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EUROPEAN COMPETITIVENESS REPORT 2001

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EXECUTIVE SUMMARY

This is the 5th edition of the Commission's Report on the European Competitiveness since the 1994 Industry Council Resolution that established the basis for the Competitiveness Report. Competitiveness in this Report is understood to mean a sustained rise in the standards of living of a nation and as low a level of involuntary unemployment as possible. The special theme of this Report is an analysis of the contribution of information and communications technologies (ICT) and of innovation to productivity and to economic growth. In addition, the Report contains a chapter on the innovative capacity of European biotechnology.

- Economic growth and the standards of living in the EU

Though for the EU the second half of the 1990s proved to be a better period in terms of employment and GDP growth than the first half, the gap in GDP per capita relative to the US widened throughout the decade. Moreover, in terms of labour productivity the EU catch-up with the US came to a halt in the middle of the decade and the gap has since then widened. Naturally, the overall EU performance hides a mix of good and disappointing performances among Member States. In the second half of the 1990s, Ireland, Luxembourg and Finland recorded the highest rates of GDP growth while scoring very high both in terms of employment growth and labour productivity growth. At the other end of the spectrum, Germany recorded the lowest GDP growth rate resulting from below average growth of employment and of labour productivity.

Empirical evidence indicates that roughly two-thirds of the gap in EU GDP per capita relative to the US can be attributed to a lower labour utilisation while a lower average labour productivity accounts for the remaining third.[1] During the second half of the 1990s, employment performance varied across the Member States with Ireland, Spain, Luxembourg, the Netherlands and Finland recording employment growth significantly higher than the EU average and the US while in all the remaining Member States employment growth fell short of the US performance. Productivity growth in Ireland, Luxembourg, Portugal, Finland and Greece was higher than in the US and considerably above the EU average.

Growth in labour productivity can in turn be attributed to capital deepening (changes in the capital/labour ratio) and technical progress, as measured by total factor productivity. In the second half of the 1990s, both components of labour productivity growth improved more in the US than in the EU. Furthermore, while historically the contribution of capital deepening to labour productivity growth has been substantially greater in the EU than in the US, in the second half of the 1990s this relationship was reversed.

A sustained improvement in standards of living, the ultimate goal of economic policy, requires substantive progress in production efficiency brought about by improvements in the stock of capital, in the form of new investment, and by technological progress. In other words, the economy must realise high growth in productivity. For this reason, understanding the forces supporting technological

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[1] Estimates for 1998, see European Commission (2000): "Economic Growth in the EU: Is a "New" Pattern Emerging?" Chapter 3 in the EU Economy 2000 Review, *European Economy*, n° 71.

progress and productivity growth is crucial for guiding policy towards achieving the ultimate objective of economic policy.

- **ICT and their contribution to productivity and economic growth**

An important common characteristic across the US economy and the EU nations whose economic performance compares favourably with that of the US is the pervasive use of information and communication technologies (ICT).

The resurgence of productivity growth in the US in recent years has been attributed to the adoption and diffusion of new technologies and to the accelerating pace of product and process innovations. In particular, the diffusion of ICT has been fundamental. These technologies now permeate a wide and ever-increasing set of activities in economic life. ICT can be seen both as innovation *per se* and – due to their general purpose character – as vehicles in the diffusion and the achievement of further innovation in other sectors and fields. As an example, many of the recent advances in the field of biotechnology and telecommunications would not have been possible were it not for the remarkable developments in computational speed and capacity.

The importance of ICT in the recent economic growth and productivity performance in the US and in some EU Member States has two aspects. First, the ICT–producing sectors, where spectacular technological advances have taken place, have directly contributed to increases in productivity and economic growth.

Clearly, if this was the only route through which ICT benefits economic performance, then only those countries with important ICT–producing sectors could be expected to reap the associated benefits.

However, the evidence suggests that the impact of ICT is not limited to the producing sectors alone but, as ICT is diffused throughout the economy, its impact becomes particularly evident in ICT–using sectors. The latter are, of course, present in virtually all facets of economic life. It is the general–purpose character of these technologies that makes it possible for other sectors using them to experience and benefit from significant improvements in productivity. As a result, the magnitude of ICT expenditure and investment in a nation may be more important for growth performance than the size of the corresponding ICT–producing sector. This is undoubtedly an important message since it implies that a low level of technology production in a nation may not necessarily inhibit productivity growth as long as the diffusion of new technologies is widespread and their take–up is efficient. In other words, nations that have virtually no production of ICT goods could still benefit substantially by adopting ICT innovations.

The growing consensus that the strong growth and productivity performance in the US is related to increased investment and diffusion of ICT goods and services has raised concerns that the weaker economic performance of EU Member States is caused by sluggishness in the adoption of these new technologies.

Recent empirical studies have estimated the contribution of ICT to aggregate economic growth. In the US, ICT investment accounts for 0.8 to 1 percentage point of output growth in the second half of the 1990s. Estimates for European countries generally indicate a lower contribution of ICT to output growth. On average, about

0.4 to 0.5 percentage points of output growth in Europe can be attributed to ICT. Compared to the US, Europe would appear to forego 0.3 to 0.5 percentage points of economic growth due to lower levels of investment in ICT.

The ICT spending gap between the EU and the US persisted throughout the 1990s, even though in both regions ICT expenditure increased. With regard to ICT investment in the business sector, the gap vis-à-vis the US is even larger. In 1999, US business investment in ICT as a percentage of GDP was almost twice the European level of 2.4 percent. Nevertheless, it should be noted that ICT spending in the EU Member States varies considerably. The UK and Sweden have already surpassed the US, and the Netherlands, Denmark and Ireland have drawn close to it, but some of the larger countries have performed less well.

The experience of the US but also of the smaller European nations that have successfully adopted ICT across economic activities suggests that a variety of complementary policies are necessary in order to reap the benefits of these technologies. The role of government policies has been important: these countries appreciated early the importance of ICT and acted decisively to remove obstacles that could inhibit their introduction and use.

An overriding priority in these countries appears to have been a commitment to a comprehensive strategy to facilitate the adoption of new technologies. They tackled issues such as upgrading labour force skills, encouraging the mobility of scientific and technical personnel across sectors and the modernisation of the regulatory framework, strengthening the interdependencies characterising the technology and innovation systems and also an explicit commitment to do things better. The early liberalisation of the telecommunications sector undoubtedly contributed to this process. Such measures made it easier for firms to adjust and adopt new organisational models and to modify their strategies to take advantage of the new technologies.

Finally, it is possible that the completion of the single market, with the intensification of competition, contributed to the understanding that smaller EU Member States had more to gain from economies of scale in a wider European market, and this could well have strengthened the commitment to develop strategies aimed at taking full advantage of ICT technologies in the Internal Market – for example though electronic commerce. It is possible that country size matters substantially more than many economists and policy makers would a priori assume, a possibility that has implications for the design of policies at regional level. Growth in biotechnology, as shown in the Report, also provides examples consistent with this possibility.

One of the critical findings of the OECD Growth Project is that improvements in the quality of labour are essential ingredients of medium–term economic growth. Yet, in recent years skill shortages in important technology areas have been reported in several European countries. At the root of this development has been the diffusion of ICT technologies coinciding with the liberalisation of telecommunication sectors and the expansion of the Internet and of new media. It appears that, unlike in previous years, when the long–term trend increase in the demand for skills was met by the supply of technology professionals from the educational system, the surge in demand for ICT–related skills in the 1990s found no corresponding supply forthcoming.

While the recent crisis in the valuation of Internet stocks may be taken to imply that the demand for ICT skills is falling off, this may be misleading. The medium–term demand for ICT skills will continue to be high as the European Union moves towards its goal, set at the Lisbon summit in March 2000, of becoming the world's most dynamic and competitive knowledge-based economy by 2010. It is essential, therefore, to ensure that skill shortages do not become obstacles to European growth.

- **Innovation and productivity in the manufacturing sector**

Modern theories of economic growth point to innovation as a critical determinant of productivity growth. Innovation is a complex process intertwined with factors such as the strength of the knowledge base, institutional arrangements, qualifications of the labour force, openness of the economy and an overall ability to take on board improvements achieved in other countries or sectors. Other than through own innovation, an economy may also improve its performance as a result of innovation diffusion or through technology embodied in inputs and new capital goods, which in turn may magnify the benefits of own research efforts. Indicators from the manufacturing sector that proxy different characteristics presumed to facilitate innovation and growth are indeed shown to be related to productivity and economic performance. Advances in ICT technologies belong to such innovation-fostering characteristics, and have played a crucial role in enhancing productivity.

A first step in understanding and identifying possible determinants of innovation performance is to study the relationship between one crucial input to innovation, research and development (R&D) expenditure, and performance indicators such as production and productivity growth. The Report finds evidence of such a relationship on data for the manufacturing sector.

During the 1990s, growth in production and in labour productivity in manufacturing in the EU was far below the rates recorded in the US, marking a reversal of the situation compared to the second half of the 1980s. Nevertheless, four countries – Ireland, Finland, Austria and Sweden – recorded both production and productivity growth rates in manufacturing above those in the US. During the 1990s, technology–driven industries experienced the highest productivity growth in the EU, followed by capital–intensive industries (in the latter group, the high growth took place mainly in the first half of the decade). In the US, technology–driven industries were likewise leading in terms of productivity growth throughout the 1990s. The good production and productivity performance of capital–intensive industries in the EU during the first half of the 1990s was most probably the result of the restructuring that took place in these industries.

Evidence from the 1990s suggests that research intensity and productivity growth are significantly related across sectors, both in the US and within the EU, though not in each Member State. This relationship suggests that research efforts play a role in fostering innovation and economic performance. At the same time, the absence of such a relationship at country level may be a sign that international spillovers are at work. Moreover, firm–level data for the EU and the US from the 1990s confirm these findings. This evidence is consistent with the importance that policy-makers attach to R&D.

If productivity performance depends significantly on technological advances resulting from innovation, and given that innovations are diffused internationally at a rather fast pace, the patterns of productivity growth should have become more similar across regions. Indeed, data indicate an increasing convergence between the US and the EU in terms of patterns of productivity growth. While in the 1980s US productivity growth across industries was significantly different from the EU, in the 1990s these patterns became more similar.

Productivity growth in technology–driven industries (for example, chemicals, pharmaceuticals, medical equipment, radio, TV and telephony equipment, motor vehicles, aircraft manufacturing, spacecraft, optical equipment), in both the US and the EU was faster in the second half of the 1990s than in the first. The impact of technology–intensive industries on overall productivity growth is greater in the US than in the EU, reflecting in part the larger share of these industries in the US economy.

When research intensity (R&D expenditure over production) and productivity growth are brought together across sectors in the US and the EU, the evidence is that high research intensity is never associated with low productivity growth, and low research intensity is usually associated with low productivity growth. Nevertheless, in the US certain sectors of low research intensity (tobacco products, apparel) have recorded high productivity growth whereas this has not been the case for the EU.

The manufacturing sector has benefited substantially from productivity advances associated with innovation during the 1990s. However, other factors have also contributed to production and productivity growth, such as the capabilities of firms, the stock of knowledge and ICT. Accumulation of these assets, many of which are intangible, often reflects strategic decisions on the part of businesses and constitutes the basis on which assets are built up in the future. This Report, in finding that these variables are important, provides some support for recent theories of economic growth that emphasise the role of institutions and strategic behaviour on the part of firms in economic growth.

The slump in the ICT sector in recent months has caused severe disruption to investment plans and to the diffusion of IC technologies in domestic economies as well as the international economy. Although these short-term developments are clearly disquieting, they should be considered in a medium-term perspective. The underlying factors that have contributed to the ICT expansion remain in place and hold the firm promise for further growth. In particular, prospects are good for continuous price declines of ICT goods, associated with the development of new, more advanced and more powerful semiconductors. These suggest that the process of ICT diffusion and ICT capital deepening will also continue for some considerable time. Furthermore, as a new generation of IC technologies comes into economic use, further reorganisation of the mode of production and exchange of goods and services will be necessary. And, finally, the structural reforms under way in Europe will undoubtedly play a supportive role in the adoption and diffusion of IC technologies.It is, therefore, virtually certain that substantial gains from information technologies and the associated innovations will be possible in the future.

- **Innovation and biotechnology**

Biotechnology is an industry where innovation has been at work at an impressive pace and with remarkable results. It is also an industry where some core issues of the innovative process are prominently present (small versus large firms, where the latter have often been instrumental in supporting the growth of the small ones, yet it is the former that are especially innovative; clusters of activity, where networking is an essential condition for dynamism and knowledge exchange; and inadequate financing). Thus, biotechnology offers a very good ground for analysis of comparative strengths in innovation and allows for the specific linking of innovation inputs such as research effort, human capital, institutional framework, firms' capabilities and collaborative arrangements, and innovation output such as patents, publications and new products or processes. In biotechnology as in other industries, innovative capacity and competitiveness coincide.

The distinctive features of innovation in this industry are the collaborative basis of research and the importance of small firms. Biotechnology highlights the importance of firms' "capabilities" – the ability to mobilise and exploit new knowledge and to reach out and exploit collaboration among agents and across stages of product development, scientific disciplines and industry frontiers. The sector is characterised by a new breed of agents, small specialised firms – Dedicated Biotechnology Firms (DBFs) – that have been developed with the explicit aim of exploiting the new technologies of life sciences for various industrial purposes. Although it took some time, the work of these firms is having a remarkable and radical impact, particularly in the health care sector.

Patent and collaborative project data indicate that the US has accumulated and maintains a dominant advantage in innovative activities in biotechnology compared to Europe.. There is now agreement that this leadership originates essentially in the strength of its DBFs and, more generally, in the development of a deep market for technology. Nevertheless, some of the smaller European countries (Ireland, the Netherlands and the Nordic countries) appear to specialise successfully in biotechnology niche markets. Also a spectacular increase has been observed recently in the number of new firms'– from 1996 to 2000 the population of independent European DBFs almost doubled to close to 2 000 – and in the clustering of research and production in Europe.

The distribution of biotechnology DBFs in Europe is dominated by a relatively small number of clusters that are located mainly in parts of Germany, the UK, France and in some areas of the Baltic coast.

Biotechnology involves the exploration of an enormous area of imprecisely defined opportunities. Consequently, for a successful biotechnology sector it is necessary to have both a decentralisation of efforts and a diversity of approaches, as well as an ability to co-ordinate these elements.

It may be argued that Europe's lag behind the US in biotechnology is partly a reflection of its late entry. Innovative activities are generally characterised by increasing returns, and being first confers long-lasting leadership. But this may not be the only factor. A fundamental precondition for a successful development of biotechnology is the availability of leading edge scientific capabilities – without a strong and diversified scientific research base, no technological take–off is possible. Moreover, success in this industry depends on a delicate blend of competencies and incentives and requires the integration and co-ordination of several differentiated agents, capabilities and functions. In particular, new European DBFs are generally smaller than their US counterparts, less active in global networks and collaborative relationships and less present in markets for these technologies. Access to an international scientific community requires direct and active participation in networks of scientists. One finding of the Report concerning European biotechnology is that whilst Europeans carry out a level of biotechnology research in the US that is comparable to that in other sectors, comparatively little US research is done in Europe. The apparent unattractiveness of Europe to US research appears to be particular to biotechnology.

US research in life sciences has undoubtedly benefited from massive public support, while European efforts in this area have remained fragmented. Moreover, the European research system in the area of biotechnology appears to be weak in terms of organisational diversity; specialised in rather narrow fields and insufficiently interconnected across different research areas, types of organisations, stages of the research process and national borders. European DBFs are still far too small to make maximum use of networks of collaborative research. Thus, their ability to grow appears severely constrained. Finally, DBFs exist in a relationship of strong complementarity with the large corporations. The latter are not only the fundamental source of demand for the products and services of DBFs but, equally importantly, they also provide the integrative capabilities that transform fragments of knowledge into products and constitute precious reservoirs of technological and managerial competencies. Especially in Europe, DBFs have been, and may increasingly become, spin–offs of large incumbents, rather than of universities, as in the US. Supporting the creation of DBFs may raise the competitiveness of the “downstream” industries, mainly pharmaceuticals.

Several Member States have had policies to promote biotechnology in place for several years. Although there has been some success, notably in the promotion of biotechnology start-ups, the growth of DBFs in Europe appears to be hindered. To a considerable extent, this may be due to regulatory, entrepreneurial, fiscal or financial factors. However, in addition to these factors, the supply of cutting edge scientific research may be inadequate. If so, this problem could be addressed not only through higher levels of research funding but also through more pluralism in funding sources, lower dependence on closed national systems and higher integration of research with teaching, clinical research and medical practice.

CHAPTER I:
INTRODUCTION

A prominent objective of the EU in recent years has been to improve the environment in which firms conduct business. This was explicitly set out in the conclusions of the Lisbon European Council of March 2000 where it was stressed that the "competitiveness and dynamism of businesses are directly dependent on a regulatory climate conducive to investment, innovation and entrepreneurship"[2]. Entrepreneurial dynamism is a pre-condition of economic and employment growth, wealth creation and raising standards of living. The ultimate objective set out in the Lisbon European Council (that the EU becomes the most competitive and dynamic knowledge–based economy in the world over the decade, capable of sustainable economic growth with more and better jobs and greater social cohesion) can only be reached through a set of policies central to which is the flourishing of entrepreneurship.

The European Commission contributes to this goal through various policy instruments falling under its responsibility. However, the principal areas where changes are necessary are the responsibility of the Member States. In recognition of this, and in order to implement the strategy, the Lisbon Council introduced a new open method of coordination among the Member States. Central to this method in the area of enterprise policy is the study of best practices, the possibility of learning, exchanging information and adopting such best practices between the Member States, and arriving at policy decisions according to the specific circumstances of each Member State.

Responding to the demands addressed to the Commission by the Lisbon European Council, the Directorate General for Enterprise has structured its work around three main activities:

- Production of *Scoreboards*. Scoreboards provide systematic comparisons of the performance of the Member States among themselves and with the best performers in the world – the Enterprise Scoreboard and the Innovation Scoreboard. Scoreboards pose rather than answer questions concerning various aspects of entrepreneurship, innovation and market access.

- The *Best Procedure.* This procedure revolves around the joint analysis with the administration of each Member State of a select number of practical issues of particular concern to enterprise policy.

- The *Competitiveness Report,* the *Observatory of European SMEs,* and other studies of similar importance and orientation in the area of *Innovation.* These constitute in-depth analyses of themes of particular interest to the performance of European industry, European SMEs and European innovation systems. These studies tend to be analytical in nature and their purpose is to build a body of diagnosis and knowledge about European enterprise and innovation performance, and to provide formal arguments that support the Commission's policy approaches.

In addition, a fourth activity centred on using quantitative targets and aimed at focusing better in the implementation of enterprise policy was launched in autumn 2001.

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[2] See Presidency Conclusions, Lisbon European Council, 23 and 24 March 2000. The message of the Lisbon Council was reiterated in the Conclusion of the Stockholm European Council; see Presidency Conclusions, Stockholm European Council, 23 and 24 March 2001.

- *Quantitative targets in enterprise policy*. Following the Stockholm Council Conclusions, the Member States have been invited to set quantitative targets in the area of enterprise policy with a view to strengthening the momentum towards the Lisbon objectives. To this effect, the Commission has already initiated the first steps in developing this voluntary and non-legislative method of coordination.

The present Competitiveness Report, which has been produced in accordance with the Council Resolution of 21 November 1994 on strengthening the competitiveness of the European industry, reviews the performance of the EU in terms of the ultimate goals of economic policy, the growth of incomes and the creation of employment. The Report will be released in time for examination and debate by Industry Ministers in December 2001. The 2001 Report is devoted to issues that are crucial for the attainment of the ultimate goals of economic policy, that is, issues of innovation in the EU and, more precisely, innovation in the manufacturing sector. While its share in economic activity and employment has been declining, the manufacturing sector has nevertheless seen impressive productivity gains, reflecting partly the impact of competition that has necessitated fundamental restructuring, a process that is still unfolding.

The resurgence of output and productivity growth in the US in the second half of the 1990s, and the failure of several Member States to measure up to this, has raised concerns across the EU about the sources and implications of these developments. This productivity resurgence does not reflect innovations implemented on the shop floor but rather new methods of organisation and work and of using technology among white–collar staff. Analysis of these developments has underlined the importance of innovation, especially in the information and communications (ICT) sector, for the acceleration in productivity growth.

ICT innovations are having a pervasive impact on economic performance. Technical progress in the semi-conductors industry since the 1960s has been such that there has been a steady decline in the price of ICT products throughout the past half-century. This decline has been transmitted to the rest of the economy through the decline in the price of ICT products – computers, computer software and telecommunications equipment. In turn, the wide application of ICT, especially in the areas of computing and telecommunications, has led to a rapid decline in the price and cost of these and of a variety of other products.

The consequent decline in the cost of ICT capital has provided powerful incentives for substitution away from other forms of capital and from some labour services. Indeed, a capital–deepening process, which has characterised European growth throughout the post-war period, has accelerated in several countries. The increasing use of ICT in various sectors of the economy is contributing not only to further substitution in favour of newer types of capital but also to capital for labour and to cost reductions across all sectors. Evidence already suggests that layers of management and support staff have been replaced by new technological initiatives and organisational changes in the US and to a lesser extent in Europe.

One area of concern for European policy makers is currently the area of biotechnology. Biotechnology is a sector characterised by rapid innovation undertaken to a large extent by innovative SMEs. As in other areas of technology and innovation, the US is currently leading commercial biotechnology research and applications. However, European research is also strong and promises to develop and compete internationally if structural, institutional, financial and legal problems are addressed appropriately. The Report reviews the complex circumstances that determine Europe’s performance in biotechnology and identifies possible reasons for its weakness compared to the US.

The Report centres around three broad questions:

- Is innovation an important element for economic growth and productivity?
- Can innovation account for differences in economic growth and productivity across the EU and across the Member States within the EU and for the growth and productivity gap between Europe and the US?
- Is Europe making sufficient progress towards the pace of innovation and commercial use observed in the corresponding US performance?

The Report is laid out as follows.

