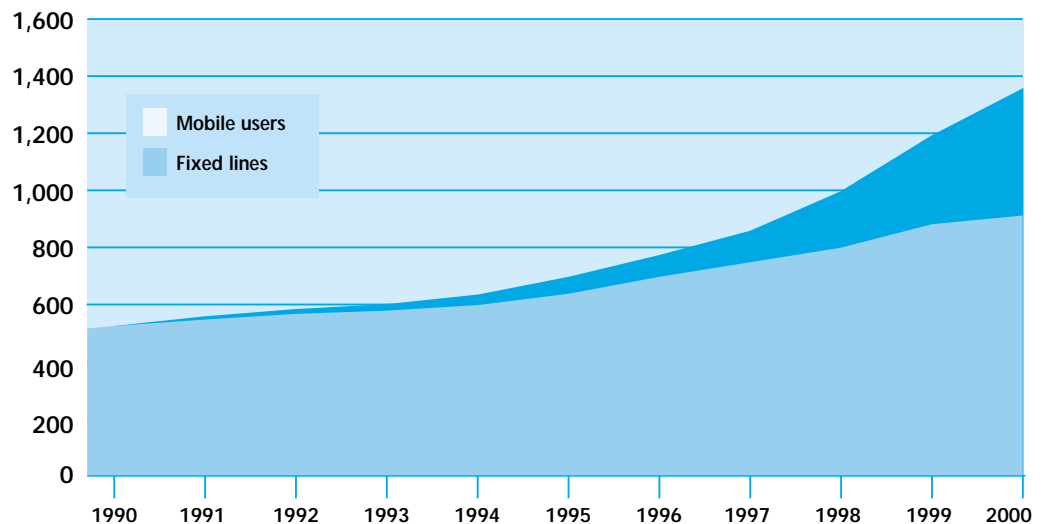
European semiconductor producers tend to specialise in niche markets, where they sometimes rank in leading positions.

European semiconductor producers ST Microelectronics, Philips and Infineon occupy the places 8 to 10 in the world ranking of this market segment by sales (in 2000). They tend to specialise in niche markets, such as applications for telecommunications and automotive components. However, in these smaller segments they rank in leading positions on a worldwide basis.

European firms also have a strong position in telecommunications equipment. In terms of telecommunications equipment revenues in 2000, the two largest companies were Ericsson and Nokia. In third position was the US company, Lucent, followed by another European company, Alcatel. Ericsson and Nokia have their particular strengths in mobile technology. Ericsson accounts

for about 40% of worldwide sales of mobile telecommunications infrastructure equipment, whereas Nokia has 30% of the worldwide sales of mobile handsets (Financial Times, 13 March 2001). These companies are favoured by the fact that mobile telecommunications is the most rapidly growing sub-market in the telecommunications industry. As Figure 2 shows, the number of mobile subscribers is growing at a much larger speed than the number of fixed lines. It is expected that within two years the number of mobile subscriber will exceed the number of fixed lines.

Figure 2. The evolution of fixed and mobile telecommunications lines in the world (in millions)



Source: ITU

New opportunities may arise for European companies from the Internet, but here too US firms have already been able to conquer leading positions.

New opportunities may arise for European companies specialising in telecommunications equipment with the convergence of information and communications technologies favoured by the emergence of the Internet. But also here, US firms such as Cisco and Oracle have already been able to conquer leading positions. Because of the strong network effects involved in these industries, early mover advantages are typically decisive for market leadership. While US companies are very successful in establishing dominant systems through market forces, European telecommunications equipment producers have proven to be more successful when there is also a regulatory element. For example, the coordinated development and introduction of GSM across Europe have been decisive in providing the momentum for making it also the most widely spread digital mobile communications technology worldwide.

Europe has developed a major position in software production (3) thanks to the growth of this sector in Ireland (see the Box). This country is the world's largest exporter of software goods, ahead even of the US (4). However, as all major EU countries are net importers, the EU net position is entirely due to Ireland.

3) The software sector is divided into products and services. Software products are commercially available packaged programmes for sale or lease. Software services instead refer to consulting, implementation and operations concerning the information infrastructure of a client.

4) In 1998 software exports were as follows: Ireland, USD 3.3 billion; United States, USD 3.0 billion; Britain, USD 0.7 billion; the Netherlands, USD 0.6 billion; Germany, USD 0.5 billion, and France, USD 0.3 billion.