Chapter II reviews evidence on developments in economic growth and standards of living in the EU and the Member States, especially in comparison with the US. Chapter III examines the sources of productivity growth and its relation to ICT. This chapter examines data and evidence from both the US and Europe on the importance of ICT in productivity growth especially in the 1990s.

Chapter IV reviews the impact of innovation in manufacturing performance again drawing comparisons between the experience of the EU and the US. Clearly, the role of R&D is crucial here. While Europe's overall productivity performance worsened when compared to the US in the second half of the 1990s, less divergence is recorded in the manufacturing sector. This chapter also reviews the factors contributing to growth across the individual EU Member States.

The final Chapter V is an extensive case study of the innovative capacity of the European biotechnology industry. This sector has been characterised by rapid innovations, most of which have been initiated in the US and often by European firms. Europe is encountering a variety of problems in realising the potential of this sector, and there is ample evidence that European researchers patent their innovations and set up their companies in the US. There are signs that in recent years activity has strengthened in Europe and it is possible that European biotechnology will be in a position to compare favourably with the corresponding US sector in coming years. The chapter explores some of the major factors behind the so far timid but fundamentally worrying trends in European biotechnology and concludes with a diagnosis of major problems and a discussion of possible responses.

CHAPTER II:
ECONOMIC GROWTH AND STANDARDS OF LIVING

2.1. Introduction

A nation's economic growth is determined by the rate of utilisation of the factors of production – capital and labour – and the efficiency of their use. Traditionally, economic growth in Europe has been characterised by increased use of capital relative to labour and by high productivity growth [3]. Productivity growth in particular has been notably higher than in the US throughout the past quarter century, reflecting a convergence process. However, in recent years new trends have emerged with output and productivity growth in the US outstripping that in the EU. This has raised important questions about the underlying determinants of these developments and their implications for growth and standards of living in the EU. It has also been recognised that, to reverse these developments, structural reforms and policies that support competitiveness and innovation are essential[4]. Competitiveness in the sense used in this report refers to the ability of an economy to provide its population with high and rising standards of living and high rates of employment on a sustainable basis[5]. These ambitions could be thwarted should productivity growth in the EU fail to accelerate in a sustainable manner.

Until recently, economic growth was analysed in a framework that essentially linked output to factor inputs (a production function). However, recent research on the determinants of growth has not only refined this framework but has also extended it and has considered a broader set of factors seen as contributing to growth. It has now become clear that, apart from the quantity and quality of factor inputs, other factors also play a crucial role in a process where economic dynamism and innovation flourish. Such factors include organisational characteristics, interactions between economic policies and economic agents, as well as relationships between economic agents. The analysis also points to a role that policy makers can play in creating an institutional framework that is conducive to innovative activity and enhanced human skills.

This chapter reviews evidence about recent EU performance with regard to various indicators reflecting competitiveness and standards of living, and compares the EU with the US and Japan. Annex 1 provides an overview of the various theories which examine the causes of economic growth. Annex 2 summarises the conclusions of the OECD's recent Growth Project.

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[3] See Crafts and Toniolo (1996) and van Ark and Crafts (1996).

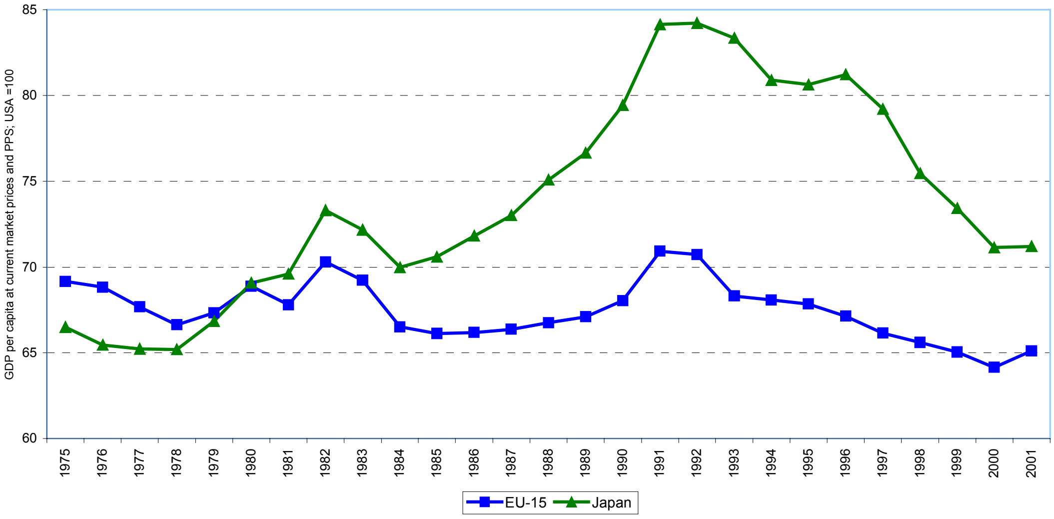
[4] See point 5 of Presidency Conclusions of the Lisbon European Council on 23-24 March 2000, available on the website of the Council at: http://ue.eu.int/en/Info/eurocouncil/index.htm.

[5] The European Commission (1996 and 1998) adopted a concept of competitiveness along these lines. Clearly, this concept differs from what is conventionally regareded as constituting competitiveness, that is, the relative price of a specific product or industry output originating in different nations in world markets. While important, the latter concept finds no counterpart where national competitiveness is concerned. Moreover, it implies that losses of competitiveness correspond to losses of output. While this may be correct for specific industries, it is not meaningful when a nation's competitiveness as a whole is under review.

2.2. GDP per capita as indicator of living standards

Over the past decade the EU has seen a sustained deterioration of its standards of living compared to the US, as measured by per capita gross domestic product (GDP). Graph II.1 shows that in 2000, the EU's relative standard of living compared to the US was lower than ever in the preceding quarter century. This undoubtedly reflects the exceptional growth performance of the US during the 1990s. Japan has also experienced a similar performance, but its relative position has deteriorated more sharply than that of the EU, and from a higher peak of around 85 percent of the US level in the early 1990s.

Graph II.1: GDP per capita: widening gap vis-à-vis the US



Source: Commission services.

The EU–15 aggregate conceals significant differences in the performance of individual Member States. Luxembourg has a per capita GDP nearly 20 percent above the US level (Table II.1). In three Member States (Greece, Portugal and Spain), GDP per capita is between 45-55 percent of the US level, while in the remaining eleven Member States, GDP per capita ranges from 60 % to 80 % of the US level.

During the 1990s, Ireland and Portugal converged further towards the EU average. In particular, Ireland has caught up in a spectacular manner. In the late 1980s, per capita GDP in Ireland was less than half that of the US. As a result of average annual GDP growth of over 7 percent, Ireland now has the second highest per capita GDP in EU-15, second only to Luxembourg and at 80 percent of the US level.

Table II.1: GDP per capita in EU Member States, US and Japan in 2001 (US=100)

Luxembourg	127
Ireland	80
Denmark	78
Netherlands	77
Belgium	73
Austria	71
Finland	68
Germany	68
United Kingdom	67
Italy	66
Sweden	66
France	64
Spain	53
Portugal	48
Greece	45
EU-15	**65**
United States	100
Japan	71

Source: Commission services.

2.3. GDP growth

The second half of the 1990s was a period of solid growth in the EU. After declining in the first half of the 1990s, employment growth rebounded and the growth of GDP accelerated in all the Member States except Germany (see Table II.2). Yet, the US did even better in terms of both GDP growth and employment creation; similarly, labour productivity growth in the US was significantly higher than in the EU. A key question is why the EU has been unable to match the strong performance of the US.

In the second half of the 1990s, three Member States stood out with their high GDP growth: Ireland, Luxembourg and Finland registered annual growth rates of 5 percent or above. Germany and Italy recorded the lowest annual growth rates, not exceeding 2 percent. The EU average of 2½ percent compares to 4 percent annual growth in the US.

The following sections will discuss the main components of GDP growth in the EU, the US and Japan. It should be noted that population growth in the EU has been slower than in the US, implying that the growth differentials in GDP per capita are smaller than those in GDP growth. Nonetheless, as the preceding section showed, the US performance has been superior to that of the EU also in terms of GDP per capita growth.

Table II.2: Growth of real GDP in EU Member States, US and Japan in 1975-2001

(average annual growth in percent, ranked according to performance in 1995–2001)

	1975-1985	1985-1990	1990-1995	1995-2001
Ireland	3,5	4,6	4,7	9,1
Luxembourg	2,4	6,4	5,4	6,1
Finland	2,9	3,3	- 0,7	4,9
Netherlands	1,9	3,1	2,1	3,7
Spain	1,6	4,5	1,5	3,7
Greece	2,1	1,2	1,2	3,5
Portugal	3,0	5,5	1,8	3,4
Sweden	1,5	2,3	0,6	2,9
United Kingdom	1,9	3,3	1,6	2,8
Belgium	2,1	3,1	1,5	2,8
Denmark	2,1	1,3	2,0	2,6
Austria	2,4	3,2	2,0	2,5
France	2,4	3,3	1,1	2,5
Italy	3,0	2,9	1,3	2,0
Germany	2,2	3,4	2,0	1,8
EU-15	**2,3**	**3,2**	**1,5**	**2,6**
United States	3,4	3,2	2,4	3,9
Japan	3,8	5,2	1,5	1,1

Source: Commission services.

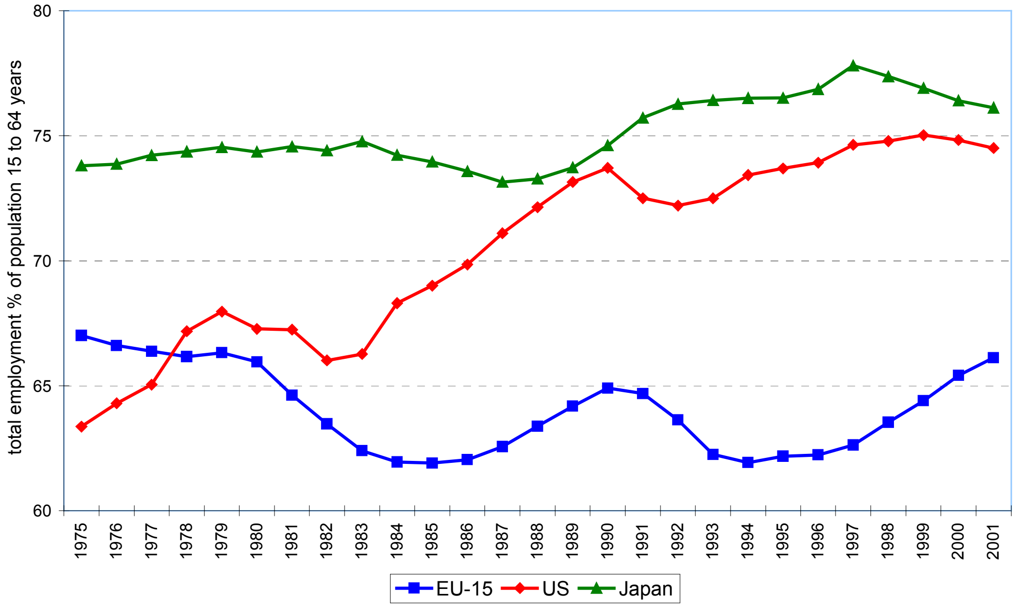
2.4. Employment growth and labour productivity

GDP growth can be broken down into employment growth and growth in the average output per employed person. The former is illustrated by trends in the employment rate, i.e. the proportion of working-age persons who are in employment. The latter, average labour productivity, implicitly captures the impact on output growth of all variables other than employment growth, such as capital investment, technological progress, or increases in human capital.

Graph II.2 shows that Japan has an employment rate above those in the EU and the US, even though the sustained increase seen in the US in the 1990s brought its employment rate very close to the Japanese level. While the US and the EU had similar employment rates in the late 1970s, in subsequent years the US saw an increase of some 10 percentage points to approximately 75 percent by 2001. The EU, in contrast, failed to raise its employment rate, which at present is 66 percent.

EU leaders, at their summit in Lisbon in March 2000, agreed on a target of raising the employment rate by 9 percentage points by 2010. This would roughly correspond to closing the actual employment gap with the US.[6, 7]

Graph II.2: Although increasing, EU employment rate far below US level



Source: Commission services.

Strong employment growth has contributed significantly to US economic growth over the past decades. EU performance has been more variable. A study by the European Commission (2000) looked at the contribution of labour inputs to growth, using a broader definition of labour inputs than just the employment rate.[8] In the first half of the 1990s, the estimated contribution of labour inputs to growth in GDP per capita was negative in the EU, due to declining employment rates and reductions in working time. Although the average hours worked continued to decline, the overall labour contribution to EU growth turned positive in the second half of the decade, when employment increased and participation rates rose. Nevertheless, the labour contribution to per capita GDP growth in the second half of the 1990s was only one third of that in the US.

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[6] This employment rate target is set on the basis of data from the Labour Force Survey, which differ from the national accounts definitions used elsewhere in this Chapter. The official target is to raise the employment rate from the 61 per cent in 2000 to as close as possible to 70 per cent by 2010 (both in terms of Labour Force Survey data).

[7] Presidency Conclusions of the Stockholm European Council on 23-24 March 2001 and the Lisbon European Council on 23-24 March 2000, available on the website of the Council at: http://ue.eu.int/en/Info/eurocouncil/index.htm.

[8] The European Commission (2000) breaks down the labour contribution to per capita GDP into four components: i) demography (share of those of working-age in total population); ii) labour force participation rate (share in working age population of those who work or are actively looking for a job); iii) extent of unemployment (total employment as proportion of the labour force); and iv) average hours worked per person in employment. In 1998, all these components except the proportion of working age persons in total population were more favourable in the US.

Estimates for 1998 indicate that lower labour utilisation in EU-15 accounted for two thirds of the gap with the US level of per capita GDP, while the remaining third was due to lower average labour productivity.[9] A variety of causes are behind the lower level of labour utilisation. While high unemployment is a major cause for concern, shorter working hours may instead reflect a social preference for leisure time over additional income.

Among the Member States, employment rates range from 56 percent in Greece to 77 percent in the Netherlands (Table II.3). The Netherlands, Sweden and Denmark have employment rates comparable to or higher than the US. Since the mid-1990s, employment increased at the highest rate in those five Member States which registered the highest GDP growth rates in the EU (Ireland, Luxembourg, Finland, the Netherlands and Spain).

Table II.3: Employment growth in EU Member States, US and Japan in 1975-2001, and employment rates in 2001

(average annual growth in percent, ranked according to performance in 1995-2001)

	1975-1985	1985-1990	1990-1995	1995-2001	Employment rate in 2001
Ireland	0,0	1,1	1,9	5,1	68
Spain	- 1,6	3,3	- 0,5	2,8	59
Luxembourg	0,0	1,4	0,5	2,6	66
Netherlands	0,5	2,3	1,1	2,6	77
Finland	0,5	0,3	- 3,8	2,0	66
France	0,2	1,0	- 0,2	1,2	63
United Kingdom	- 0,2	1,8	- 0,9	1,2	71
Belgium	- 0,4	1,0	- 0,2	1,1	60
Italy	0,8	0,8	- 0,7	1,1	59
Denmark	0,5	0,1	- 0,5	1,0	76
Sweden	0,5	1,0	- 2,2	0,9	75
Greece	1,2	0,7	0,6	0,7	56
Germany	0,2	1,4	- 0,3	0,6	69
Austria	0,1	0,7	0,2	0,6	74
Portugal	- 0,3	1,1	- 0,5	0,4	73
EU-15	**0,1**	**1,4**	**- 0,5**	**1,2**	**66**
United States	2,2	2,0	0,9	1,4	75
Japan	0,9	1,0	0,7	0,0	76

Source: Commission services.

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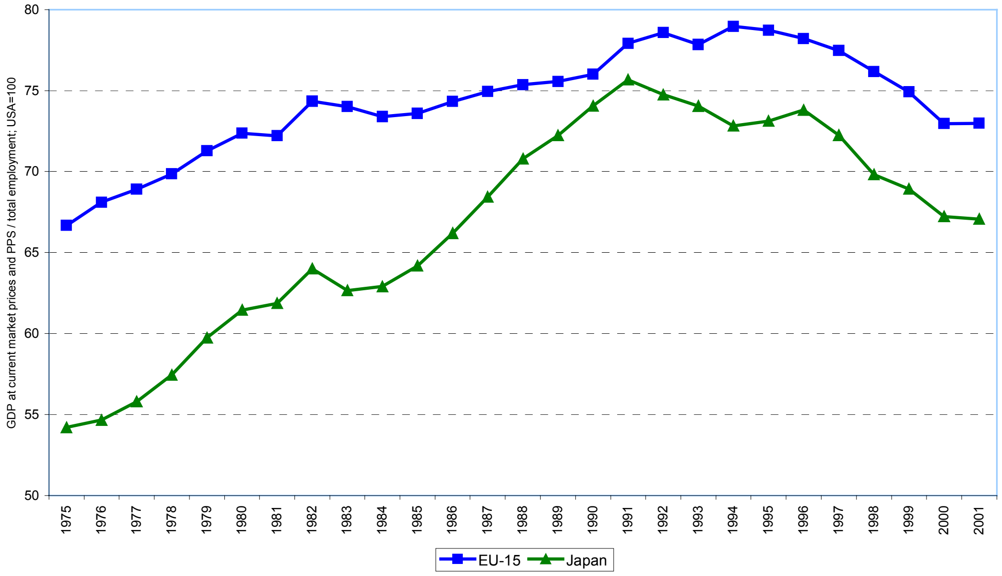
[9] See European Commission (2000).

The long term trend in the EU towards catching up with the US in labour productivity came to an end in the mid-1990s, when the productivity gap started to widen again (Graph II.3). In the second half of the decade, the rapid acceleration of labour productivity growth in the US and the simultaneous slowdown in the EU led to a new widening of the productivity gap vis-à-vis the US (see Table II.4). Of the EU Member States, only Luxembourg has a higher level of labour productivity than the US. In the majority of the Member States, labour productivity is currently between 60-80 percent of the US level.

Graph II.3: Labour productivity in the EU falls further compared to the US



Source: Commission services.

Table II.4: Labour productivity in EU Member States, US and Japan in 1975-2001

(average annual growth of GDP/employed person in percent, ranked according to performance in 1995-2001)

	1975-1985	1985-1990	1990-1995	1995-2001	Labour productivity in 2001 (US=100)
Ireland	3,5	3,5	2,7	3,9	87
Luxembourg	2,3	5,0	4,9	3,4	145
Portugal	3,3	4,4	2,3	2,9	48
Finland	2,4	3,0	3,2	2,9	76
Greece	1,0	0,5	0,7	2,7	59
Austria	2,3	2,5	1,9	1,9	70
Sweden	1,0	1,2	2,8	1,9	67
Belgium	2,5	2,1	1,7	1,6	92
United Kingdom	2,2	1,5	2,5	1,6	72
Denmark	1,6	1,2	2,5	1,5	76
France	2,3	2,2	1,2	1,3	78
Germany	2,0	2,0	2,3	1,2	71
Netherlands	1,4	0,8	1,0	1,0	72
Italy	2,2	2,0	2,0	0,9	82
Spain	3,2	1,2	2,0	0,9	65
EU-15	**2,2**	**1,8**	**2,0**	**1,3**	**73**
United States	1,2	1,2	1,5	2,5	100
Japan	2,9	4,1	0,8	1,1	67

Note: Growth rates were calculated on the basis of GDP at constant 1995 prices and national currencies, while the 2001productivity levels are based on GDP at current market prices and PPS.

Source: Commission services.

Table II.5 illustrates the breakdown of GDP growth in the Member States into employment growth and labour productivity growth.[10] Countries are classified in groups according to whether their performance was above, close to or below the average. The benchmark for these comparisons is the average EU growth rate of the respective variable. In Ireland, Luxembourg and Finland, high GDP growth in the second half of the 1990s was associated with both strong employment growth and rapidly rising labour productivity. These three Member States registered the highest GDP growth rates in the EU.

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[10] Annex 1 to Chapter IV provides more information on the national developments and strategies of individual Member States.

The fourth and fifth in terms of GDP growth were the Netherlands and Spain: growth in these two countries was based mainly on a solid increase in employment, while labour productivity increased only moderately. Above-average growth of labour productivity in Portugal and Greece reflects that they are continuing to catch-up with the rest of the EU; despite rapid productivity growth, their productivity levels are still clearly below the EU average (Table II.4). The performance of the five largest Member States was below, or close to, the EU average.

Table II.5: Employment and labour productivity growth, 1995-2001

		Employment growth		
		< average	Close to average	> average
Labour productivity growth	< average		Italy	Spain
	Close to average	Germany Japan	Belgium UK Denmark France	Netherlands
	> average	Greece Portugal Austria	US Sweden	Ireland Finland Luxembourg

Note: On both axes, countries are compared to the average annual growth rate in EU-15 in 1995-2001. Total employment growth in the Member States ranged from 0.4 percent to 5.1 percent p.a. The category ‘close to average’ includes countries with a growth rate of +/-0.4 p.p. around the EU average of 1.2 percent.

Labour productivity growth ranged from 0.9 percent to 3.9 percent p.a. among the Member States. The category ‘close to average’ includes countries with a growth rate of +/-0.3 p.p. around the EU average of 1.3 percent.

Source: Commission services.

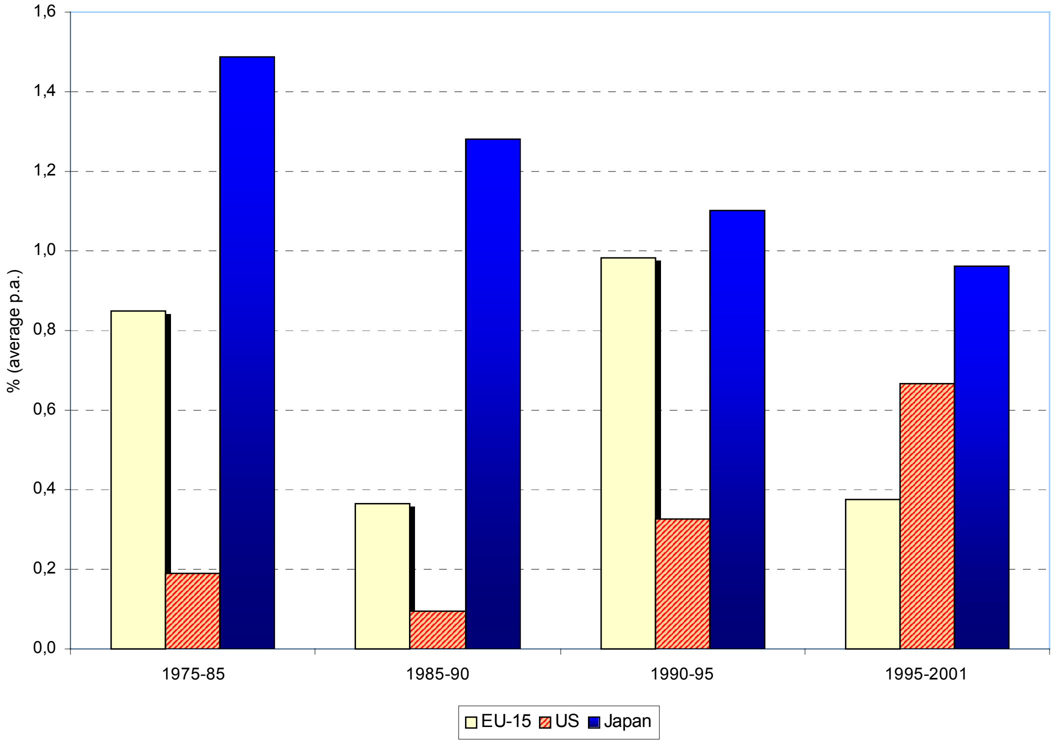
2.5. Capital deepening and technological progress

Labour productivity growth is determined by capital deepening, i.e. growth in the stock of capital per employed person, and technological progress, measured by growth in total factor productivity (TFP).

Capital deepening is a long-term process determined primarily by investment. In the short run, changes in employment can have a great impact on the capital/labour ratio. An increasing capital/labour ratio in the EU helped it to catch-up with the US in terms of labour productivity until the mid-1990s (Graph II.4 and Table II.4). It should, however, be stressed that declining employment explains a considerable part of the increase in the capital/labour ratio in the first half of the 1990s.

In the second half of the 1990s, capital deepening was very rapid in the US, whereas there was a clear slowdown in the EU. The rise in US investment was linked to the rapid increase in the quality of information and communication technology (ICT) products, combined with a steep decline in their relative price, which decisively boosted ICT investment.[11]

Graph II.4: Capital deepening in EU, US and Japan



Note: The figures indicate how much (in percentage points) capital deepening, or the substitution of capital for labour, contributed to overall labour productivity growth. See also footnote 12.

Source: Commission services.

For the EU Member States, changes in the capital/labour-ratio in 1995-2001 were strongly correlated with changes in employment. Portugal, Greece and Austria, where capital deepening was most marked, were among the weakest performers in terms of employment growth (Tables II.2 and II.4). The opposite is true for Ireland, the Netherlands and Finland, where strong employment growth led to a declining capital/labour-ratio. In contrast, the US registered rapid growth regarding both employment and investment; both factors contributed significantly to US economic growth in the second half of the 1990s.

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[11] For more information on ICT investment in the EU and the US, see Chapter III.

Table II.5: Capital deepening in EU Member States, US and Japan in 1975-2001
(average annual contribution to labour productivity growth in percentage points; ranked according to performance in 1995-2001)

	1975-1985	1985-1990	1990-1995	1995-2001
Portugal	1,5	0,8	1,1	1,1
Greece	1,1	0,7	0,6	0,8
Austria	1,0	0,6	1,0	0,7
Germany	0,8	0,2	1,0	0,5
Belgium	1,1	0,5	0,9	0,4
United Kingdom	0,6	0,2	0,8	0,4
Luxembourg	0,6	0,1	0,8	0,4
Denmark	0,5	0,7	0,5	0,4
Italy	0,7	0,6	0,9	0,3
Spain	1,7	0,2	1,3	0,3
France	1,0	0,7	0,9	0,3
Sweden	0,5	0,4	1,0	0,0
Ireland	1,7	0,5	0,1	- 0,1
Netherlands	0,9	0,1	0,4	- 0,1
Finland	0,9	1,0	1,4	- 0,4
EU-15	**0,9**	**0,4**	**1,0**	**0,4**
United States	0,2	0,1	0,3	0,7
Japan	1,5	1,3	1,1	1,0

Note: The figures indicate how much (in percentage points) capital deepening, or the substitution of capital for labour, contributed to overall labour productivity growth. See also footnote 12.

Source: Commission services.

Growth in total factor productivity (TFP) is measured by the difference between output growth and the growth of inputs (weighted average of labour and capital)[12].

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[12] The relationship between output and inputs can be described by a production function for the economy as a whole. Assuming that the production function is of the Cobb-Douglas type, the rate of output growth (y) depends on: the rate of growth of labour inputs (e) – measured by the growth in total employment; the rate of the growth of capital input (k) – measured by the growth of the capital stock; and a residual which is total factor productivity growth (TFP; Graph I.5 and Table 1.5). The equation reads: $\mathbf{y = TFP + \alpha e + (1-\alpha)k}$

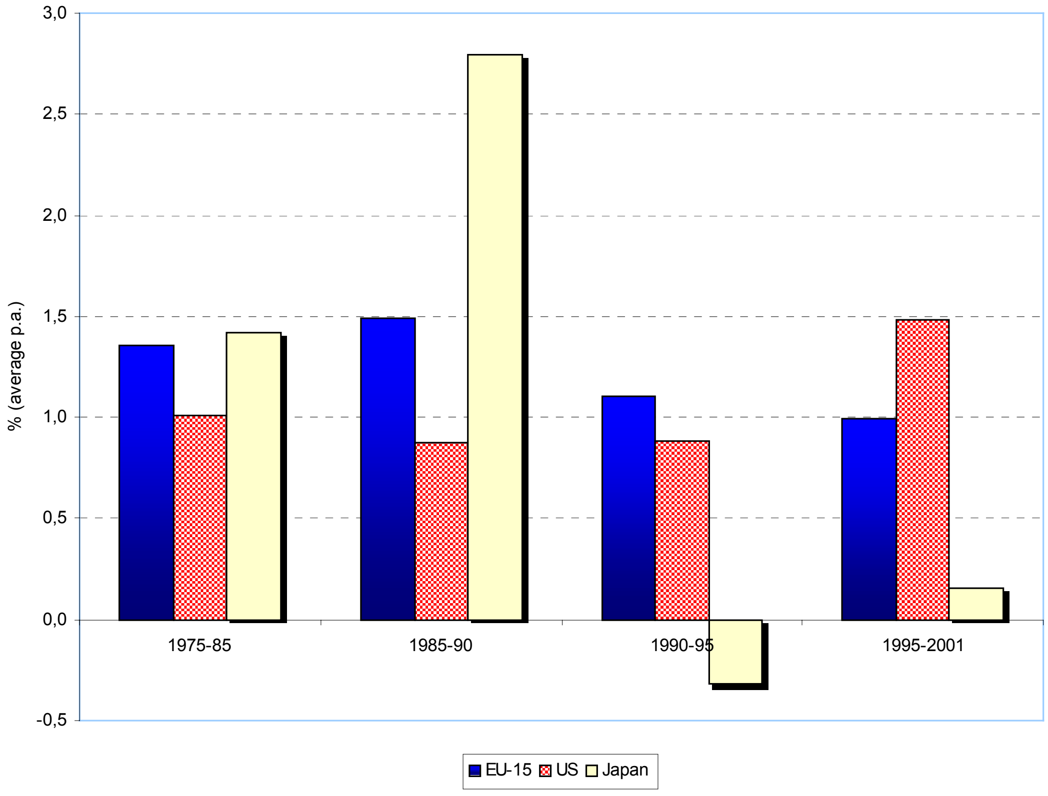
where α denotes the partial elasticity of output with respect to labour. As the rate of growth of labour productivity corresponds to the difference between the growth of output (y) and of labour (e), subtracting (e) from both sides of the equation yields the desired division of the rate of growth of labour productivity: $\mathbf{y - e = TFP + (1-\alpha)(k-e)}$

where (k-e) corresponds to the rate of growth of the capital-labour ratio and measures the speed of capital deepening. Multiplied by (1-α), this expression measures the effect of the substitution of capital for labour (Graph I.4 and Table I.4) on labour productivity growth.

An increase in total factor productivity means that more output can be produced with a given level of labour and capital inputs. As a residual, TFP growth incorporates the effects of changes in the degree of factor utilisation, innovation and technological progress, or measurement errors. Furthermore, as the present method of calculating labour productivity growth does not take into account changes in the quality of inputs (such as better capital goods or an improvement in the educational attainment and skills of the labour force), such changes are also reflected in TFP growth. One of the key factors enhancing TFP in recent years has been investment in new ICT capital goods which have a higher marginal product than many other capital goods.[13] Finally, cyclical factors are also likely to have an impact on TFP growth – in periods of rapid growth, the degree of factor utilisation tends to be higher and vice versa.

Graph II.5 illustrates the growth of total factor productivity in the EU, the US and Japan. A comparison with Graph II.4 shows that TFP growth was by far more important than capital deepening in explaining labour productivity growth in both the EU and the US in the second half of the 1990s. In EU-15, TFP growth slowed somewhat, while the US registered a strong acceleration. Japan's TFP growth collapsed in the 1990s.

Graph II.5: Total Factor Productivity Growth in EU, US and Japan



Source: Commission services.

Table II.5 presents total factor productivity growth rates in the Member States, which are ranked in descending order according to their performance in the period

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[13] Chapter III deals with ICT and its impact on productivity, while Chapter IV discusses the role of ICT, knowledge and innovation for productivity growth in manufacturing.

1995-2001. The data confirm that European TFP growth exceeded by a considerable margin the US rate in the period 1975-1995. However, during the past six years the pattern has been reversed, with the US forging ahead.

Ireland and Finland posted exceptionally high TFP growth rates in the second half of the 1990s. Greece, Sweden, Portugal, Luxembourg and Austria also registered average TFP growth at or higher than the US rate during this period. All the best performers were small Member States, while the large EU countries performed quite weakly – Germany, Italy and Spain especially poorly.

Table II.6: Total Factor Productivity Growth in EU Member States, US and Japan in 1975-2001

(average annual growth in percent, ranked according to performance in 1995-2001)

	1975-1985	1985-1990	1990-1995	1995-2001
Ireland	1,8	2,9	2,6	4,0
Finland	1,5	2,0	1,8	3,3
Greece	- 0,2	- 0,1	0,1	1,9
Sweden	0,5	0,8	1,7	1,9
Portugal	1,8	3,6	1,3	1,8
Luxembourg	1,6	3,1	1,9	1,6
Austria	1,3	1,9	1,5	1,5
Belgium	1,3	1,6	0,8	1,2
United Kingdom	1,6	1,3	1,7	1,2
Denmark	1,2	0,5	2,0	1,2
France	1,4	1,7	0,6	1,1
Netherlands	1,1	1,1	1,0	1,1
Italy	1,3	1,5	1,2	0,7
Germany	1,2	1,7	1,1	0,7
Spain	1,6	1,0	0,6	0,5
EU-15	**1,4**	**1,5**	**1,1**	**1,0**
United States	1,0	0,9	0,9	1,5
Japan	1,4	2,8	- 0,3	0,2

Source: Commission services.

2.6. Concluding comments

An estimated two-thirds of the EU gap with the US GDP per capita level results from lower levels of labour utilisation, while the remainder is due to lower labour productivity in the EU. While part of the lower utilisation of labour reflects shorter working hours in the EU and may be considered as a matter of social choice, the higher level of unemployment constitutes a cause for concern. The EU leaders have set an employment rate target, calling for a 9 percentage point increase in the EU's employment rate between 2000 and 2010. While higher employment is needed in order to catch up with the US GDP per capita levels, in the longer run productivity growth will be the key to achieving higher standards of living.

Labour productivity in the EU had converged towards the US level for several decades. However, the mid-1990s marked a turning point in this process. A rapid acceleration of productivity growth in the US coincided with a deceleration in the EU and led to a renewed widening of the productivity gap, thus erasing to some extent the convergence gains made. EU performance in the second half of the 1990s was not by itself especially discouraging, with GDP growth accelerating and employment rising. The central issue is to explain why the US could still do significantly better in both respects. For an explanation, it is necessary to review the causes behind the differing productivity performances. This is the task of the following two chapters, which review the evidence on the impact of ICT investment on productivity and growth, and analyse the factors behind productivity growth in the manufacturing sector respectively.

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ANNEX II.1:

THEORIES OF ECONOMIC GROWTH

- Neo–classical growth models

Early neo-classical growth models emphasised the role of capital accumulation. In the Solow–Swan model[14], output is produced by capital and labour. Economic growth is compatible with labour-augmenting technical progress, which acts as if it were increasing the available amount of labour. In the long-term, output per capita and labour productivity grow at an exogenously given rate of technical progress. Technical progress is entirely exogenous to these models so that in reality economic growth is left unexplained.

The canonical model provides a methodology (growth accounting) for measuring the rate of technical progress, the so-called Solow residual or total factor productivity (TFP) growth[15]. TFP is defined as the difference between output growth and the (share-weighted) growth rates of capital and labour inputs. Because of its nature as a residual, it is in fact a "measure of our ignorance". Clearly, many factors can cause a shift in the production function, such as technical innovation or organisational and institutional change. The difficulties with this methodology are revealed by the contradictory estimates: while in Solow's pioneering study growth in per capita income was almost entirely (88 percent) attributed to TFP growth, subsequent more careful measurement of factor inputs led to inputs explaining virtually all of output growth, thus reducing the residual to zero[16].

Empirical studies in the 1990s, based on the neo-classical tradition, set out to reconcile the Solow–Swan model with, among other issues, international empirical evidence on convergence. Mankiw et al. (1992) augmented the aggregate production function with human capital proxied by educational attainment. They found that the Solow model performs well in explaining cross-country differences in income levels and is even more successful when human capital is taken into account, and concluded that the model is consistent with the international evidence, if one acknowledges the importance of human, as well as physical, capital. A major drawback of this work is the assumptions that the level of productivity and the rate of technical change are the same across nations; these are not empirically verifiable assumptions.

- Endogenous economic growth and the role of ideas

A group of models that emerged in the course of the 1980s explain long-term economic growth endogenously, by relaxing the assumption of diminishing returns to capital and by rendering technological progress endogenous to the model. Output and productivity growth do not rely on exogenous technical progress.

In a pioneering paper, Romer (1986) postulated that R&D activities are associated with externalities which affect the stock of knowledge available to all firms. A firm's

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[14] See Solow (1956) and Swan (1956).

[15] Growth accounting continues to be used, especially today in the area of measuring the contribution of ICT to economic growth; see Stiroh (2001).

[16] See Jorgenson and Griliches (1967).

production function is defined by firm–specific variables (capital services, labour and R&D inputs) and a shift term (index of technology) which is a function of the stock of knowledge available to all firms; this reflects the public-good characteristics of knowledge–generating activities such as R&D. Clearly, it is possible to view the shift term as reflecting a "learning by doing" process, or the influence of the stock of human capital[17]. It is evident that the endogenous growth theory has the potential to take into account a variety of factors enabling innovation.

R&D– or ideas–based endogenous growth models identify and explicitly model innovation (in particular, the accumulation and diffusion of technological knowledge) as the driving force of long-term economic growth. In these models, "ideas" (in the form of blueprints for new products or new processes) are generated by investment in R&D. Thus, these models treat R&D as an entrepreneurial activity performed by profit-maximising firms. "Ideas" generated by R&D lead to new processes and products that are used as inputs in the production of final goods. As input goods of superior quality, or as more specialised intermediate or capital goods, these products raise productivity[18]. It is now widely recognised that while R&D–based innovation is a crucial determinant of the competitiveness of firms, it does not exclusively affect the performance of those actually undertaking these activities but gives rise to important external effects ("R&D spillovers"). An important element of these external effects is "knowledge spillovers", which take place if new knowledge generated by the R&D activities of one agent, stimulates the development of new knowledge by others, or enhances their technological capabilities.

The commercial outcome of “ideas” – new processes and products – is very often characterised by very high fixed costs and low marginal costs. It can be very costly to produce the first copy of a computer programme, whereas reproducing it can subsequently be done at virtually zero cost. This implies that the economics of ideas is typically associated with increasing returns and imperfect competition.

Economic theory also suggests that the international diffusion of knowledge increases the growth of output and productivity. Eaton and Kortum (1996) find that more than 50 percent of the productivity growth in each of the 19 OECD countries included in their sample can be attributed to innovations from just three countries (US, Germany and Japan). These three countries, together with France and the United Kingdom, reap more than 10 percent of their growth from domestic research.

The impact of international technology diffusion on productivity growth takes place through three channels. First, access to a larger pool of knowledge increases the productivity of R&D activities in the countries involved, thereby enhancing future productivity growth. As a consequence, a country's productivity growth is positively correlated with the degree of its openness to flows of information and to its capability to absorb and utilise knowledge generated abroad. In this process, domestic R&D may be instrumental in building and maintaining absorptive capacities. Second, international trade provides opportunities to use the input goods developed abroad that differ qualitatively from domestic input goods, and thus to increase productivity. And, third, both international trade and foreign direct investment are vehicles for cross–border learning about products, production

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[17] See Lucas (1988).

[18] See, for example, Romer (1990).

processes, market conditions, etc. and may lead to a reduction in the costs of innovating and contribute to increases in TFP.

- **Evolutionary models of economic growth**

The evolutionary approach to growth draws attention to three aspects that are neglected in both neo-classical and endogenous growth models. First, technological advancement ought to be conceptualised as a disequilibrium process involving high ex–ante uncertainty, path dependency and long–lasting adjustment processes. Secondly, growth theory should be based on a more realistic theory of the firm that stresses (strategic) firm capabilities in a broad sense, rather than just investment in human capital and R&D. Thirdly, it must take into account the institutional framework that presumably contributes strongly to an explanation of cross–country differences in economic growth[19].

It is clear that, in this approach, measures to enhance firm capabilities and the development and strengthening of institutions conducive to growth, become core areas of policy. The relevance of the evolutionary approach is reflected in policy discussions and design in many countries, as well as implicitly in the European Union and in the work of the OECD.

Dynamic firm capabilities

The standard approach to explaining productivity (growth) at the firm level is a production function, a concept that is seen as particularly narrow. To create value and gain a competitive edge, a firm uses a whole bundle of specific assets, among which R&D is only one, though an important one. Others are marketing, organisational and managerial skills, individual and collective learning capabilities, social capital (trust, etc.), networking (customer links, outsourcing, co-operation with universities, strategic alliances, etc.), property rights (patents, brand names), etc. This bundle of firm–specific, mostly intangible assets are considered to be the firm's capabilities. They are dynamic in nature, being the result of strategic decisions in the past, and represent the resources to create additional assets in the future. Strategic asset accumulation enables a firm to change restrictions with respect to technology and taste. It is obvious that this accumulation process is path–dependent and gives rise to important differences among firms[20].

As capabilities are difficult to measure at the aggregate level, it may also be difficult to use this approach to explain aggregate economic growth. Nevertheless, empirical work in Peneder (2001) yields a strongly positive cross–country correlation between various capability indicators and performance measures such as productivity, unit values and wages. The (aggregate) capability approach, which appears to be useful for comparing and explaining economic performance among countries, is adopted in the empirical analysis of manufacturing growth in Chapter IV of the present Report.

National Innovation Systems – the role of interconnected institutions

The evolutionary approach recognises that institutions are crucial in explaining the performance of firms and of the economy as a whole. The institutional framework is

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[19] See Nelson (1998).

[20] See Foss (1997).

shaped to a large extent at the national level, giving rise to important differences across countries. However, the internationalisation and diffusion of knowledge can be a mitigating factor in this regard. This aspect of growth theory belongs to the "National Innovation Systems" (NIS) approach, which can be seen as the macroeconomic counterpart of the capability view of the firm.

NIS is a set of interconnected institutions (firms, universities, governments, etc.) which commonly determine a country's performance in the generation and diffusion of technologies and the development of skills[21]. This approach is based on the hypothesis that the performance of a (national) economy in terms of innovation and productivity is not only the result of public and private investments in tangibles and intangibles, but is also strongly influenced by the character and intensity of the interactions between the elements of the system. As a consequence, country differences with respect to innovation and growth might reflect not just different endowments with innovation–related factors of production but also varying degrees of the "knowledge distribution power" or, more generally, the efficiency of NIS.

However appealing, this approach encounters severe data problems in empirical work. Important properties like the "quality of public policy", incentive mechanisms in firms and in "non–market" institutions, etc. are difficult to approximate empirically with confidence. In view of this, it is not surprising that there is no overall measure of the efficiency of an NIS which could be used as an explanatory variable in the empirical analysis of economic growth. What is available at present is only pieces of evidence showing the importance of several types of interaction for innovation performance; for a summary of this evidence see, for example, OECD (1999)[22]. Nevertheless, because the evolutionary approach yields insights into the dynamics of growth processes at the conceptual level, its basic ideas provide a useful framework for policy design and analysis. Consequently, it is now the dominant paradigm for innovation policy and a core element in policy–oriented growth analysis, and plays a crucial role in defining best policy practices in these fields. In Chapter IV, a set of indicators based on suggestions from the evolutionary model are used to explain empirically cross-country differences with respect to economic growth.

While the evolutionary theory shares the basic policy conclusions of the endogenous growth theory, the former also sees the need for some specific measures. By stressing the ex-ante uncertainty of technical change, it implies that it would be necessary to have a mechanism to guarantee technological variety at an early stage of technological development in order to avoid large-scale investment failures. Therefore, creating a favourable environment for entrepreneurship and new ventures is an important policy task (lowering start-up costs, fostering the provision of venture capital, etc.), while the selection of superior technologies is left for the market to determine. The capability view of the firm implies that measures facilitating investment in intangibles are important. While in principle such investments are up to private business to undertake, there might be at the same time scope for a policy, for example, to make sure that incentives for training are put right (measures against poaching, tax incentives, etc.).