Box. The Irish software industry

The software sector played a significant role in the development of the Irish economy, and was triggered off by massive foreign direct investment. Thirty years ago, when the first steps were being taken by the Industrial Development Authority (now IDA Ireland) to promote the software industry in Ireland, few could have imagined that this sector would develop as successfully as it has. Approximately 24 000 people are currently employed in the industry, which has combined annual revenues of over 6.6 billion. Nineteen of the top 25 computer companies in the world operate in Ireland (including Microsoft, Computer Associates, Oracle, Informix, Novell, SAP and Symantec) and together with the 400 indigenous companies they employ over 7 000 people. Over 40% of all packaged software and 60% of business applications software sold in Europe is produced in Ireland. Foreign owned firms accounted for 84% of total software revenue, and 88% of software exports from Ireland. This success was made possible by the combination of a favourable economic environment (low inflation, financial support schemes, tax concessions, low operating costs), a well-educated, young and English speaking labour force, and the development of a nation-wide software-oriented support infrastructure.

Sources: OECD (1999), Barry (1999), and www.jobsireland.com.

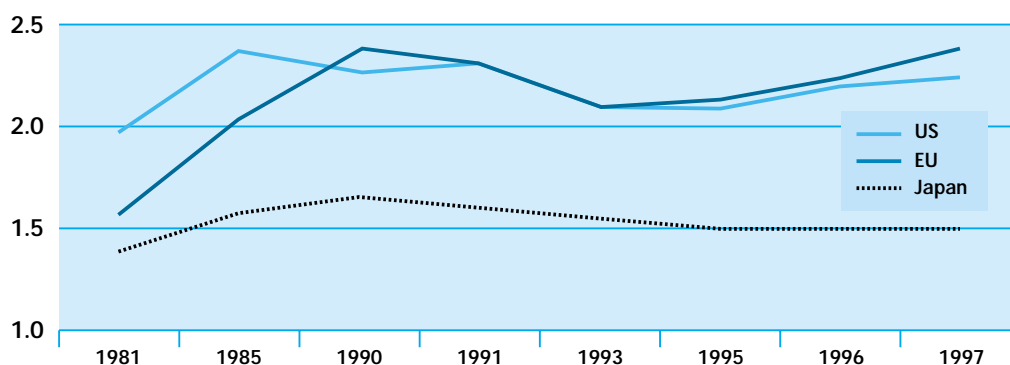
Market leadership through innovation

Firms operating in IT industries need to invest heavily in R&D to sustain the rapid pace of innovation. Along with pharmaceutical companies, IT firms are the main R&D spenders in the economy. For the world's top 20 IT companies, average R&D expenditure amounts to about 7% of total revenues (OECD, 2000a). This figure however conceals the R&D intensity of smaller companies, in particular in the semiconductor industry, where the R&D to sales ratio is typically in the 15-20 per cent range. R&D carried out in the ICT sector usually accounts for a large part of national R&D expenditure undertaken by the business sector.

EU industry is substantially less R&D intensive than US and Japanese industry.

Figure 3 shows the comparative evolution of business expenditure on R&D (BERD) as a share of the domestic product of industry (DPI). This shows that EU industry is substantially less R&D intensive than US and Japanese industry, both of which have a 50% higher relative spending. A closer look at the data also shows that Europe is not only spending less for R&D because it is specialised in less R&D intensive sectors, but also because it is spending relatively less on R&D in almost each sub-sector of the economy.

Figure 3. The evolution of business expenditure on R&D (BERD) as a percentage share of domestic product of industry



Source: OECD 1999.

Much innovation in IT is created by new firms (CEA, 2001; European Commission, 1995). Start-up firms also play a fundamental role in the adoption of IT. These companies are a source of permanent renewal of technology, of technological breakthroughs, and of competitive pressure for large incumbent firms, which are compelled to innovate in order to keep their technological edge. Unfortunately, Europe is also weak in creating new technology-based firms. Indeed, the US venture capital market is an example of a uniquely supportive climate for technology start-ups. Venture capitalists not only provide finance, but also match entrepreneurs with other resources that are crucial for the success of the company. Kortum and Lerner (2000), show venture capital financing significantly improves the success rate for innovative activity. The relatively slower development of venture capital markets in Europe may therefore contribute to the performance gap of Europe compared to the US in the IT sector.

Figure 4. IT and telecoms intensity and business R&D intensity in the EU (1999)



Source: Data from OECD and EITO.