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[21] See, for example, Freeman (1987) and Nelson (1993).

[22] See also Stern et al. (2000) and the material from the OECD Growth Project in OECD (2001).

The NIS framework also supports the need for specific policies. Here, measures aimed at improving the interaction between the various elements of the system (strengthening science/industry relationships and joint research, facilitating university spin-offs, exchange of highly qualified staff, facilitating R&D co-operation in the private sector) ought to be encouraged. Policy makers should also take into consideration the specificity of the policy context. In particular, the best policies have to be adapted to the specific properties and needs of the NIS.

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ANNEX II. 2:

THE OECD GROWTH PROJECT: FOCUS AND RECOMMENDATIONS

- The objective

The OECD Growth Project (OECD, 2001) explores the causes of differences in growth performance in the OECD area, with particular emphasis on the acceleration of trend growth in the US and selected OECD economies over the past decade. It reviews how growth patterns have changed in recent years and examines the implications of those shifts for policy makers.

- Divergence in economic growth and contributing factors

Three OECD countries - Australia, Ireland and the Netherlands – have registered markedly stronger trend growth of GDP per capita over the past decade than in the 1980s, and several other countries have also experienced an improvement. These include the US, where trend growth of GDP per capita accelerated sharply in the second half of the decade. In contrast, growth in GDP per capita in many other OECD countries, including Japan and much of Europe, registered a slow down. Nevertheless, in several countries – Finland, Canada, Greece, Iceland and Sweden – trend growth picked up only in the second half of the 1990s.

The OECD analysis shows that the following factors contributed to the growth patterns of the 1990s:

- New capital, in particular ICT
- Increased use of labour
- Rising quality of labour
- Greater efficiency in how capital and labour are combined, or total factor productivity

- Key policy recommendations deriving from the OECD Project

According to the OECD Growth Project, a comprehensive growth strategy should be based on a combination of actions:

1. *Strengthen economic and social fundamentals*, by ensuring macroeconomic stability, encouraging openness, improving the functioning of markets and institutions and addressing the distributive consequences of change.

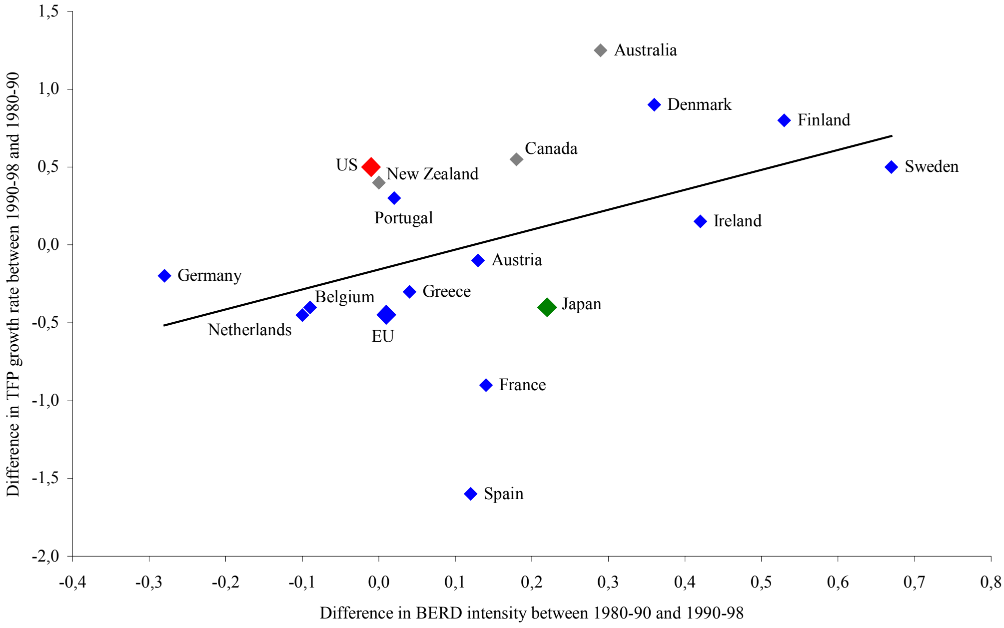
2. *Facilitate the diffusion of ICT*, by increasing competition in telecommunications and technology, improving skills, building confidence and making electronic government a priority.

3. *Foster innovation*, by giving greater priority to fundamental research, improving the effectiveness of public R&D funding, and promoting the flow of knowledge between science and industry.

4. *Invest in human capital*, by strengthening education and training, making the teaching profession more attractive, improving the links between education and the labour market and adapting labour market institutions to the changing nature of work.

5. *Stimulate the creation of firms*, by improving access to high-risk finance, reducing burdensome administrative regulations and instilling positive attitudes towards entrepreneurship.

Graph A II.2.1: Total factor productivity and business R&D intensity



Source: Bassanini et al. (2000); TPF = Total factor productivity (hours-adjusted version). BERD = Business Enterprise Expenditure on R&D.

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CHAPTER III:
INFORMATION AND COMMUNICATION TECHNOLOGIES AND GROWTH OF OUTPUT AND OF PRODUCTIVITY

Information and communication technologies (ICT) are a core element of the knowledge-based society. ICT expenditure, investment and production shares are rising in the US and in the EU - albeit at different rates across Member States. Building on the remarkable performance of the US economy and on research on the growth and productivity impact of ICT, a consensus is growing that the "new" economy does have a significant economic impact[23], although the magnitude of this impact is still subject to controversy.

In the 1990s, several causes combined to accelerate ICT diffusion and growth. Technological change, coupled with large price reductions, led to a surge in the use of digital technologies. With firms ready to exploit the opportunities offered by ICT, the liberalisation of telecommunications and the growth of the Internet economy – allowing for economies of scale and network effects – brought new vigour and eagerness to invest in new technologies. In the US, business investment in computers and peripheral equipment, measured in real terms, jumped more than fourfold between 1995 and 1999[24] and a rapid increase is also detectable in the EU, though not at the same pace as in the US.

Although there are still differing opinions on the importance of ICT for the economy, recent research supports the view that the impact of ICT goes beyond the ICT-producing sector and has a positive effect on overall output and productivity growth.

3.1. International trends in ICT expenditure and investment

3.1.1. ICT expenditure

ICT expenditure, production and investment are increasing, though at different rates in different countries. ICT expenditure measures the diffusion of ICT goods and services and thus the absorption of ICT by firms, private households and the government sector (see Box III.1 for definitions and data availability). Expenditure in the EU is on average lower than in the US, although there are some noteworthy exceptions; for example, as a percentage of GDP, Sweden and the UK spend as much on ICT as the US.

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[23] See, for example, Bureau of Labour Statistics (2000), European Commission (2000), Daveri (2000, 2001), Gordon (2000), Jorgenson and Stiroh (2000), Kiley (1999), OECD (2001A, 2001B), Oliner and Sichel (2000) and Whelan (2000). These studies give evidence on the positive impact of ICT on aggregate output and productivity growth.

[24] See Oliner and Sichel (2000).

Box III.1: Data availability and definitions of ICT expenditure

ICT expenditure measures the diffusion of computer hardware and peripherals, communications equipment, software and telecommunication services. It should be noted that ICT expenditure encompasses spending by businesses, private households and the government sector. For Europe no official data are available, but figures are available from surveys by private sources. The predominantly used data source is collected by International Data Corporation (WITSA, 2000). EITO also uses IDC data as a source and publishes its ICT expenditure data based on some adaptations of IDC data.

The data collected by IDC is gathered both at country level and from corporate headquarters[25]. IDC is the only available source for European countries which allows systematic cross-sectional comparisons for the 1992–1999 period. As IDC does not publicly release information as to the size and structure of its sample, the degree of comprehensiveness of the data set remains hard to gauge.

As the quality of these data sets is difficult to assess, OECD has extracted ICT investment figures from the System of National Accounts 1993 (SNA 1993). This approach provides information for a limited number of countries since the SNA 1993 guidelines are not systematically implemented by all countries (see OECD, 2001B).

The situation in the US is very different. The Bureau of Economic Analysis maintains the "Tangible Wealth Survey", which provides information on 57 distinct types of capital goods in current and chain-weighted dollars for 62 industries from 1947 through 1996. The distinct types of assets for each industry can be aggregated to calculate capital stocks for computer hardware and communications equipment. Software investment is not included in this survey, but BEA started to publish data on aggregate investment in software in its 1999 revision.

Source: Stiroh (2001), European Commission (2000), WITSA (2000), Oliner and Sichel (2000) and Landefeld and Grimm (2000).

Indicators on ICT expenditure reveal distinct differences across OECD countries. Sweden and the UK in Europe, and Australia and the US lead, with ICT spending of about 8 % of GDP in 1999, followed by the Netherlands and Denmark with expenditures close to 7 %. France, Germany, Italy and Spain are grouped around or below the EU average (5.6 % in 1999). The situation in the EU is thus very heterogeneous. Small countries like Sweden, the Netherlands and Denmark exhibit ICT expenditure shares which are above or close to the US share, while Germany, Italy and Spain – large countries with significant impact on average spending in the EU – are lagging behind. The overall result is that the expenditure share is 2.5 percentage points, or nearly one third, lower than in the US – see Table III.1.

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[25] Each local IDC office conducts *interviews* with local computer vendors and distributors. These data are compared with information from multinational vendors, collected and updated at IDC headquarters and regional research centres, and cross-checked with global vendor census data. Vendor data are then supplemented by user interviews and surveys (see Daveri, 2001).

Table III.1 International comparison of ICT expenditure and production

	Share of ICT in business sector employment, 1998	Share of ICT in business sector value added, 1998	ICT expenditure as % of GDP, 1998	ICT expenditure as % of GDP, 1992-1999
Belgium	4,3	5,8	5,7	5,6
Denmark	5,1	-	6,7	6,6
Germany	3,1	6,1	5,1	5,3
Greece	-	-	5,1	3,8
Spain	-	-	4,0	3,9
France	4,0	5,3	5,9	5,9
Ireland	4,6	-	6,4	5,9
Italy	3,5	5,8	4,5	4,2
Netherlands	3,8	5,1	6,9	6,7
Austria	4,9	6,8	4,7	4,8
Portugal	2,7	5,6	5,1	4,5
Finland	5,6	8,3	5,7	5,6
Sweden	6,3	9,3	9,5	8,2
United Kingdom	4,8	8,4	9,0	8,1
EU (*)	**4,0**	**6,4**	**6,0**	**5,6**
Japan	3,4	5,8	6,2	6,0
US	3,9	8,7	8,7	8,1
Switzerland	6,0	-	7,3	7,3
Australia	2,6	4,1	8,5	8,1
Canada	4,6	6,5	8,1	7,6

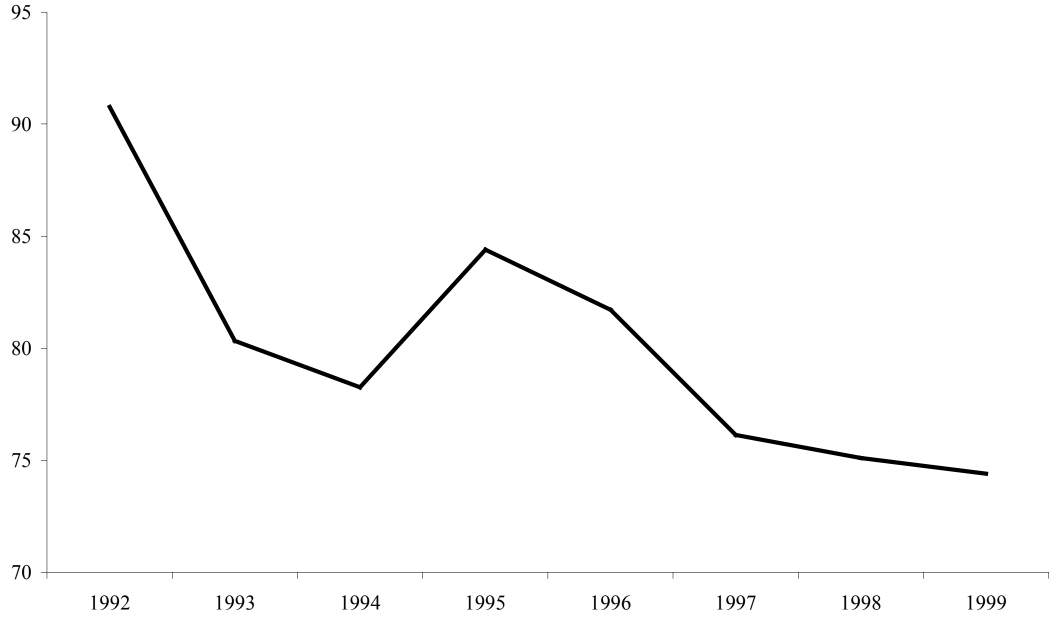
(*) Weighted average GDP (1990), WIFO calculations.

Source: OECD (2001A), WITSA (2000), WIFO calculations.

The lower level of ICT spending in the EU compared to the US reflects in part the smaller ICT–producing sector but also less dynamic spending by the government sector and private households. Australia demonstrates that a large ICT sector is not a prerequisite for high ICT expenditure. Australia is among the big ICT spenders even though the ICT-producing sector encompasses only 2.6 % of overall business sector employment and 4.1 % of value added.

Throughout the 1990s, ICT spending increased both in the EU (4.7 % p.a.) and in the US (7.8 % p.a.), substantially accelerating in the second half of the decade in the US (from7.3 % p.a. to 8.1 % p.a., see Table III.2). ICT expenditure increased far more steadily in the US than in the EU. The annual growth rates in the EU appear to be related to business cycle fluctuations, rising at above-average rates in periods of sound economic growth and stagnating or even declining in phases of slow GDP growth. In the US, both the overall growth and the growth of ICT expenditure have been smoother during the period under consideration.

Graph III.1: EU ICT expenditure as a percent of US expenditure



Source: WITSA (2000), WIFO calculations.

The difference between the share of ICT expenditure in GDP in the EU and the US has widened since 1992 (exactly 2.3 percentage points higher in the US in 1992 and 2.7 percentage points in 1999). Measured relative to US expenditure, EU expenditure in ICT declined from 90 % in 1992 to 75 % in 1999 – see Graph III.1. Overall, the acceleration of ICT spending between the first and second half of the 1990s in the EU is not as pronounced as in the US. This can be seen at country level (see Table III.2), where only the UK, Sweden, Italy, Ireland and Spain recorded an acceleration during this period.

Table III.2: Annual growth rates of ICT expenditure (1992-1999, percent)

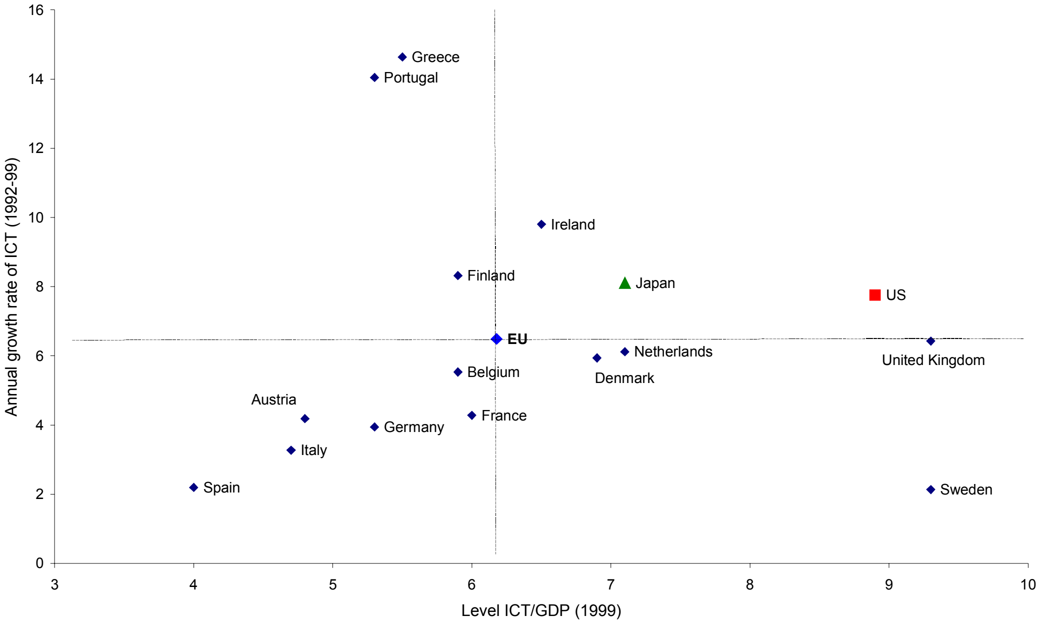
Country	Annual growth rate			Acceleration
	1992-1995	1995-1999	1992-1999	second half - first half
Belgium /Luxembourg	6,8	4,6	5,5	- 2,2
Denmark	7,6	4,7	5,9	- 2,9
Germany	5,8	2,6	3,9	- 3,2
Greece	23,7	8,3	14,6	- 15,5
Spain	- 1,7	5,2	2,2	6,9
France	5,7	3,2	4,3	- 2,4
Ireland	9,4	10,1	9,8	0,8
Italy	0,3	5,5	3,3	5,2
Netherlands	7,0	5,5	6,1	- 1,5
Austria	5,1	3,5	4,2	- 1,6
Portugal	24,9	6,5	14,0	- 18,4
Finland	12,6	5,2	8,3	- 7,3
Sweden	- 1,7	5,1	2,1	6,8
United Kingdom	4,2	8,1	6,4	3,9
EU	**4,7**	**4,8**	**4,7**	**0,1**
US	7,3	8,1	7,8	0,9

Source: WITSA (2000).

The most dynamic European countries with respect to ICT expenditure growth are Greece, Portugal, Ireland and Finland (see Graph III.2). All increased their share of ICT expenditure in GDP in the 1990s and are now close to the EU average (see Table III.3). In the case of Greece and Portugal, the high growth rates reflect heavy investment in telecommunications infrastructures, an investment that the majority of European countries had already made in the first half of the 1990s. In the UK, the Netherlands, Denmark and Belgium, ICT expenditure grew at a rate slightly below the EU average, but for the first three countries the share of ICT in GDP in 1999 is clearly above average (see Graph III.2).

In contrast, countries like Spain, Germany, Austria and France on average registered growth in ICT expenditure well below the EU average in the 1990s, and a stagnating share of GDP devoted to ICT leading to below average ICT shares in 1999. Sweden registered the lowest growth of ICT expenditure, but the share of ICT spending in GDP grew at rates close to the EU average, and in 1999 its ICT share was the highest of all the Member States – see Table III.3 and Graph III.2.

Graph III.2: Growth rate of ICT expenditure and level of ICT share in GDP (in percent)



Source: WITSA (2000), WIFO calculations.

Table III.3: ICT expenditure as a percent of GDP

Country	1992	1995	1999	Differences 1999 - 1992	Annual growth rate of shares 1992-1999
Belgium /Luxembourg	5,5	5,5	5,9	0,4	1,0
Denmark	6,4	6,5	6,9	0,5	1,1
Germany	5,4	5,2	5,3	- 0,1	- 0,3
Greece	2,4	3,9	5,5	3,1	12,6
Spain	3,9	3,9	4,0	0,1	0,4
France	5,8	5,9	6,0	0,2	0,5
Ireland	5,5	5,9	6,5	1,0	2,4
Italy	3,7	4,2	4,7	1,0	3,5
Netherlands	6,7	6,6	7,1	0,4	0,8
Austria	5,0	4,7	4,8	- 0,2	- 0,6
Portugal	2,8	5,0	5,3	2,5	9,5
Finland	4,7	5,7	5,9	1,2	3,3
Sweden	7,6	7,8	9,3	1,7	2,9
United Kingdom	7,2	7,8	9,3	2,1	3,7
EU	**5,2**	**5,6**	**6,2**	**1,0**	**2,9**
Japan	5,7	5,4	7,1	1,4	3,2
US	7,5	7,9	8,9	1,4	2,5

Source: WITSA (2000), WIFO calculations.

3.1.2. *ICT investment*

In the EU, ICT business investment corresponds to about a third of total ICT expenditure.[26] The main trends for ICT investment are similar to those of ICT expenditure. US investment as a percentage of GDP is higher than in the EU, where investment, while growing, is declining relative to the US. However, none of the EU countries – and this is in contrast to ICT expenditure – reaches the US share of ICT investment in GDP, which in 1999 was twice the EU share (see Table III.4). This may be due to the different weighting of the components (hardware, software, and communications equipment) in the calculation of ICT investment for Europe.

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[26] Daveri (2001) calculates investment data for Europe based on a comparison of WITSA figures for the US with the official investment data from the Bureau of Economic Analysis (BEA). The relationship between WITSA expenditure and BEA figures for investment on hardware, communications equipment and software is used to calculate the share of business expenditure/investment in the overall figure. Under these assumptions, hardware investment in the US is 58.6 % of total hardware spending as reported by WITSA, communications equipment is 31.6 % of WITSA expenditure and software investment (including own-account software) is about 212.5 % of the WITSA software item. These coefficients are then multiplied by the corresponding WITSA spending items for EU countries to obtain nominal ICT investment data for the 1992–99 period.

Table III.4: Business investment in ICT in percent of GDP

	ICT investment/GDP			Total fixed investment/GDP		
	1992	1999	Difference 1999-1992	1992	1999	Difference 1999-1992
Belgium /Luxembourg	2,12	2,59	0,47	21,29	20,99	- 0,30
Denmark	2,04	2,72	0,68	18,14	20,97	2,83
Germany	1,74	2,17	0,43	24,04	21,29	- 2,76
Greece	0,75	1,80	1,05	21,32	23,00	1,69
Spain	1,52	1,58	0,06	23,09	23,69	0,60
France	1,70	2,05	0,35	20,93	18,86	- 2,07
Ireland	1,82	2,32	0,50	16,59	24,13	7,53
Italy	1,49	1,77	0,28	20,47	18,43	- 2,04
Netherlands	2,23	3,09	0,86	21,32	21,47	0,15
Austria	1,61	1,89	0,28	23,50	23,65	0,15
Portugal	0,96	1,81	0,85	25,01	27,48	2,46
Finland	1,61	2,48	0,87	19,61	19,28	- 0,32
Sweden	2,49	3,64	1,15	18,26	16,47	- 1,79
United Kingdom	2,43	3,76	1,33	16,53	17,97	1,44
EU	**1,81**	**2,42**	**0,61**	**20,72**	**21,26**	**0,54**
US	2,60	4,54	1,94	17,01	20,33	3,32

Source: Daveri (2001).

The rapid diffusion of information technology is mirrored in the rising share of ICT investment goods in gross capital formation in the business sector. In 1999, about one third of business sector investments in Finland and the US were devoted to ICT goods while in France, Germany, Italy and Japan this share was about half as large (OECD, 2001A). The dramatic drop in ICT prices (see Box III.2) boosted investment in these new technologies and led to substitution of ICT for other types of capital goods.

There are considerable differences across countries in investment and uptake of ICT, reflecting partly policy differences. Competition is particularly important in that it contributes to lowering costs, thus encouraging ICT investment and diffusion. Policy plays an important role in ensuring sufficient competition, e.g. through regulatory reform, effective competition policy and the promotion of market openness at the domestic and international level. Regulatory reform of the telecommunications sector is of particular importance, as the use of ICT in networks relies to a considerable extent on the costs of communications (OECD, 2001A). Consequently, the effects of recent liberalisation measures, such as those undertaken in 1998, are likely to become evident in forthcoming data releases.

Table III.5: Annual growth of ICT and aggregate capital stocks (1991-1999, percent)

	Communications equipment	Hardware	Software	All capital goods (business sector)
Belgium	10,3	27,9	8,4	3,0
Denmark	9,8	26,6	11,7	2,9
Germany	13,5	29,6	13,3	2,6
Greece	16,4	42,6	16,1	2,7
Spain	12,6	25,2	7,2	4,0
France	11,4	24,0	10,3	2,3
Ireland	13,2	28,8	15,9	3,2
Italy	11,1	23,6	5,1	2,7
Netherlands	9,9	32,1	14,0	2,3
Austria	9,7	29,9	12,4	4,3
Portugal	24,6	43,2	11,1	4,5
Finland	8,8	23,8	9,7	0,5
Sweden	5,2	25,0	9,6	2,1
United Kingdom	7,8	31,6	14,3	2,9
EU	**11,2**	**27,6**	**10,8**	**2,7**
US	4,9	31,2	17,4	2,6

Source: Daveri (2001).

Over the past two decades, the share of ICT in total business investment increased substantially. In particular, investment in software expanded spectacularly. In the US, the share of ICT in total business investment rose from 15 percent in 1980 to 32 percent in 1999. As Table III.5 shows, the stock of ICT capital has risen much faster than that of capital goods in general. The capital stock of both communications equipment and software increased by about 11 percent annually in the EU, that of hardware by about 28 percent (unweighted averages). Compared to the US, growth rates for capital stock of communications equipment were higher in the EU, about the same for hardware and lower for software.

3.2. The economic impact of ICT investment

Investment in information technology affects output and productivity growth through three separable channels (see Stiroh, 2001 and European Commission, 2000):

1. **Technological progress in the production of ICT goods:** Technological progress allows production of improved capital goods at lower prices, thus raising total factor productivity growth in the ICT-producing sector. The magnitude of this effect on the total economy depends on both the speed of this technological progress and the share of the ICT sector in the economy.

2. **Capital deepening in the total economy:** The most important effect of ICT use could be an increase in labour productivity through additional capital formation (ICT capital), which raises the productivity of labour.

3. **Spillover effects:** ICT investment induces embodied technological change, thus increasing total factor productivity growth outside the IT sector, generating production spillovers or externalities.[27]

One approach to estimate the impact of ICT on economic growth and productivity at the macroeconomic level has been growth accounting. Growth accounting is based on the neo-classical growth model pioneered by Solow (1957). Although subject to several limitations, this approach has produced considerable evidence confirming the presence of the three effects mentioned above. Additional evidence produced by alternative methods has also been useful to validate the results (see Oliner and Sichel, 2000 and Stiroh, 2001). Studies at the sectoral or firm level usually apply econometric models based on production functions to assess the impact of ICT use.[28]

3.2.1. Estimates for the US and the EU

The evidence suggests not only that ICT significantly contribute to growth and productivity, but also that this impact is larger in the US than in the EU. Moreover, this impact is greater in the second half of the 1990s compared to earlier periods. These findings are consistent with the higher levels of ICT investment in the US compared to the EU and with the fact that in both regions these levels have been rising through the 1990s, as reported in the previous section.

The US economy grew rapidly in the 1990s, especially in the second half. The EU also registered an acceleration, albeit more modest, in economic growth – see the discussion in Chapter II. Most studies conclude that "there is no single factor that explains the divergence in growth performance. OECD countries that have improved performance in the 1990s have generally been able to draw more people into employment, have increased investment, and have improved total factor productivity (TFP)". [29]

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[27] OECD (2001A) finds evidence that there is a strong positive correlation between indicators of ICT use (e.g. numbers of secure servers, Internet host density, PC density and Internet access costs) and the rise in TFP growth in the second half of the 1990s. Countries that experienced a substantial acceleration in TFP growth in this period typically have wider diffusion and lower costs of ICT technologies.

[28] For a survey see Brynjolfsson and Yang (1996), Brynjolfsson and Hitt (2000) and Stiroh (2001).

[29] See OECD (2001A), for further empirical evidence see also Schreyer (2000), Scarpetta et al. (2000) and Federal Reserve Board (2000).

Box III.2: The growth contribution of hardware, software and communications equipment

Some growth-accounting studies calculate capital stocks for computer hardware, software and communications equipment and assess the impact of these components of ICT investment separately. This provides information on the relative growth impact of the various forms of information technology. In the US, the largest contribution to output growth stems from hardware investments[30]. In the second half of the 1990s, hardware investment raised output by 0.5 to 0.6 percentage points (see Table III.6). Software contributed about 0.2 to 0.3 percentage points and communications equipment about 0.1 to 0.15 percentage points. Hardware and communications equipment doubled their impact in the second half. The increase was slightly lower for software. The evidence available for Europe (Daveri, 2001) estimates the growth contribution of hardware at about half the US level (0.24 percentage points – weighted average based on Daveri, 2001), slightly lower for software (0.13) and at the same level for telecommunications equipment (0.12). Thus, lower hardware spending seems to be the major cause for lower ICT capital stocks in Europe and consequently lower contributions of ICT to overall growth.

The estimated growth impact of hardware investment is to a significant extent due to the use of hedonic indices to deflate prices for ICT equipment (see Schreyer, 2001). For example, quality-adjusted prices for computers and peripherals have been falling at about 24 % annually (Landefeld and Grimm, 2000). This is a much faster decline than for software and communications equipment. Research in Germany (Moch, 2001) confirms the rate of price decline of computer hardware found for the US.

Rapidly falling prices for information technology push up the growth rate of real capital stocks (see Table III.5), thus allocating a larger part of overall growth to information technology. As demonstrated by Sterner (2001), heeding price measurement may in some countries double the magnitude of growth effects for hardware investments.

One candidate for explaining the performance of the US economy is the rapid diffusion of information technologies, which was fuelled by a steep decline in prices for ICT goods. The key result of various studies is that ICT investment explains about 0.4 to 0.5 percentage points of output growth in the first half of the 1990s, and 0.8 to 1 percentage point in the second half (see Table III.6).[31]

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[30] Firm-level evidence supports this view. These studies suggest that computers did have an impact on economic growth that is disproportionately large compared to the size of the capital stock or investment, and that this impact is likely to grow in the future (Brynjolfsson and Hitt, 2000).

[31] See Bureau of Labour Statistics (1999), European Commission (2000), Daveri (2000, 2001), Gordon (2000), Jorgenson and Stiroh (2000), Kiley (1999), OECD (2001A, 2001B), Oliner and Sichel (2000) and Whelan (2000). The major exception is Kiley (1999) that estimates a negative growth impact of ICT that is due to adjustment costs associated with the implementation of ICT. In this framework the effect of ICT would turn positive once investment in ICT is reduced or halted and adjustment costs no longer cancel out the positive impact of ICT on output growth.

Table III.6: ICT growth contribution (percentage points)

	Country/ Region	Period	Software	Hardware	Communications equipment	Total ICT
OECD (2001)	US	1990-95	0,14	0,20	0,08	0,42
		1995-99	0,27	0,49	0,13	0,89
Jorgenson & Stiroh (2000)	US	1990-95	0,15	0,19	0,06	0,40
		1995-99	0,21	0,49	0,11	0,81
Oliner & Sichel (2000)	US	1991-95	0,25	0,25	0,07	0,57
		1996-98	0,32	0,59	0,15	1,06
Daveri (2001)	EU	1991-99	0,12	0,24	0,13	0,48
European Commission (2000)	EU	1992-94	-	-	-	0,27
		1995-99	-	-	-	0,49

There are basically two estimates available on the growth impact of ICT investment covering all Member States[32] (European Commission, 2000 and Daveri, 2001). OECD (2001B) and Schreyer (2000) present estimates for four European countries as part of a sample of eight countries. Estimates for European countries generally indicate a lower contribution of ICT to output growth than in the US. On average, in the 1990s, about 0.4 to 0.5 percentage points of output growth in the EU are estimated to be due to ICT investment.

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[32] With the exception of Luxembourg.

Table III.7: Contribution of ICT investment to growth in the EU (percentage points)

	Daveri (2001) 1991-99	Daveri (2001) 1991-95	European Commission (2000) 1992-94	Daveri (2001) 1996-99	European Commission (2000) 1995-99
Belgium	0,48	0,48	0,35	0,49	0,60
Denmark	0,52	0,42	0,22	0,65	0,38
Germany(*)	0,49	0,54	0,25	0,45	0,41
Greece	0,34	0,25	0,12	0,46	0,21
Spain	0,36	0,38	0,19	0,34	0,39
France	0,41	0,40	0,24	0,44	0,42
Ireland	0,64	0,38	0,84	0,96	1,91
Italy	0,31	0,28	0,25	0,35	0,42
Netherlands	0,68	0,65	0,41	0,72	0,67
Austria	0,45	0,47	0,24	0,43	0,41
Portugal	0,43	0,39	0,25	0,49	0,55
Finland	0,45	0,21	0,31	0,74	0,63
Sweden	0,59	0,38	0,30	0,85	0,68
United Kingdom	0,76	0,43	0,35	1,17	0,64
EU	**0,48**	**0,43**	**0,27**	**0,57**	**0,49**
US	0,94	0,53	-	1,45	-

(*) Germany = 1992-1999.

Source: Daveri (2001), European Commission (2000).

The estimates in the two available studies for the full sample exhibit some differences (see Table III.7). Daveri (2001) estimates a substantially larger ICT growth contribution for the EU than the European Commission (2000) in the first half of the 1990s; as a consequence, the acceleration between the two periods in Daveri (2001) is not as strong. The differences in the growth contribution of information and communication technologies in Member States and the US can be seen in Table III.7. Both in the 1990s and in the two sub-periods, no EU country achieved a growth contribution of ICT investments comparable to the US.[33] The growth contribution from ICT in the UK was 0.76 percentage points in the 1990s, which was the highest value in the EU. In the US, ICT investments accounted for 0.94 percentage points of output growth in the same period.

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[33] The difference in the results between Europe and the US is somewhat lower in the OECD (2001B) estimate, which uses official data from the System of National Accounts (France, Germany, Finland and Italy are the only European countries in the sample).

Compared to the US, the EU appears to have forgone 0.3 to 0.5 percentage points of economic growth.[34] The major cause for the lower contribution of ICT to aggregate growth in the EU is lagging investment in ICT. Other factors which normally affect the outcome of growth-accounting exercises (price measurement and capital utilisation costs) were assumed to be similar to the US in these exercises, and thus cannot account for these growth differences (see Daveri, 2001, European Commission, 2000).

3.2.2. ICT productivity or ICT spillovers?

There is uncertainty about the relative importance for overall economic and productivity growth of two factors: 1) the contribution of productivity growth within the ICT sector and 2) spillovers from the ICT sector to other industries on the other hand.

Box III.3: The productivity impact of ICT–producing industries

The importance of ICT to productivity growth can be evaluated by analysing the sectoral productivity performance and the contribution of each sector to overall productivity growth. It is widely accepted that rapid productivity increases in the ICT-producing industries contributed substantially to overall productivity growth. OECD studies confirm this for several OECD countries (Scarpetta et al., 2000).

The contribution of the ICT-producing sector to overall economic performance depends on its rate of productivity growth and on the size of the sector. Labour productivity growth was much higher in the two key ICT-producing sectors, i.e. In general, the ICT manufacturing sectors (in particular the electrical and optical equipment industries) have a considerably higher productivity growth than manufacturing overall, and the ICT services sectors tend to have more rapid productivity growth than the services sector as a whole. The large variation in performance across countries points, among other factors, to varying specialisation within the ICT sector. Some countries are specialised in ICT products for which technological progress was not as fast as in semi-conductors or computers (OECD 2001A).

The OECD (2001A) study on Denmark, Finland and Germany – the only countries with sufficient data –indicates that in Finland[35] and Germany the contribution of the ICT-producing sector increased substantially in the second half of the 1990s compared to the first half. In contrast, the role of ICT-producing industries in Denmark declined over the same period.

The importance of the ICT-producing sector for the recent growth performance has been confirmed also in several country-level studies. In Finland, the mobile telephone producer Nokia accounted for 1.2 percentage points of the country's GDP growth of 4 percent in 1999, even though it produced only 4 percent of overall GDP (Forsman, 2000). The Bank of Korea reports that 40 % of recent GDP growth in Korea came from the ICT sector, five times its 1999 share in GDP (Yoo, 2000). In the Netherlands, the ICT-producing sector accounted for about 17 % of GDP growth over the 1995–98 period, four times its share in GDP (CPB, 2000). The ICT-producing sector is thus an important driver of growth and productivity, although countries such as Australia, which do not have a large ICT-producing sector, have also improved their growth and productivity performance.

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[34] The major forces determining ICT growth contribution are the size of the capital stock, its growth rate, capital utilisation costs and price trends for ICT goods.

[35] See also OECD (2001A): "...Finland shows a substantial acceleration of TFP growth in both machinery and equipment and electrical and optical equipment in each sub–period. For Finland, the TFP calculations broadly confirm the importance of the ICT sector for overall TFP growth; about 20 % of TFP growth over 1995–1999 is due to the ICT sector, which is substantially more than in previous periods."

The acceleration of labour productivity growth in the US between 1973/95 and 1995/99 is mainly due to capital deepening (the estimates range from 0.1 to 0.33 percentage points; see Table III.8) and total factor productivity growth (0.3 to 0.9 percentage points). Both are substantially influenced by ICT production and use. A positive impact of ICT-related capital deepening is found in all studies reported in Table III.8, reflecting a direct effect of ICT investment on the growth of labour productivity. In contrast, the contribution of non-ICT-producing sectors to total factor productivity growth remains controversial. Gordon (2000) attributes almost all of the acceleration in total factor productivity growth to the ICT-producing sectors – see Box III.3 for further information on the impact of the ICT-producing sector. Although Jorgenson and Stiroh (2000) and Oliner and Sichel (2000) obtain about the same effect for ICT-producing sectors as Gordon (2000), they still find a substantial contribution from non-ICT related sectors to total factor productivity growth (0.4 to 0.5 percentage points), thus supporting the view that ICT use has had positive effects in non-ICT producing industries.

Table III.8: Sources of acceleration in labour productivity in the US

	Bureau of Labor Statistics (2000)	**Gordon (2000)**	**Jorgenson & Stiroh (2000)**	**Oliner & Sichel (2000)**
Average Labour Productivity, 1995-99	2,30	2,75	2,37	2,57
Average Labour Productivity, 1973-95	1,39	1,42	1,42	1,41
Acceleration 1973-95 to 1995-99	0,91	1,33	0,95	1,16
Sources of the acceleration:				
• **Capital Deepening:**	0,10	0,33	0,29	0,33
– **IT-Related**	0,38	n.a.	0,34	0,50
– **Other**	- 0,31	n.a.	- 0,05	- 0,17
• **Labour Quality (skill composition)**	0,06	0,05	0,01	0,04
• **Total Factor Productivity:**	0,90	0,31	0,65	0,80
– **IT-Related**	n.a.	0,29	0,24	0,31
– **Other**	n.a.	0,02	0,41	0,49
• **Cyclical Effect**		0,50		
• **Price Measurement**		0,14		

Source: Stiroh (2001).

Gordon (2000) argues that the recent productivity growth is not based on ICT use but that the increase in labour productivity is a normal, cyclical acceleration as the economy expands.[36] In his estimates the contribution of non-ICT-producing sectors to the acceleration of total factor productivity growth is almost nil (see Table III.8). The exercise is repeated for sub-samples of the economy by either excluding the ICT–producing industries or the manufacturing sector and thus leads to lower total factor productivity in the remaining parts of the economy. Gordon's interpretation of these findings is that there is no such thing as a "new" economy but that the massive ICT investments outside the ICT–producing sector may be focused on unproductive activities like market share protection, duplication of existing operations, or on–the–job consumption and thus have a negative productivity impact.[37]

This controversy cannot be solved at the aggregate level but requires evidence either at sectoral or firm level. If there is a positive impact of ICT across the economy, it should be visible in the largest users of ICT investment in the service sectors – communications, wholesale and retail trade, finance, insurance and business services (see OECD, 2001A). However, there are various problems in measuring the output of these sectors, which may partly explain why most of these service sectors have exhibited rather weak measured productivity growth.

Modest acceleration of productivity growth in non-ICT-producing industries was found in a number of studies (see Brynjolfsson and Hitt, 2000, Brynjolfsson and Yang, 1996 for studies at firm level), which suggests that productivity growth is mainly confined to ICT–producing industries. However, the OECD (2001A) found evidence of a positive productivity impact of ICT in the ICT–using sectors. Denmark, Finland, Germany, the Netherlands and the US experienced an increased contribution of ICT–using industries to labour productivity growth, while industries which are less intensive users of ICT did not increase their contribution to labour productivity growth. This positive effect on labour productivity growth was confined to the second half of the 1990s. In contrast, the European Central Bank (2001), using data for Germany, France, Italy and Finland for the period 1991-1998, finds no clear evidence of ICT spillovers – unlike in the ICT-producing sectors, labour productivity in the ICT-using sectors (both in services and in manufacturing) did not rise significantly faster than in the remaining sectors.

To be successful, the introduction of new technologies through investment has to be coupled with organisational changes and improvements in labour force skills[38], which in turn require flexibility in input markets, namely in labour markets. Conceivably, such changes have taken place only recently and as a consequence more recent studies detect a positive impact of ICT use while older ones do not.

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[36] In a fast-growing economy , labour input is quasi-fixed in the short run. The labour force adapts to rising demand by working harder and sometimes longer (variable utilisation and resource allocation effects) as inputs are not immediately increased in a business cycle upturn. Consequently labour productivity rises although the basics of the economic process are unchanged. The argument that ICT is behind productivity increases in the second half of the 1990s is weakened by this longstanding observation of a positive relationship between productivity and growth. Even without increased ICT investment, productivity would have increased in the upturn of the 1995 to 1999 period (see Gordon, 2000).

[37] There are also other critical comments: Roach (1998) argues that much of the productivity growth is due to the understatement of actual hours worked, which leads to an overstated productivity growth, as the white-collar working week expands faster than the data measure. Kiley (1999) assumes large adjustment costs that create frictions which cause investment in ICT capital to be negatively associated with productivity, at least in the short run.

[38] See Bresnahan et al. (1999).

Stiroh (2001) concludes that "... those industries that made the largest IT investment in the early 1990s show larger productivity gains in the late 1990s and production function estimates show a relatively large elasticity of IT capital, indicating that IT capital accumulation is important for business output and productivity." This again suggests that the impact of ICT investment takes time to emerge in output and productivity data, and it implies that productivity growth due to ICT is not confined to the ICT–producing sectors alone.[39] Stiroh (2001) also provides evidence that the US productivity revival appears to be fundamentally linked to ICT. It should be stressed that the cyclical effect, claimed by Gordon (2000) to be the major factor behind the revival of productivity growth, should have materialised at the beginning rather than in the middle of the expansion. Moreover, if the productivity increase is a cyclical phenomenon, it should be evenly distributed over industries and be unrelated to ICT use. On the contrary, the acceleration in US productivity growth coincides with a significant increase in ICT spending and according to Stiroh (2001) the most intensive ICT sectors experienced the largest productivity gains. This suggests that a structural change has indeed taken place.

3.3. Concluding comments

The growing consensus that the strong growth and productivity performance in the US is related to increased investment and diffusion of ICT goods and services has raised concerns that the weaker economic performance of EU Member States is caused by a sluggishness in the adoption of these new technologies.

The ICT spending gap between the EU and the US widened in the 1990s, even though both regions expanded their ICT expenditure. In 1992, EU ICT expenditure as a percentage of GDP (5.2 %) was 2.3 percentage points below the corresponding US level. While the gap narrowed in the first half of the 1990s, it thereafter increased to 2.7 percentage points in 1999. In 1992, ICT expenditure in the EU still amounted to 90 % of US expenditure, but by 1999 had declined to about 75 % of the US level. The gap is even larger for ICT investment in the business sector. In 1999, US business investment in information technologies was about 4.5 % of GDP, almost twice the European level of 2.4 %

ICT spending in the EU Member States is diverse. While the UK and Sweden have already surpassed the US, and the Netherlands, Denmark and Ireland have drawn close to it, some of the larger countries have performed less well.

Recent growth-accounting studies have demonstrated the increasing contribution of ICT to aggregate economic growth. In the US, ICT investment accounted for 0.8 to 1 percentage point of output growth in the second half of the 1990s. Most studies found that the importance of ICT for economic growth in the second half of the 1990s more than doubled compared to the first half. Estimates for European countries generally indicate a lower contribution of ICT to output growth. On average, about 0.4 to 0.5 percentage points of output growth in Europe are due to ICT. Compared to the US, Europe would appear to forego 0.3 to 0.5 percentage points of economic growth as a result of lower investment in ICT.