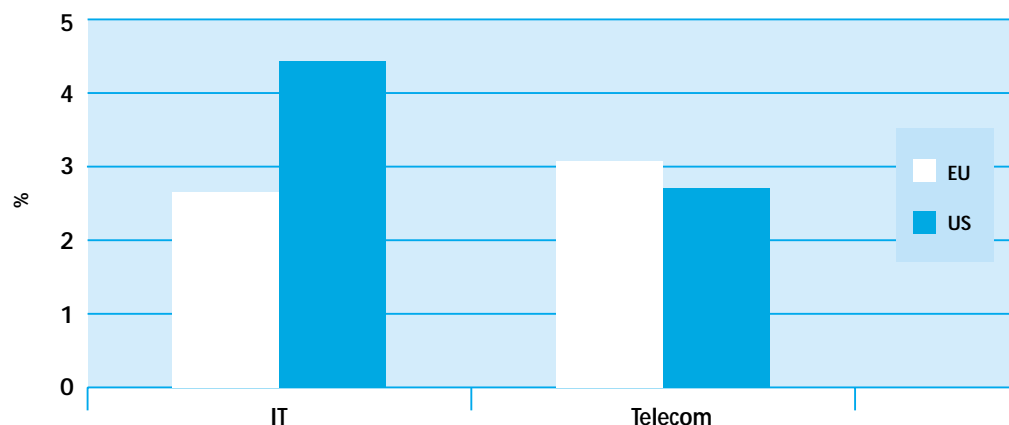
There could be an agglomeration pattern whereby IT adoption has cumulative effects.

Figure 4 shows how within the EU the R&D intensity is fairly closely correlated with IT intensity. This suggests that there could be an agglomeration pattern whereby IT adoption has cumulative effects. Conversely, there appears to be no significant relationship between telecommunications intensity and R&D intensity. With this in mind we now turn to factors influencing the demand for IT and telecommunications.

3. The demand and diffusion of IT

Over the last decade, firms in all sectors of the US economy have invested massively in IT (Sichel, 1997). As Figure 5 shows, Europe is far behind the US in terms of IT intensity: the IT market in the EU represents 2.7% of GDP, compared with 4.5% for the US (EITO, 2000). Thus, Europe is behind in both the production and the adoption of IT. Even though in an integrated world economy with extensive trade flows, one would expect that production should be of secondary importance, there seems nevertheless to be a link between competitiveness in production of IT and the adoption of IT.

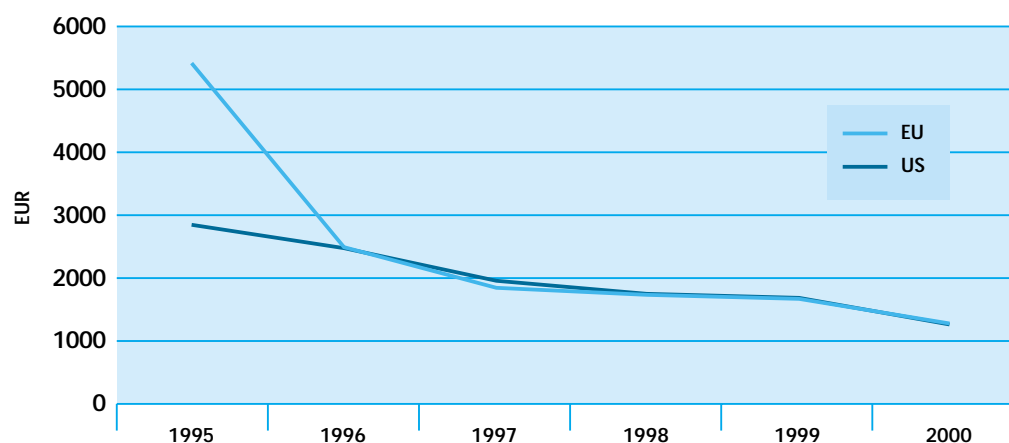
Figure 5. Share of information technology and communications expenditure as a percentage of GDP in 1999



Source: OECD

In general, prices for IT equipment in Europe are similar to those in the US. This is not surprising as it concerns internationally widely traded goods, which do not carry import duties. A significant price difference may, however, occur during the early stage of the product life cycle. The typical pattern then is as in Figure 6, which shows the evolution of the selling price of a representative PC (equipped with a Pentium-Pro processor) in Europe and the US. In the early stage US users benefit from a substantial price advantage, and this may induce US users to adopt innovations earlier than European users.