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[39] See also Bailey and Lawrence (2001) and Nordhaus (2001).

The acceleration of labour productivity growth in the second half of the 1990s in the US is due to capital deepening (the estimates range from 0.1 to 0.33 percentage points) and to total factor productivity growth (0.3 to 0.9 percentage points). Both categories are substantially influenced by ICT production and use. Evidence suggests that ICT have a positive impact on productivity in ICT–using industries. In the US, both ICT producers and ICT users experienced significant productivity gains; in contrast, industries that experienced no ICT impact made no contribution to the productivity revival in the US.

The effects of ICT investments take time to manifest themselves since ICT technologies are most productive when associated with organisational changes, improvements in the skills of the labour force and favourable framework conditions encouraging and rewarding innovation. Given the complementary investments needed, it is not surprising that much of the evidence on the positive productivity impact of ICT use has been obtained only in recent studies. In earlier years, the size of the ICT capital stock was too small and the time to implement the technology too short, with the consequence that the impact was not visible until the second half of the 1990s.

Even if there is an emerging view that ICT has lead to both a permanent rise in productivity and an acceleration in productivity growth, it is not possible to completely dismiss the idea that some of the impact attributed as permanent may in fact be based on cyclical factors. From an analytical point of view, the current downturn in the economy, and in the ICT industry in particular, should shed more light on the question. Based on data from a full economic cycle it should be possible to say with even more confidence how much of the productivity increase was cyclical and how much is permanent.

It should be noted, that though ICT makes a positive contribution to output and productivity growth, it does not explain entirely the divergence in the growth performances of the main industrialised countries. Countries that have improved production and labour productivity performance in the 1990s have generally been able to draw more people into employment, have increased investment, and have registered improvements in total factor productivity. ICT investment is playing a crucial and probably growing role in setting the foundation for future growth. Hence, policies should ensure that competition (and regulation) will allow further lowering of prices for ICT equipment and services and foster adequate skill upgrading, thus making it possible to draw more people into employment and supporting complementary organisational innovation at firm level.

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ANNEX III.1:

EUROPEAN SKILL SHORTAGES IN ICT AND POLICY RESPONSES

- Why has the demand for ICT skills increased in recent years?

Technological progress and the globalisation of the economy have increased the importance of human skills in our economies (see Berman et al., 1998). The share of university and college graduates in the population has increased trendwise since the Second World War. Evidence from econometric and case studies indicates that the demand for more skilled workers is positively correlated with capital intensity and the implementation of new technologies, both across industries and across plants within industries. Autor et al. (1998) find evidence for the US that "...skill-biased technological and organisational changes that accompanied the computer revolution appear to have contributed to faster growth in relative skill demand within detailed industries starting in the 1970s". This rapid skill upgrading was concentrated in the most computer–intensive sectors of the US economy and resulted in increasing wage inequality and growing educational wage differentials.

It is important not to oversimplify the relationship between the introduction of computers and demand for "skilled" workers. Several authors (e.g. DiNardo and Pischke, 1997 and Haisken-DeNew and Schmidt, 1999) stress that the causal relationship between computer use and demand for "skilled" workers is not straightforward but rather entangled with complex innovation processes which involve increased computer usage and, more importantly, changes in organisation and in production processes. Studies that analyse the employment impact of innovative activities support the existence of a relationship between skill upgrading and the introduction of new technologies. Innovations tend to increase the overall demand for labour but simultaneously lower the demand for unskilled labour (see Leo and Steiner, 1995 and Leo et al., forthcoming).

However, indicators of the use of new technologies (e.g. PCs), innovations and educational qualifications as a proxy for skills and competencies may not capture some of the fundamental changes behind the skill upgrade in the economy. In particular, educational qualifications may fail to capture many important skills which are needed at the workplace. Howell and Wolff (1992) conclude from case studies that "most jobs require a multitude of different skills for adequate task performance, ranging from physical abilities, like eye-hand co-ordination, dexterity and strength, to cognitive skills (analytic and synthetic reasoning, and numerical and verbal abilities) and interpersonal (supervisory, leadership) skills".

Howell and Wolff's analysis of the situation in the United States attempts "to account for skill composition and its change over time with direct measures of job skills and a more complete model of the demand for skills than appears in previous work". They therefore distinguished between cognitive, interactive and motor skill requirements for different jobs and adjusted their figures for industry characteristics. In their results they obtained little support "for either the standard factor substitution model or the widely accepted capital–skill complementary hypothesis". They found that capital intensity was strongly associated with rising interactive skills and declining cognitive skills. These results are in line with many case studies, which find that mechanisation is linked to the de-skilling of production workers and to the growing share of managers and supervisors.

Although this annex focuses on the demand for ICT skills, it is important to recognise that the effects of the new technologies on working life go beyond the increased demand for specialised technical skills. Firm-level evidence on the impact of ICT investment suggests that ICT use is correlated with increases in the demand for human capital skills, but also with more decentralised decision–making and greater use of teams (Bresnahan et al. 1999)[40]. These authors conclude that "the combination of computerisation, workplace organisation and increased demand for skilled workers appears as a cluster of changes in modern firms, almost certainly because they are complements". This of course implies that the recent changes in the structure of the corporation and the demand for human capital have a common origin in technological change.

The demand for labour with skills in information and communications technology (ICT) has increased rapidly in both the ICT sector itself and in the rest of the economy. The ICT-producing sector ranks amongst the most knowledge–intensive sectors in our economies. ICT production is highly research-intensive: in 1997, more than one third of all business R&D in Ireland and Finland, and more than one fifth in Canada, France, Italy, Japan, Sweden and the US, was carried out in the ICT sector (see OECD 2000A). The rapid development and diffusion of new digital technologies in the fields of telecommunications, the Internet and new media has led to a pronounced expansion of the demand for ICT skills throughout the economy. During the 1990s, ICT became a common form of economic infrastructure. In the EU, computer density (PCs per 10 000 inhabitants) rose from 930 in 1992 to about 2 500 in 1999; during the same period, Internet density (estimated Internet users per 10 000 inhabitants) saw an even more dramatic increase, from 31 to about 1 600.

Several trends have shaped the demand for ICT-skilled personnel in the past quarter of a century:

- Digitisation of telephony led to a decrease in the demand for lower-skilled ICT personnel who had been necessary for the operation and rollout of an analogue network. In turn, the demand for the skills needed to handle digital equipment increased. In net terms, the number of employees in public telecommunications operators has been falling since the beginning of the 1980s.
- Liberalisation of the telecommunications sector has not only forced former monopolists to introduce cost-saving measures, but has also permitted the entry of a large number of new competitors into the market. In the European Union, the number of operators authorised to offer public voice telephony almost doubled between 1998 and 2000 (European Commission, 2000).
- Internet and new media diffusion has created a demand for ICT skills both in specialised IT firms and in companies which have sought to establish a presence on the Internet and/or to engage in electronic commerce.

The downswing of Internet and technology stocks in spring 2000 led to significant layoffs and to low recruitment activity in the ICT sector. Nevertheless, given the

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[40] These empirical results are confirmed by a survey of managers that found that ICT is skill–increasing, a tendency particularly pronounced in high human capital, ICT-intensive, and decentralised firms.

positive long-term perspectives of the sector and the need for ICT skills in the rest of the economy, skill shortages are likely to remain a problem for the economy.

- **Estimates of ICT skill shortages in Europe**

Existing studies on ICT skill shortages differ widely in terms of their methodology and scope. ICT skill shortages are measured, for instance, in terms of the number of vacant jobs, or the expected number of jobs to be created in the future, or the required number of persons with specific qualifications. Several studies analyse only the ICT branches of industry, which were the first to experience skill shortages. The ICT skill shortages have since spread throughout the economy, rendering it increasingly difficult to come up with an estimate of the skills gap for the whole economy.

Differences in educational curricula impose further difficulties for the estimation of skills shortages. Any estimate of the future skills gap requires information not only on demand, but also on the future supply of labour with ICT skills. In order to estimate the supply of skills, data are needed on the output of the educational system at a highly disaggregated level. Furthermore, training and re-training activities also generate ICT skills, while their overall effects are difficult to estimate.

The overall business cycle and developments at industry level affect the demand for labour with specific skills and increase the uncertainty of any projections of skill shortages. This is particularly so in areas like ICT, where technological change is rapid and the organisation of commercial activities changes at an equally rapid pace. Hence, the estimates which are presented below should be taken as indicating the order of magnitude of the trends in the demand for and supply of ICT skills.

Two studies on ICT skills shortages are available at European level, both carried out by the International Data Corporation (IDC)[41]. In 2000, the IDC finalised a study on ICT skills shortages for Microsoft (IDC, 2000). The study covered the skill needs for Internetworking Environments (i.e. Internet-related activities), Technology-Neutral Environments (i.e. IT-supported business processes) and Other Technology Environments (i.e. host-based, distributed and applications environments).

The demand for ICT skills was expected to grow from approximately 9.5 million ICT professionals in 1999 to 13.1 million in 2003, while supply was estimated to grow from 8.6 million in 1999 to 11.3 million in the same period. Consequently, the ICT skill shortages in Western Europe (EU-15, Norway and Switzerland) were estimated to reach 1.7 million ICT professionals by 2003, representing 13 percent of the demand for such skills.

The level of demand for ICT professionals varies strongly among the West European countries included in the study (see Graph A III.1.1). On average, the demand for ICT specialists amounts to 5.7 percent of total employment. This ratio is almost twice as high in the Netherlands, Belgium and Sweden, while Greece, Ireland, Portugal and Spain display the lowest levels of demand for ICT professionals.

In relative terms, the ICT skill shortages are highest in those countries where ICT also has the highest weight in total employment: in the Netherlands, the shortage of ICT-skilled personnel amounts to 1.2 percent of total employment; it is followed by Sweden, Austria and Belgium (Graph A III.1.1). At the opposite end of the range is Greece, where supply and demand are balanced.

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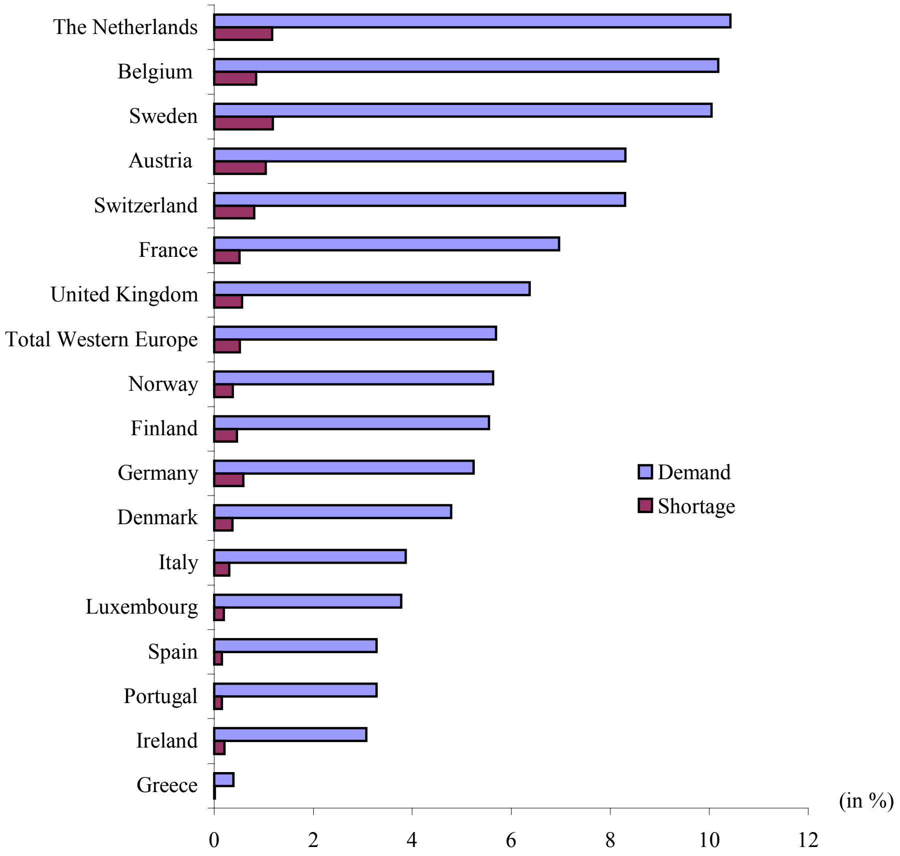
[41] As part of its continuous tracking of the IT services industry, IDC reviews, on a bi-annual basis, the level of demand for and supply of skilled professionals. From more than 12 000 interviews with information systems (IS) managers across Europe, IDC translates IS spending intentions into the amount of work that needs to be done in order to assimilate acquired technology.
IT work is segmented into activities that have to be performed during the planning, implementation, maintenance, management and training phases. For example, in networking environments, these activities would include needs assessment, network design, configuration, capacity planning, optimisation, network monitoring, maintenance and management. This segmentation, along with trends in IT investment, is analysed by company size for each country, generating a picture of demand for skills over time.
Investigation of trends among “intermediaries”, typically recruitment agencies, provides a validation of this demand profile. IDC estimates that these intermediaries fill 40–70 % of all vacancies (depending on the country). Trends in their activities thus provide valuable validation of the demand profile generated by IT spending patterns.
The supply of resources has been analysed and forecast by researching output levels in the network of universities and other educational establishments. IDC conducted a survey of the academic community in Western Europe; the primary research was carried out in cooperation with administrators with insight on intake trends, evolution of courses and the subsequent employment tracks of graduates. These data have been used to compile baseline trends in the supply of new professionals to the IT sector. In addition to data from the academic community, IDC has also factored in a contribution (12 % of new supply) from the re-skilling of workers from other industries, for example the defence and manufacturing sectors. Source: IDC (2000).

<u>Graph A III.1.1</u>: Demand for and shortage of ICT skills as percent of total employment, 1999



<u>Source</u>: WIFO calculations using IDC (2000); European Commission (2001).

The projected evolution of demand up to 2003 follows a fairly similar pattern in all the countries covered in the study. In most countries, demand for ICT skills is expected to grow at annual rates between 7 and 10 percent in the period 2000-2003. After a moderate slowdown in 2001, growth is expected to accelerate again in 2002. In Spain, growth in the demand for ICT skills was significantly higher than in the other countries in 2000, while Luxembourg and Greece are expected to record below-average growth until 2002.

In 2001, the IDC carried out a second study on ICT skill shortages, this time on behalf of EITO (EITO, 2001). This study has a broader occupational coverage than the previous one: three main categories of ICT skills are analysed. The first category consists of ICT professionals, who support and develop technology environments in the industries that use ICT. This category roughly corresponds to the narrower scope of the earlier study (IDC 2000, see above). The second category covers e-business professionals, who support business strategies related to the Internet. The third category consists of call centre professionals, who provide sales and support activities.

Table A III.1.1:Demand, supply and shortage of ICT skills in Western Europe

	1999	2000	2001	2002	2003
Demand (1 000 persons)					
ICT professionals	9 450	10 397	11 170	12 127	13 030
E-business	1 812	2 800	3 914	5 084	6 327
Call centre	1 000	1 300	1 690	2 113	2 577
Total	12 262	14 497	16 774	19 324	21 935
Supply (1 000 persons)					
ICT professionals	8 613	9 188	9 815	10 609	11 344
E-business	1 481	2 255	3 040	3 761	4 347
Call centre	900	1 183	1 546	1 954	2 397
Total	10 994	12 626	14 401	16 324	18 088
Shortage (1 000 persons)					
ICT professionals	837	1 208	1 355	1 519	1 686
E-business	331	546	874	1 324	1 980
Call centre	100	117	144	158	180
Total	1 268	1 871	2 373	3 001	3 846
Shortage in % of demand					
ICT professionals	8,9	11,6	12,1	12,5	12,9
E-business	18,3	19,5	22,3	26,0	31,3
Call centre	10,0	9,0	8,5	7,5	7,0
Total	10,3	12,9	14,1	15,5	17,5
In % of total employment					
Demand	7,4	8,9	10,2	11,6	n.a.
Supply	6,6	7,7	8,7	9,8	n.a.
Shortage	0,8	1,1	1,4	1,8	n.a.

Source: WIFO calculations using EITO (2001).

The total demand for ICT, e-business and call centre skills in Western Europe is estimated to have exceeded 10 percent of total employment in 2001, exceeding the supply of such skills by 1.4 percent of total employment (Table A III.1.1).

It is forecast that between 1999 and 2003 the demand for personnel with ICT, e-business and call centre skills in Western Europe will almost double. By 2003, demand for these skills will exceed 21.9 million jobs. The growth pattern of demand is similar across the countries covered in the study. Despite the expected increase in the supply of personnel with ICT, e-business and call centre skills, the skills gap will continue to widen.

The estimated shortage of ICT professionals in 2003 – the first of the three categories included, which corresponds to the narrower scope of the earlier study (IDC 2000) – is similar to the estimate given a year earlier, 1.7 million persons. Adding to this the categories of e-business professionals and call centre professionals leads to a total estimated skills gap of 3.8 million persons. The shortage of e-business professionals is expected to increase particularly rapidly, reflecting the more than threefold increase in the demand for e-business skills over the forecast period 1999-2003. For call centre skills, the gap between demand and supply will increase moderately in absolute terms, but narrow in relation to total demand in the sector.

In relative terms, the estimated skills gap is highest for e-business skills, where it is projected to amount to 31 percent of demand in 2003. The skills gap for ICT professionals is forecast at 13 percent of demand, and that for call centre professionals at 7 percent of demand. Under the category ICT professionals, businesses appear to be looking primarily for Internet specialists (where the shortage amounts to 32 percent of demand).

In Table A III.1.2, the estimates of the two IDC studies [IDC (2000) and EITO (2001)] are compared with a selection of national-level studies. Differences in the scope of the studies, sector definition, time horizon, data-gathering method or period of study are likely to explain at least partly the wide differences in the estimates for ICT skill shortages. National-level estimates for ICT skills demand, or skill shortages, are in most cases substantially lower than the IDC estimates.

In more recent studies, the estimates of ICT skill shortages tend to be lower than in earlier studies (see e.g. the studies by ITAA in the US). This is likely to reflect the recent downswing of the ICT industry. However, the studies still point to existing shortages, and these may aggravate once an upswing sets in.

Table A III.1.2: Country level studies of the ICT skills gap

Country	Source	Period covered	Demand	Shortage	Scope/Sector
Belgium	IDC (2000)	2003	-	72 932	total economy
	INSEA (1)	Annually	-	5 000	software engineers
Denmark	IDC (2000)	2003	-	24 679	total economy
	SHAPIRO (1998)	1998-2002	40 000	-	employees MA level computer skills
Germany	IDC (2000)	2003	-	404 951	total economy
	EITO (2001)	2003	-	353 900	total economy
	D21 (2001)	Currently	-	150 000	total economy
	BMWI & bmb+f (1999)	Currently	-	75 000	total economy
	BMWI (1999)	1999-2002	350 000	-	total economy
	ZEW	2000-2002	340 000	-	total economy
Greece	IDC (2000)	2003	-	2 005	total economy
Spain	IDC (2000)	2003	-	101 011	total economy
	EITO (2001)	2003	-	107 100	total economy
France	IDC (2000)	2003	-	223 709	total economy
	OECD (2000B)	Currently	-	25 000	total economy
Ireland	IDC (2000)	1998-2003	-	9 881	total economy
	Forfás (2001)	2001-2005	9 304	3 332	IT experts in total economy
Italy	IDC (2000)	2003	-	167 439	total economy
	EITO (2001)	2003	-	161 300	total economy
	Ministry of Labour (3)	Currently	-	50 000	total economy
Luxembourg	IDC (2000)	2003	-	967	total economy

Country	Source	Period covered	Demand	Shortage	Scope/Sector
Netherlands	IDC (2000)	2003	-	118 882	total economy
	FENIT (2000)	End of 2000	14 500	-	telecom sector
	Dutch Ministry of Economic Affairs and Ministry of Education (2000)	2000-2003	-	24 000	total economy
Austria	IDC (2000)	2003	-	85 013	total economy
	Leo (2000)	1997-2003	13 000	-	ICT
	Synthesis (2001)	2002	-	7 400	total economy
Portugal	IDC (2000)	2003	-	21 913	total economy
Finland	IDC (2000)	2003	-	2 314	total economy
	Ministry of Labour (2000)	2002	-	8 000-12 000	computer experts in total economy
	Employers Confederation of Services Industry (1)	2001	2 500-3 000	-	IT service sector in member companies
Sweden	IDC (1999)	2003	-	67 092	total economy
	Swedish National Labour Market Board (2001)	Annually 2001-2011	10 500		total economy
UK	IDC (2000)	2003	-	329 573	total economy
	EITO (2001)	2003	-	326 700	total economy
	IER (2)	1997-2006	340 000	-	IT Service
	Cambridge Econometrics (2)	2010	421 000	-	computer services
Japan	Ogura - Suzuki (1999)	1996	-	9 000	system engineers & programmers
US	ITAA (2000)	2001	900 000	843 000	total economy
	ITAA (2001)	2001	-	425 000	total economy

Notes:

(1) Quoted from WITSA 2001.
(2) Quoted from Department for Education and Employment, 1999.
(3) Quoted from Ministero del Tesoro, del Bilancio e della Programmazione Economica.

- **Policy responses to the ICT skills gap**

Many governments and businesses alike have taken measures to combat ICT skill shortages. Member States have introduced changes to their educational systems and intensified ICT training; some have also encouraged immigration. At the EU level, the European Commission launched the Initiative for New Employment, the eLearning Initiative and the European Computer Driving Licence. Ten Member States participated in a benchmarking project on "ICT and new organisational arrangements"[42], which recommended *inter alia* that more be done to train the personnel and management of SMEs in new technologies. Some firms have established learning centres outside Europe, or transferred part of their development and production units to non–EU countries (for examples, see EITO 2001).