Figure 6. Price comparisons of PCs equipped with Pentium-Pro



Source: EITO

Figure 5 also showed that with respect to the telecommunications intensity of the economy Europe is ahead of the US. Table 4 shows the size market of the IT sub-sectors (5). What strikes here is the sheer size by which the European telecommunications equipment market exceeds the US market. Indeed, it is the only sub-sector where this is the case.

5) This Table refers to the market size in terms of sales of the sector. These figures should not be compared with the data on value added (Table 2) because of the different data sources which use slightly different sector definitions.

Table 4. The sub-markets for information and communication technologies in 1999 (in EUR billion)

	EU	US
IT hardware	98.6	141.2
Software	43.5	68.2
IT services	77.6	141.4
Total IT	219.7	350.8
Telecom equipment	58.1	23.8
Telecom services	192.1	189.7
Total telecom	250.2	213.5

Source: EITO (2000)

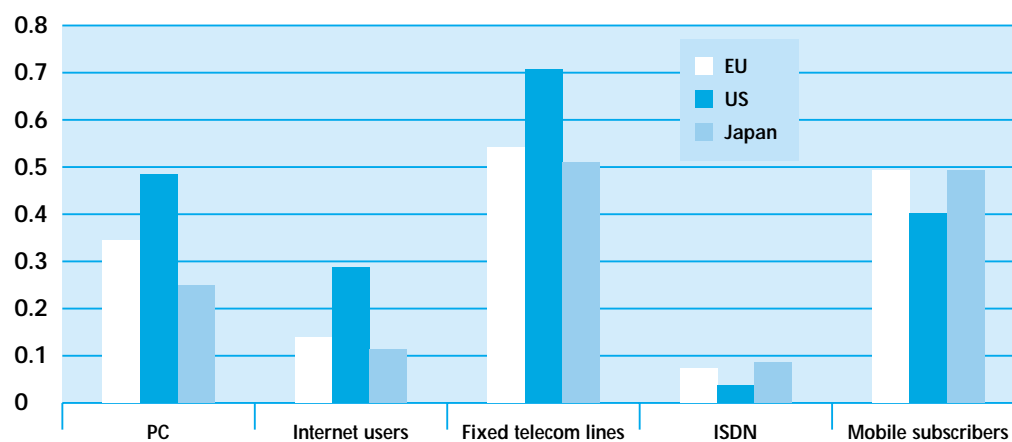
There could be structural reasons that prevent the European economy from assimilating IT.

There could be structural reasons that prevent the European economy from assimilating information technology. These may reside in a lack of skilled workers to operate IT, as well as organisational rigidities that weaken the incentives for companies and public sector institutions to adopt IT. A survey of the adoption rate of equipment for accessing the information and communication infrastructure (see Figure 7) shows that Europe is also lagging behind the US in the adoption of PCs, the predominant mode of access to the Internet. Therefore it is not surprising that Internet usage is lagging in Europe too. Figure 8 also shows that there is a huge diversity in the adoption of IT equipment within Europe. The average number of 35 PCs per 100 inhabitants varies from a maximum of 66 for the Netherlands to a low of 15 for Greece. Likewise, Internet access has also a very large variation across EU countries.

Europe is also behind in the diffusion on fixed telecommunications lines (see Figure 7). However, with overall penetration rates of more than 50 lines per head, all households and firms are connected, and differences in diffusion may not have important implications. Europe is also ahead of the US in the diffusion of enhanced data rate telecommunications access, such as ISDN. Finally, Europe is definitively leading in the diffusion of mobile telecommunications. As Figure 9 shows, in this sector the variation across EU countries is also less pronounced than for PCs and Internet access. Around the EU average of 65 lines per 100 inhabitants, there is a maximum of 75 for Austria and Sweden and a minimum of 50 for France. What is also interesting is that the usual ranking of high tech industries with Scandinavian countries in the lead and Southern European countries lagging, does not apply with the diffusion of mobile telecommunications.

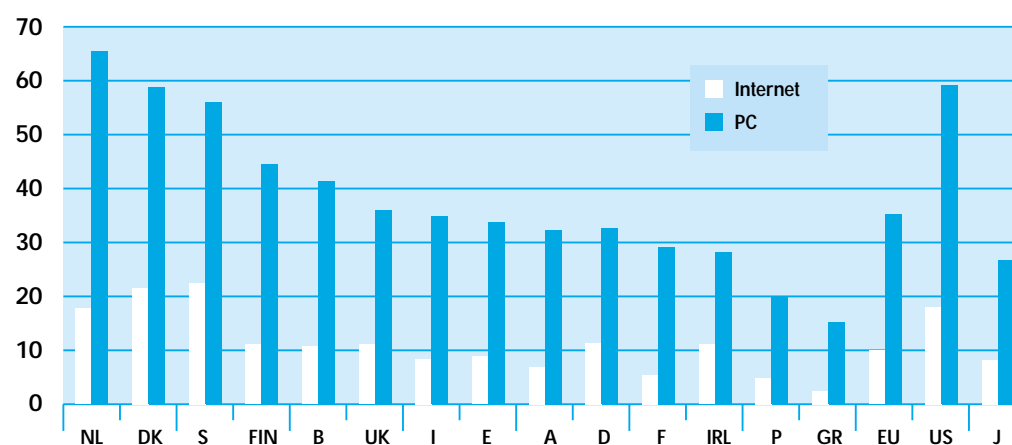
This raises the question on what makes Europe so much more successful in the telecommunications sector compared to IT. One answer may be related to a lack of exposure to IT equipment. Surveys (EITO, 2000; INRA, 2000) show that there are significant educational hurdles in the adoption of IT. A large share of the population, and this share increases with age, declare that they do not use IT because it is too complex. In the US there is a long-standing tradition of spreading computer literacy, starting at school. In Europe this is much less the case. For instance, Finland, which is Europe's most advanced country in the adoption of ICT, had one PC for 12 primary school pupils in 1997 (25 pupils for the EU on average). This compares with 6 for the US. A further implication of the low diffusion of computers in Europe is that teaching personnel are poorly trained to teach these new technologies. The bottom line is that the widespread adoption of IT needs a well-disposed environment of sufficiently well paid and skilled people, working within an economy prepared for innovation.

Figure 7. Adoption of ICT equipment (on a per head basis)



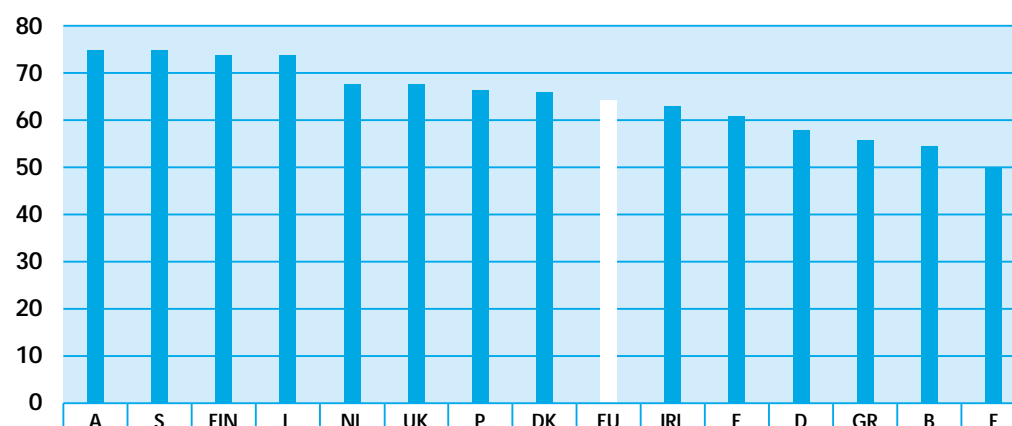
Source: EITO

Figure 8. Computer ownership and Internet access (per 100 inhabitants) in 2000.



Source: OECD (Internet) and INRA (PC).

Figure 9. Mobile telecommunications subscribers (per 100 inhabitants) in 2000.



Source: Mobile Communications

Note: December 2000 data

The policy environment needed for the “new economy” to thrive includes, investment in education, and liberal trade policies that induce competition and broaden the market opportunities for firms.

4. Policy issues

The fact that IT pervades all sectors of economic activity puts new challenges to policy makers. First of all, the “new economy” will not emerge spontaneously: it requires an appropriate economic policy environment to thrive. The experience of the US shows that this is a policy framework based on sound fiscal policy, investment in education, and liberal trade policies that induce competition and broaden the market opportunities for firms (CEA, 2001). European policy makers are aware of the shortcomings in Europe and are undertaking action to remedy the shortfall in both the production and diffusion of IT. Indeed, the issue is permanently on the agenda of European Council meetings and most national governments have launched initiatives in this field.