Table A III.1.3: Actions in response to the ICT skills shortage

	Short–term demand	**Long–term demand**
Highly–skilled ICT personnel	Immigration Outsourcing to non-EU countries with a highly qualified labour force	Increase output of tertiary education
Medium–skilled ICT personnel	Immigration Outsourcing to non-EU countries with a qualified labour force E-learning Training and retraining activities	Increase output of secondary education
Low–skilled ICT personnel	European computer driving licence Training and requalification activities	Increase computer and Internet literacy in primary and secondary education

The appropriate response to the ICT skills gap depends on the type and urgency of the skills needs. Table A III.1.3 groups the possible measures according to the level of skills needed, and to the urgency of the skills shortage.

In most cases, the obvious response to skill shortages would be the adaptation of the national educational system to provide more graduates with the required skills. If highly skilled ICT personnel with ICT specific training of more than three years are needed, changes in the education system may take too long to reduce current shortages. Introducing new courses has lead times of one to two years as new curricula have to be developed and additional resources are needed. Altogether, it may take five to seven years before additional highly-skilled graduates leave the

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[42] See recommendations in "Summary of Results of Best Practice-related Activities in the field of Enterprise Policy" (SEC(2000) 1824 of 26.10.2000) p.4-5. Detailed information on the benchmarking project are available on Internet:
http://www.benchmarking-in-europe.com/eu_initiatives/enterprise_dg/framework_conditions/index.htm

education system and enter the labour market. Consequently, immigration or outsourcing to countries with sufficient highly skilled ICT personnel may be the only available short-term solution.

Short-term shortages of medium-skilled ICT personnel (with ICT-specific training of one to three years) may also call for outsourcing and/or immigration policies, but to a lesser extent than for highly-skilled ICT personnel. In the short run, ICT skills at both intermediate and lower levels can be increased through training measures. Training programmes may also have the beneficial side-effect of drawing more people into the labour market and increasing participation rates. To succeed, it is essential that public training measures be implemented in close co-operation with firms.

Only some governments and few experts predicted the skill shortages in time, and many were surprised by the magnitude of the problem in 1999 and 2000. While it is difficult to predict with accuracy the future demand for occupational skills, it is essential that the education and training regime be sufficiently flexible to accommodate shifts in skills demand, especially when these are of a permanent character.

- Concluding comments

The long-term increase in the demand for highly skilled professionals and the recent shortage of ICT-skilled workers is bound up with technological change. The longer-term trend was matched by a constant increase in output from the education system. In contrast, the more recent surge in ICT investment in the 1990s led to a constant widening of the ICT skill gap, which was at its widest in the first half of 2000 and was not accompanied by an increase in the output of the education system. This more recent increase in demand for ICT skills is the direct product of the development and diffusion of new technologies and has been intensified by the digitisation and liberalisation in the telecommunication sector and the rapid expansion of the Internet and new media.

Shortages of ICT skills have appeared both in the ICT sectors itself and in companies which use ICT, for instance electronic commerce. The current shortages of personnel with ICT skills may be even as high as 1½ percent of total employment in Western Europe. The skills shortages are expected to worsen in the coming years, despite an increased supply of the requisite skills.

While changes in educational curricula may be the solution in the medium to long term, short-term skill shortages have been met by measures such as targeted training, immigration or outsourcing.

In recent years, measures to combat shortages of ICT skills have topped the policy agenda in the Member States and in ICT firms. Both have been promoting strategies, occasionally by co-operative arrangements, to increase the supply of ICT–skilled labour. The Commission put forward the Initiative for New Employment, the eLearning Initiative and the European Computer Driving Licence. Member States have also initiated changes in their education systems and have intensified training and requalification activities. Businesses have introduced new ways to recruit skilled people (most notably online recruiting) and to raise employee loyalty by offering stock options. They have also invested in technology-focused alliances with partners, launched eLearning systems, virtual learning centres, etc. Some Member States have also tried to solve the ICT skill shortages by encouraging immigration, and some firms have established learning centres outside Europe or transferred part of their development and production units to non–EU countries.

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CHAPTER IV:
THE IMPACT OF INNOVATION ON MANUFACTURING PERFORMANCE

This chapter discusses the influence of innovation on production and productivity growth. It focuses on manufacturing, first at the aggregate level, then at the level of sectors and industries. The data confirm the key role of capabilities, knowledge , ICT and research output in growth and productivity. The industry pattern of productivity growth appears to be similar across countries and to have recently become even more similar, with technology-driven industries now taking the lead in productivity increase in Europe also. With respect to the forces facilitating innovation and growth, lagging European countries are catching up, albeit slowly, and some European countries compare well with the US.

As discussed in Chapter I, the US is forging ahead in productivity growth. Following a long period of more rapid productivity growth in Europe, productivity growth accelerated in the US during the last decade and is now higher than in Europe and in Japan.[43] Between the first and the second half of the 1990s the US experienced an acceleration in terms of both output and productivity. In contrast, in the EU productivity decelerated by 0.7 percentage points despite acceleration in output of 1.1 percentage points. The next section investigates these trends in the manufacturing sector.

4.1. Manufacturing production and productivity growth in the EU and the US

Labour productivity in EU manufacturing increased at 3 percent per year during the 1990s and, in contrast to productivity in the whole economy, a modest acceleration was registered between the first and the second halves of the decade. Nevertheless, this acceleration was less strong than in the US (see Graph IV.1). The highest productivity growth in the EU during the nineties was recorded in Ireland, Finland, Austria and Sweden; in these four countries, productivity in manufacturing rose faster than in the US (see Graph IV.2). The lowest growth rates were recorded in Portugal, Spain and France (less than 2 % p.a.). In the second half of the 1990s, three countries saw productivity increase faster than in the US, eleven countries experienced productivity growth lower than in the US, and in Spain productivity growth was negative (see Table IV.1).[44]

In manufacturing production, EU growth, which had been superior to that in the US in 1986–90, declined at a lower rate than US growth in the 1990s (1.7 % annually compared to 4.1 % annually in the US). Countries with low growth recorded barely more than 1 % annually for the decade, while countries with high growth achieved around 4 %, with the exception of Ireland (11.2 %) and Finland (6.2 %). Nevertheless, an important acceleration took place in almost all Member States between the first and the second half of the 1990s.

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[43] This is true not only for labour productivity, both for the whole economy and for manufacturing, but also for total factor productivity.

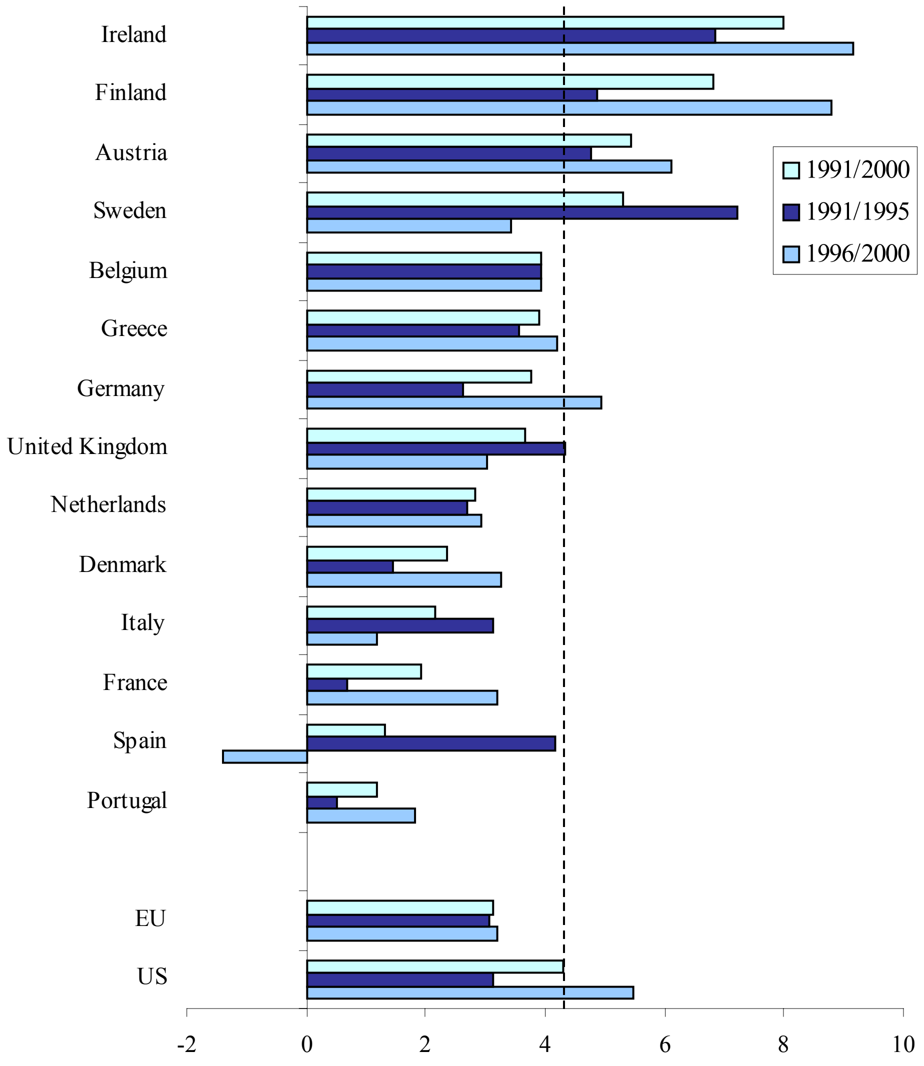
[44] If ranked according to the acceleration observed between the first and the second halves of the nineties, Finland, France, Ireland and Germany spurred up productivity fastest while Denmark, Austria and Portugal came in next.

Graph IV.1: Performance in manufacturing in EU and US

Note: Average annual growth in percent. Productivity is measured as manufacturing production per employee.

Source: WIFO calculations using EUROSTAT (New Cronos); 1999-2000 estimate, Economic Forecasts 2000-2002 (European Commission).

Graph IV.2: Productivity growth in manufacturing (countries ranked according to growth in the 1990s)



Source: WIFO calculations using EUROSTAT data (New Cronos); 1999-2000 estimate, Economic Forecasts 2000-2002 (European Commission).

Table IV.1: Growth performance in manufacturing

	Production of manufacturing					Productivity of manufacturing				
	Growth p.a. in percent				Acceleration	Growth p.a. in percent				Acceleration
	1986/1990	1991/1995	1996/2000	1991/2000	Second half minus first half	1986/1990	1991/1995	1996/2000	1991/2000	Second half minus first half
Belgium	3,5	1,3	3,4	2,3	2,1	3,4	3,9	3,9	3,9	0,0
Denmark	1,6	3,0	3,6	3,3	0,6	2,6	1,5	3,3	2,4	1,8
Germany	3,5	- 0,8	3,6	1,4	4,4	2,0	2,6	4,9	3,8	2,3
Greece	0,2	- 0,7	3,2	1,3	3,9	0,5	3,6	4,2	3,9	0,6
Spain	3,4	0,9	2,4	1,6	1,5	2,1	4,2	- 1,4	1,3	- 5,6
France	2,2	- 0,4	3,7	1,6	4,1	3,8	0,7	3,2	1,9	2,5
Ireland	8,3	10,2	12,2	11,2	2,0	7,7	6,8	9,2	8,0	2,3
Italy	3,2	1,4	1,8	1,6	0,4	3,8	3,1	1,2	2,2	- 2,0
Netherlands	1,8	1,4	3,6	2,5	2,2	0,0	2,7	2,9	2,8	0,3
Austria	4,5	2,4	5,6	4,0	3,2	5,8	4,8	6,1	5,4	1,3
Portugal	4,9	- 0,8	2,8	1,0	3,7	5,0	0,5	1,8	1,2	1,3
Finland	2,7	2,8	9,8	6,2	7,0	4,6	4,9	8,8	6,8	3,9
Sweden	2,1	3,2	5,1	4,2	1,9	2,1	7,2	3,4	5,3	- 3,8
United Kingdom	3,4	0,6	1,1	0,8	0,5	3,5	4,3	3,0	3,7	- 1,3
EU	**3,3**	**0,4**	**2,9**	**1,7**	**2,5**	**3,0**	**3,0**	**3,2**	**3,1**	**0,1**
Japan	4,5	- 0,6	1,1	0,2	1,7	4,0	1,0	3,0	2,0	2,1
US	2,4	2,9	5,2	4,1	2,3	2,3	3,1	5,5	4,3	2,3
Standard deviation EU countries	1,91	2,80	3,05	2,78		2,05	2,00	2,78	2,04	
Standard deviation Triad	1,08	1,84	2,09	1,95		0,86	1,22	1,37	1,15	

Source: WIFO calculations using EUROSTAT data (New Cronos); 1999-2000 estimate, Economic Forecasts 2000-2002 (European Commission).

4.2. The underlying forces

As discussed in Annex II.1, modern growth theories suggest that innovation is a crucial determinant of growth. Innovation can be achieved through different channels – through own R&D activities leading to new products or processes, but also through a diffusion effect associated with imported technology or inputs or due to the presence of multinational firms; or through spillover effects that magnify the benefits of own R&D efforts. For this reason, when evaluating the innovative strengths of a country, indicators other than the ones directly related to own innovation (such as measures of R&D effort) must be taken into account. In particular, equally relevant are indicators on the ability of a country to build on and to make the most of existing knowledge and innovation through a process of diffusion and adoption. Stern et al.(2000) in fact shows that innovative performance depends not only on research input but also on other variables such as the existing stock of knowledge, the openness of the country to international trade and investment and the share of GDP spend on higher education.

This section examines the relation between indicators on research, the knowledge base, ICT and capabilities, and growth of output and productivity. Each indicator is subject to measurement problems and can account for only part of the growth differences; together they establish a system of growth forces which relate to the performance differences of EU countries in the 1990s. Clearly, these indicators do not capture all aspects relevant for fostering and implementing innovation. Factors such as the presence of multinational firms, the degree of labour mobility between universities and firms or across countries, or the openness of an economy, are important determinants of the absorptive capacity of a country and of the extent to which spillovers can successfully take place.[45]

The present discussion concerns exclusively the manufacturing sector.[46] There is evidence that it is the manufacturing rather than the service sector that drives productivity growth and differentials thereof.[47] Moreover, examination of the manufacturing sector allows the use of additional information on research intensity at sectoral level. Other than the indicators related to knowledge, innovation and ICT, this section also uses information contained in the Community Innovation Survey to verify the importance of capabilities.[48] These variables are presented in Table IV.2. Also, a measure of the speed of structural change may indirectly add information regarding the need, as well as the potential, for change, building a bridge to the country profiles presented in Annex 1. Finally, the potential relation between the

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[45] One area where these factors are particularly important is biotechnology, which is discussed in Chapter V of the Report.

[46] Results for macroeconomic growth are already available in the OECD growth project (OECD 2001) and it is not necessary to repeat them here. Its main results and one of the core findings - that in OECD countries the acceleration of total factor productivity in the total economy is significantly related to increases in business research intensity - are reported in Annex II.2.

[47] See, for example, *Scarpetta* et al. (2000).

[48] Though the indicators chosen are all linked to, and suggested by, theories of economic growth and are also partly related to the empirical evidence discussed earlier, a certain ambiguity remains as to which indicators should be used; first, because most indicators are poor proxies for the processes considered important; and, second, because each single indicator is flawed by severe measurement problems. These obstacles are partially overcome by using rank correlations (which are more robust than simple quantitative indicators) and by looking at the combined rankings of several indicators.

growth forces and the performance indicators is evaluated by means of rank correlations and the results are reported in Table IV.2. It should be stressed that correlation indicates only the closeness of a relation but proves no causality. Graph IV.3 shows the relationship between productivity growth and each of the underlying forces.

- **Research indicators**

Growth of production and productivity are positively related to research inputs, patents and publications. Although the relationships are not particularly close, those between growth and publications and between productivity growth and patents are statistically significant (see Table IV.2 and Graph IV.3). Sweden and Finland rank high according to both research and performance indicators; Germany ranks high in patents and research input, but has only a moderate position in output growth and productivity; the UK, which is among the leading countries with respect to research indicators, displays low productivity growth. In contrast, Austria is far better ranked in growth performance than in research indicators. The southern countries – Greece, Spain, Portugal and Italy – rank low in all research indicators and in performance indicators. Ireland, the fastest growing economy, has seen an increase in its research input and output, and enjoys a high share of technology-driven industries, but lags behind compared to research-intensive countries.

- **Knowledge base**

To capture the concept of knowledge base, human capital indicators (such as secondary and tertiary education and human resources in technology as discussed in Chapter II) are combined with indicators of production and use of ICT. Sweden (see Graph IV.3) ranks highest according to human capital indicators and Denmark and Belgium also rank high, reflecting high expenditure on higher education. The UK performs less well in this category, and Austria and Ireland rank better in human capital than according to research and ICT (see Graph IV.3). For ICT, Ireland ranks high in consumption and in the production share of ICT industries in manufacturing, but only moderately with respect to diffusion (Internet hosts and computers per resident). Germany and Belgium rank lower in ICT production and computers per resident. The Member States ranking lower in this category are the same as those for R&D indicators.

Finally, all correlations are positive and the share of the work-force with tertiary education, computers per resident and Internet hosts are significantly correlated with production growth (see Table IV.2).

- **The role of capabilities**

The results show that indicators meant to capture the notion of firms’ capabilities are closely related to growth. There is a consensus that capabilities are decisive for the performance of firms, but also that they are difficult to measure. Four indicators from the CIS innovation survey which proxy some aspects of capabilities are used here, (see Table IV.2). Innovation expenses relative to sales,[49] and the share of firms that report co-operative and continuous research are significantly related to production growth; the last two are also related to productivity growth. However, the share of new products in sales does not find decisive statistical support.

According to the capability indicators, Ireland and Austria rank lower than according to the performance indicators, while the opposite holds for Germany, France and the United Kingdom. Greece, Spain, Italy and Portugal rank low in terms both of performance and capability indicators – and in particular rank the lowest in innovation expenditure and in the share of firms reporting co-operative activities and continuous research. In contrast, Finland and Sweden rank high in both dimensions.

- **Growth and speed of change**

The speed of change of industrial structure[50] is significantly related to productivity growth, being highest in the case of Ireland where productivity growth is also the highest. Finland, which registers high productivity growth, ranks fourth in the speed of change indicator. At the lower end, Germany, Italy and the UK display both slow speed of change and slow productivity growth. Austria's and Sweden's productivity has increased despite slow structural change, while in Portugal rapid change combines with low productivity growth – see Table IV.2 and Graph IV.3.

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[49] Innovation expenditure includes software, acquisition of patents, know-how, trademarks, training, industrial design, etc. Some of these reflect activities that allow firms to build up a competitive advantage and make use of knowledge that is in principle available, but requires specific abilities to get hold of. Thus innovative expenditure signals elements addressed by the capability approach but not contained in research expenditure.

[50] This indicator measures the sum of absolute changes in the shares of sectors or industries in total manufacturing between a base year and the final year. It is a proxy reflecting changes in demand, but it also indirectly measures rigidities, see Aiginger (2000) and European Commission (2000). In the correlations, a comprehensive indicator was used which combines changes in value added, exports and employment at the 2–digit and 3–digit level (see Aiginger, 2001A).

Table IV.2: Correlation, across EU countries, between growth and underlying forces (rank correlation coefficients, p value in parentheses)

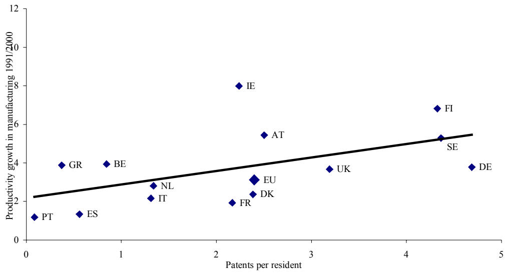
	Production growth manufacturing[1]		Productivity growth manufacturing[1]	
Research				
R&D/GDP	0.3319 (0.2464)		0.3187 (0.2668)	
R&D personnel as a % of the labour force	0.4374 (0.1178)		0.3626 (0.2026)	
Patents per inhabitant	0.3670 (0.1967)		0.5253 (0.0537)	*
Publications per inhabitant	0.4593 (0.0985)	*	0.3363 (0.2398)	
Human Capital				
Public expenditure on education	0.4813 (0.0814)	*	0.1736 (0.5528)	
Percentage of the population that has attained at least upper secondary education by age group (1998)	0.3758 (0.1854)		0.4110 (0.1443)	
Percentage of the population that has attained at least tertiary education (1998)	0.4316 (0.1234)		0.4094 (0.1460)	
Human resources in science and technology by country	0.3451 (0.2269)		0.2703 (0.3499)	
Working population with tertiary education	0.4681 (0.0914)	*	0.3670 (0.1967)	
Information and Communication Technologies				
ICT expenditure as a % of GDP	0.3011 (0.2955)		0.2440 (0.4006)	
ICT production as a % of total manufacturing	0.4559 (0.1022)		0.2967 (0.3030)	
PCs per inhabitant	0.6484 (0.0121)	**	0.4681 (0.0914)	*
Internet users per inhabitant	0.6088 (0.0209)	**	0.5341 (0.0492)	**
Cellular mobile subscribers per inhabitant	0.4286 (0.1263)		0.2396 (0.4094)	
Capabilities				
Innovation expenditures as a % of sales	0.5431 (0.0447)	**	0.3444 (0.2278)	
Share of new/improved products as a % of sales	0.4462 (0.1098)		0.3495 (0.2207)	
Share of co-operations	0.6084 (0.0210)	**	0.4596 (0.0983)	*
Share of firms with continuous research	0.7582 (0.0017)	**	0.6396 (0.0138)	**
Other				
Structural change indicator (speed of change)[2]	0.4154 (0.1397)		0.4637 (0.0949)	*
Combined indicator	0.6264 (0.0165)	**	0.4593 (0.0985)	*

[1] Growth 1991/2000; [2] Aiginger (2001B).

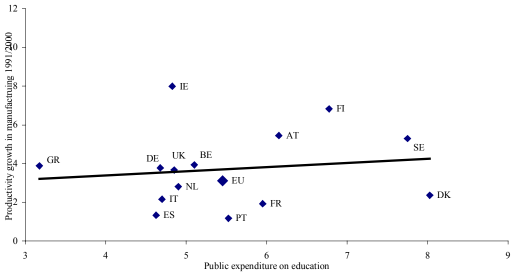
Note: * (**) denotes significance at 10 % (5 %) level; for growth drivers: average of the nineties (usually up to 1998).