Some significant steps have been taken towards the provision of a liberal market environment. The diffusion of IT was supported by the worldwide trend of trade liberalisation such as the establishment of the Information Technology Agreement (ITA), by which the EU, US and Japan engaged to eliminate tariffs on semiconductors, computers, software and communications hardware by the year 2000. This had a significant impact on Europe, as these products typically carried import duties in the range of 5 to 15%. The ITA was complemented by the liberalisation of the European telecommunications market.

Market forces and private investment have always been the engines for economic growth. However, IT is central in shifting the economy towards the production of goods embodying knowledge rather than physical capital. R&D is the principal means by which knowledge capital is created, and this is exactly where Europe is not doing very well. On the IT production side, Europe loses out by not having a vigorous sector with above average productivity growth. On the diffusion side, the lack of resources reduces the propensity of an economy to absorb IT based innovations and to create new opportunities for further growth. Hence, there is the urgency for Europe to increase the resources for innovation, through larger R&D expenditure, both public and private.

Importantly, the nature of the R&D process has changed fundamentally. Innovation traditionally was a highly vertically integrated activity, performed by large firms working independently from each other. In the IT sector today innovation is performed increasingly by small firms in collaboration with each other, with academic institutions, and with government agencies. It is clear that the financing of innovation within a network of small firms requires completely different instruments compared to the world of innovation in large companies. Hence, there is an increased role for private equity and venture capital, which is geared towards financing high risk undertakings by small firms (Gompers and Lerner, 1999). Public bodies in most countries share the awareness that their task consists in removing bottlenecks, which impede private financing of investments in this field.

European policy makers are also keen on managing the social aspects of new technologies. In other words, public organisations not only have to safeguard competition and solve market failures: policy should also smooth as much as possible the social and economic frictions from the introduction of new technology. This objective, however, may be in conflict with the promotion of diffusion. To ensure a rapid diffusion of new technology more flexibility of the economy is required. Diffusion of new technology not only involves a reallocation of workers across sectors and firms, it also leads to a complete reshuffling of hierarchies and competences within firms. For instance, increased recourse

to IT means that supplier relationships become more integrated, shifting rapidly as strategic alliances are made with supplier, customers and even competitors. The most representative example of how IT has changed this is the introduction of procurement based on the Internet.

Dealing with the labour market consequences of IT requires education and training. The introduction of IT requires different skills compared with the previous form of work organisation. If a significant gap in the technical and cognitive skills of users persists, the critical mass for certain types of IT applications may not be generated. This may also help to explain failures in reaping the benefits of investment in IT, as the applications of new technologies may not have been adequately supported by organisational changes and upgrading of individual skills.

A second issue of social concern derives from the regional inequality in the spreading of IT (6). Today, IT technology is unequally spread across European countries. There are entire countries lagging behind; even in the more advanced countries there are regions and groups of citizens that are still excluded from access to the information society. In these cases, public institutions in the educational, cultural, medical, social and economic fields of local communities should provide the services the market is not able to provide.

5. Conclusions

The dramatic decline in the cost of processing and transmitting information has led IT to pervade all sectors of economic activity, leading the way to an economy that is information intensive. The convergence of IT with telecommunications has opened up the way to a whole range of new capabilities that were previously unimagined. Through the dynamic interaction of these powerful innovations, the economy has become "lighter", in the sense that products embody more knowledge and less physical capital. Investment in IT and in creation of knowledge has become a major part of total investment activity.

Evidence from the US suggests that the benefits from the shift to the "new economy" could be sustained productivity growth. Europe is trying to unleash a similar virtuous cycle. In this attempt, however, Europe is handicapped by its lagging position in both the production of IT and the adoption of IT. This paper has discussed the causes and the effects of these lags. Though there is considerable heterogeneity across countries, clear European shortcomings emerge. Europe is devoting far too little resources to innovative activity, both in terms of investment and in terms of human resources. Europe is also doing very little to valorise its innovative capability, by, for instance, creating new technology based firms.

The remedies suggested consist of stepping up the resources for innovation, improving the access to IT, increasing the investment in education, and in adopting policies favouring greater flexibility and entrepreneurial activity.

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6) For a description of the challenges see Brynjolfson and Kahin (2000), and OECD (2001).

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