Graph IV.3: Forces underlying productivity growth

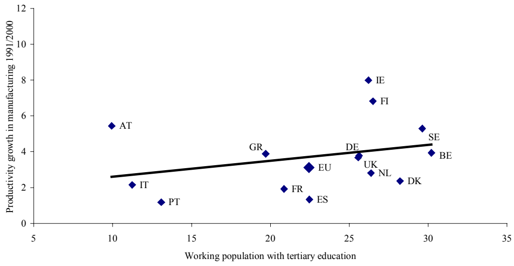
Relation between productivity growth and patents per resident



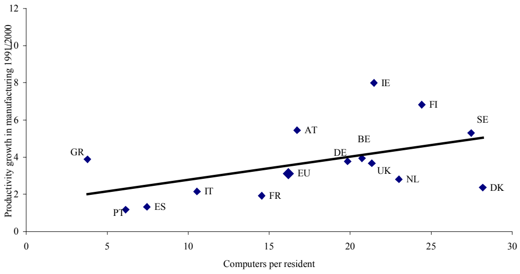
Relation between productivity growth and public expenditure on education



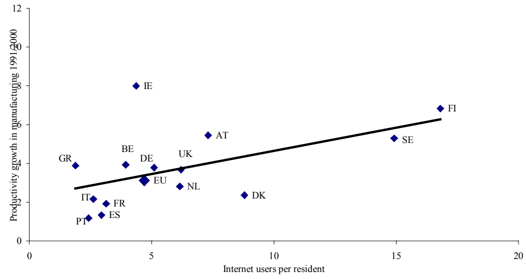
Relation between productivity growth and working population with tertiary education



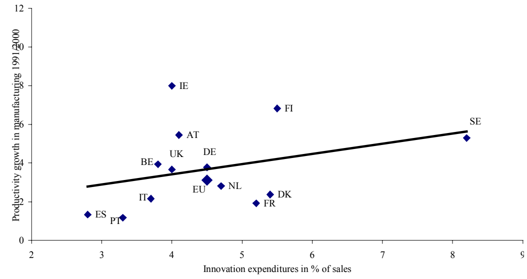
Relation between productivity growth and computers per resident



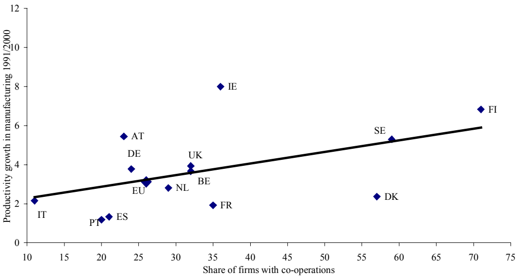
Relation between productivity growth and internet users per resident



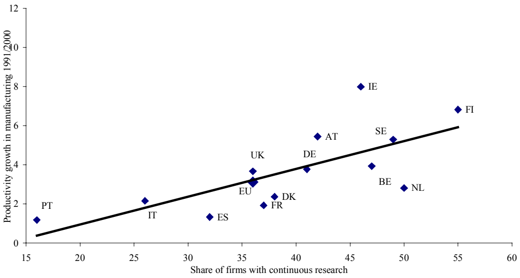
Relation between productivity growth and innovation expenditures in % of sales



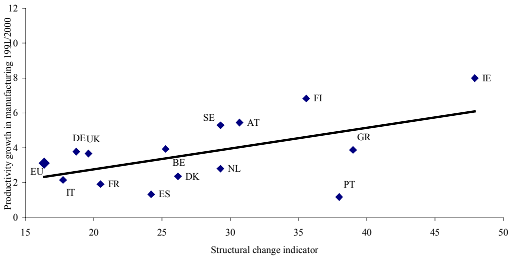
Relation between productivity growth and share of firms with co-operations



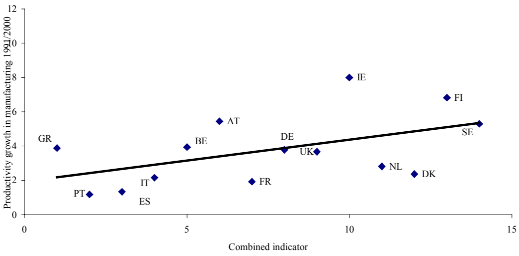
Relation between productivity growth and share of firms with continuous research



Relation between productivity growth and speed of change



Relation between productivity growth and the combined factor



Given the complexity of the relationship between the innovation system and productivity growth, no close statistical correlation between any single indicator and growth performance should be expected. When information on the possible growth factors is combined in a single indicator (called "combined indicator" in Table IV.2 and Graph IV.3), measurement errors in the individual series are reduced, and the results indicate that a statistically significant relation between the variables exists.

To sum up, among the various sets of indicators, those meant to capture the notion of capabilities appear to bear the closest relation with manufacturing growth performance, supporting the relevance of evolutionary theories and of approaches emphasising the absorptive capacity of firms.[51] None of the available indicators on human capital shows a significant relation with productivity growth in manufacturing, and only public expenditure in education and working population with tertiary education bear a significant relation with production growth. Among the indicators on ICT, Internet penetration and number of PCs per inhabitant display a positive relation with both production and productivity growth in manufacturing, while ICT production or expenditure do not appear to be significantly related to the performance, indicators. Concerning research, R&D inputs, R&D intensity and R&D personnel in the labour force are not significantly related to growth performance while research outputs – patents and publications per resident – bear a significant relation with performance, the first with productivity growth and the second with production growth. Note that, in general, the indicators are more closely related to production growth than to productivity growth.[52]

4.3. Productivity growth and research intensity at sectoral level in the EU and the US

In the second half of the 1990s productivity increased fastest in technology-driven industries, while in the first half it grew fastest in capital-intensive industries.[53] The experience of the second half of the decade suggests that a close connection between research intensity and productivity growth across sectors could be present. However, the experience of the first half weakens this relationship since own–research input is typically low in capital–intensive industries.[54]

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[51] The indicators also offer a partial explanation for the acceleration of production growth in the nineties, as compared to the eighties. Best again are indicators from the category including capabilities (innovation/sales ratio, co–operations, continuous research), as well as human capital, ICT share in value added and speed of change. On the other hand, no satisfactory correlations provide an explanation of the acceleration of growth in the second half of the nineties, as compared to the first. The reason is that the distribution of growth between the two halves of the nineties is determined by the business cycle, economic crises and measurement problems.

[52] For the combined indicator, significance levels are 2 % for production growth, and 10 % for productivity growth.

[53] For a classification of industries according to main inputs used, see Table IV.7 at the end of the chapter.

[54] Productivity is measured by real value added per employee, and research intensity by research outlays as a percentage of value production. Real value added (when not available from SBS) was estimated using nominal value added from SBS and price data from STAN (OECD). ANBERD was used for research and development, and STAN for production (both provided by the OECD). For the correlations, a combined indicator of productivity (with nominal and real value added and production value as the numerator) was also used, which should help to eliminate noise and measurement errors in each of the series. The results reported here are robust across indicators.

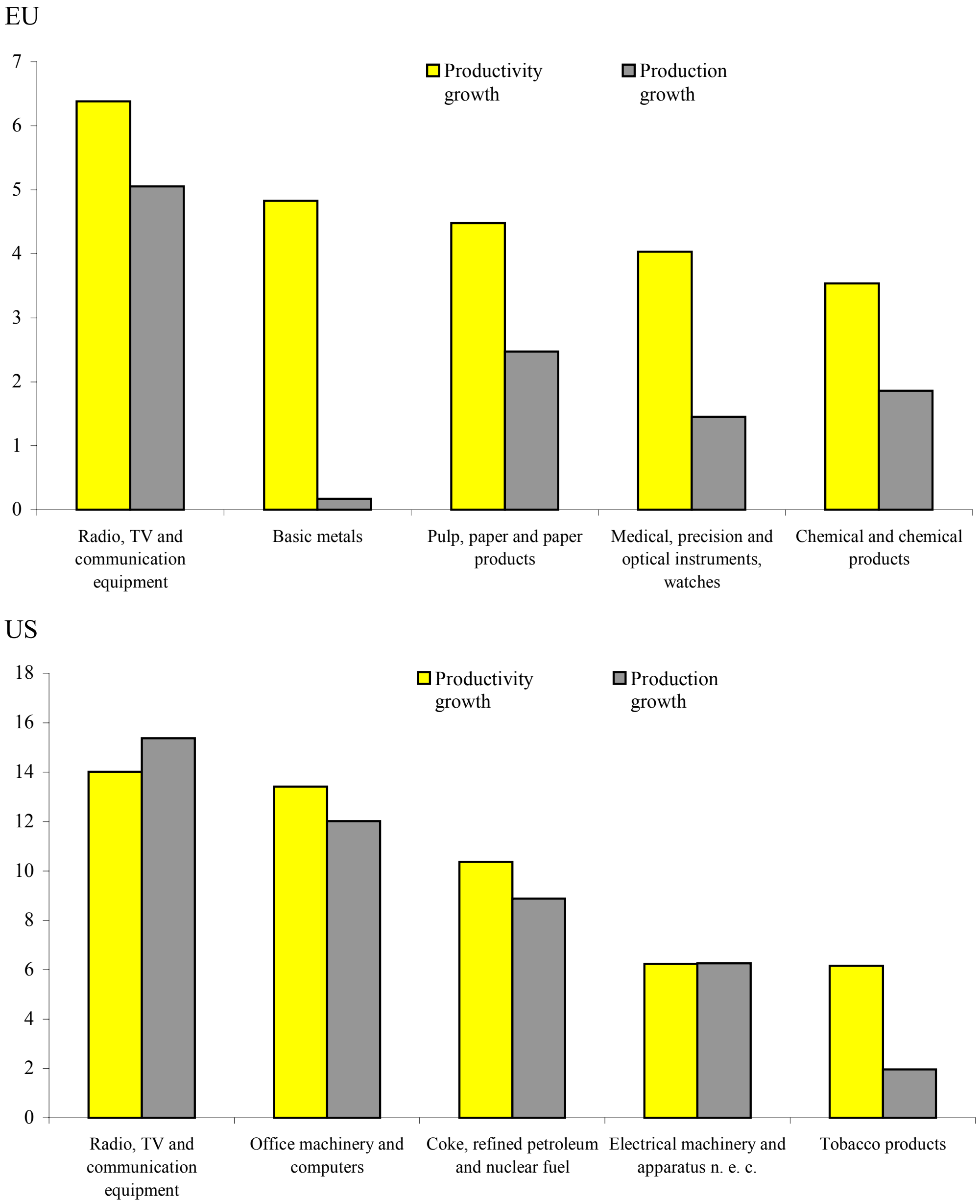
- **Technology, restructuring, and productivity growth**

Graph IV.4 presents data on manufacturing production and productivity growth in the EU and the US for the period 1991–1998. High–tech industries with strong productivity growth in the EU are electronic equipment and medical equipment, but productivity also increased very fast in capital–intensive industries like basic metals, pulp and paper, and chemicals. In the last two sectors, apparent productivity growth was influenced by reductions in employment.

The smallest increases are found in the cases of apparel, leather and the food sector. Textiles registered an average growth in productivity and a steep decline in employment. In printing and publishing, productivity increases were modest and employment was on the increase.

Graph IV.4: Sectors with the highest increase in productivity, EU and US

(annual growth of real value added per employee in percent; 1991-1998)



Source: WIFO calculations using EUROSTAT data (New Cronos).

In the second half of the 1990s, technology–driven industries recorded marked increases in productivity growth. None of the capital–intensive industries mentioned above recorded an increase in productivity growth between the first and second halves of the decade.[55] In the early 1990s, the greatest productivity increase took place in capital–intensive industries (4.1 %), followed by technology–driven industries (3.4 %), with labour-intensive and marketing–driven industries trailing in productivity performance. In the latest years, however, technology–driven industries increased productivity most strongly (4.8 %). This suggests that this group accounts for a large part of the acceleration in productivity growth observed during this period. Capital–intensive industries experienced a modest 2 % productivity growth during this latter period (see Graph IV.5).[56]

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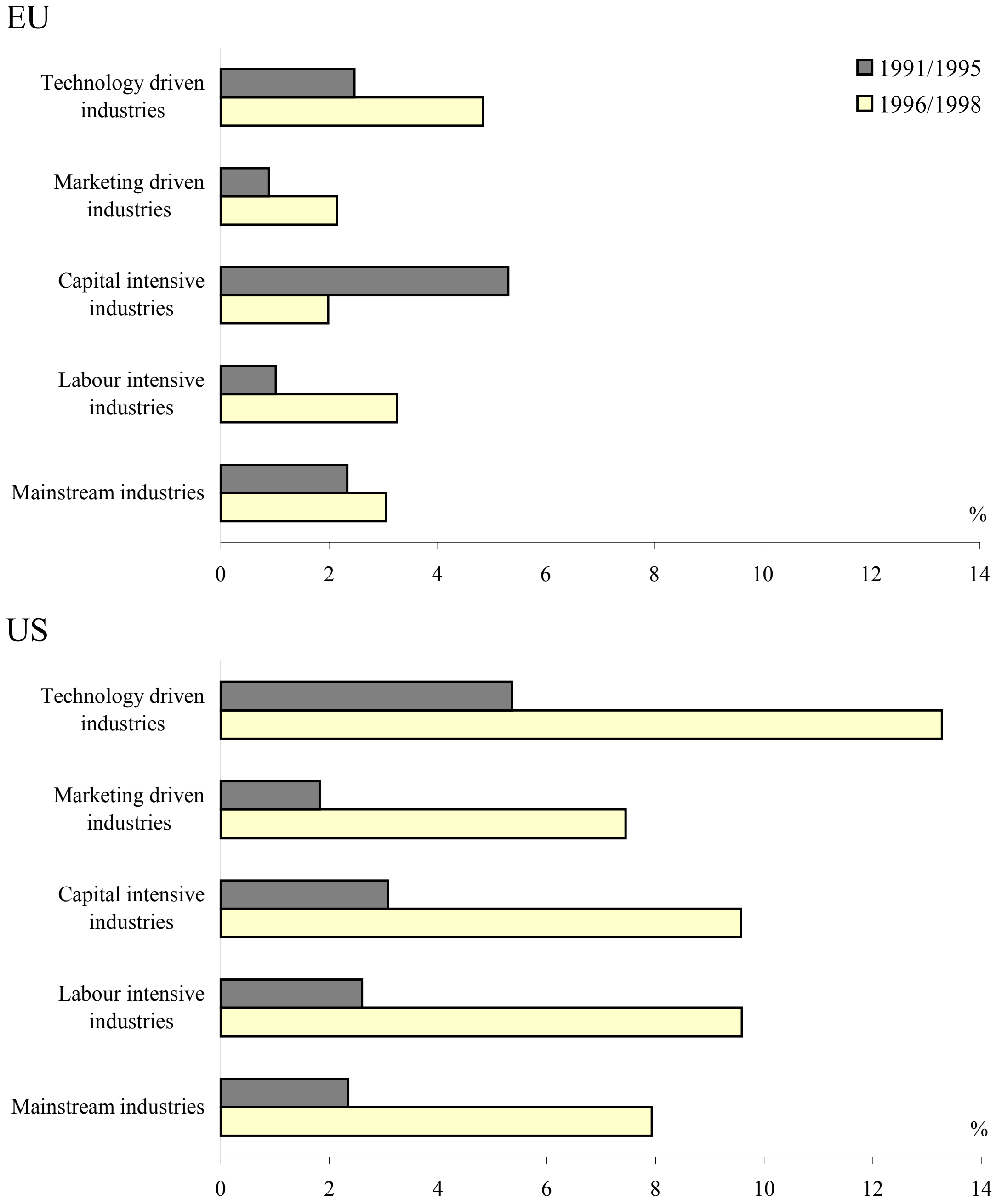
[55] Taking the acceleration of productivity alone as a criterion shows several industry–specific and cyclical effects not linked to innovation; for example, in the petroleum industry productivity accelerated, while in pulp and paper it declined.

[56] All these tendencies are replicated if nominal data or a combined productivity indicator is used.

<u>Graph IV.5</u>: The role of technology-driven and capital-intensive industries in EU and US productivity growth



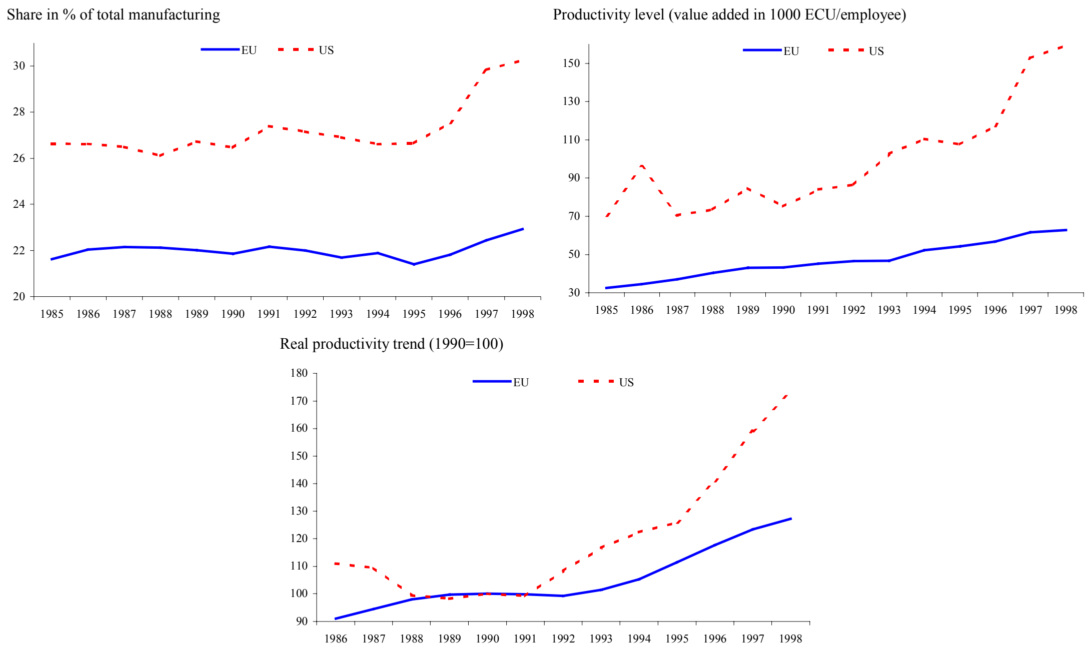
<u>Note</u>: Productivity is measured as real value added per employee. For the industry classification see table IV.7.

<u>Source</u>: WIFO calculations using EUROSTAT data (New Cronos).

- **Impact of technology on US industry**

In the US, the role of technology-driven industries in productivity growth is even more important than in the EU. First, their share in manufacturing is larger than in the EU (see Graph IV.6). Second, in the US these industries recorded an average annual productivity increase of 8.3 % in the 1990s – a much higher rate than the 3.5 % achieved by the EU technology-driven industries. In technology-driven industries, productivity accelerated from 5.4 % per year in the first half of the decade to 13.3 % per year in the second. In 14 industries, productivity increased at double–digit rates in the period 1996–1998, most of which are technology-driven industries. In Europe, only four industries enjoyed such large productivity increases.[57]

Graph IV.6: Share, productivity level and productivity growth of technology–driven industries


Share in % of total manufacturing

Productivity level (value added in 1000 ECU/employee)

Real productivity trend (1990=100)

Source: WIFO calculations using EUROSTAT data (New Cronos).

- **Sectoral research intensity in the EU and the US**

Graph IV. 7 presents data on research intensity during the 1990s, measured by R&D expenditure over production, for the 11 highest and lowest research intensity sectors in the EU and the US.

The data show that the telecommunications equipment sector has the highest research intensity among European sectors. In the leading sectors, research relative to sales declined in the late 1990s, while productivity growth increased.

In the US, office machinery, other transport, and telecommunications equipment are the most research–intensive sectors. Productivity – notoriously difficult to measure in these industries – increased during the 1990s, partly in the second half (in office machinery and aerospace), and partly in the first. The ranking of sectors by research intensity is very similar in the US and the EU, but research intensity is higher in the US in 16 of the 22 sectors. Three sectors with low research activity are leading in increases: leather, textiles and printing recorded large increases in research intensity.

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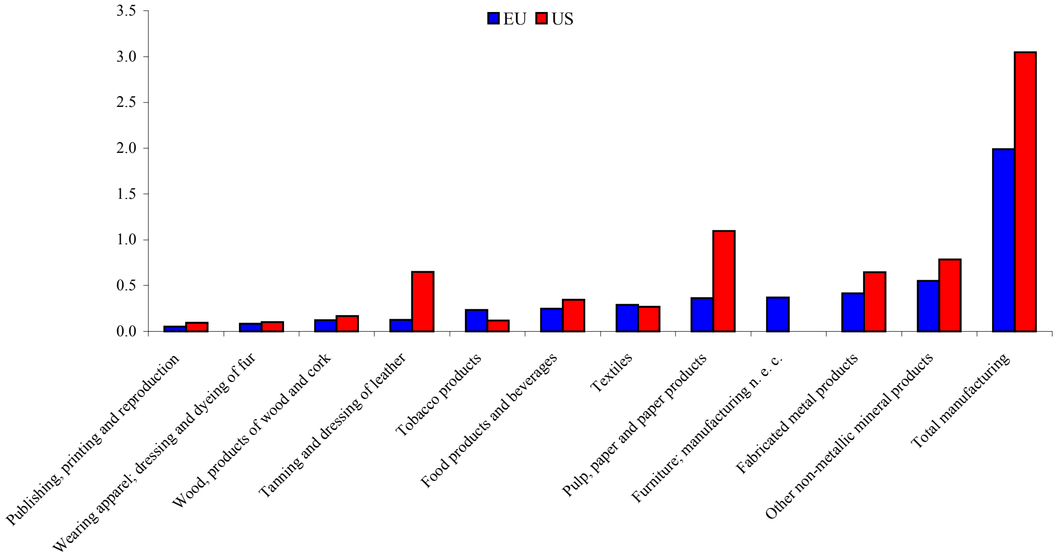
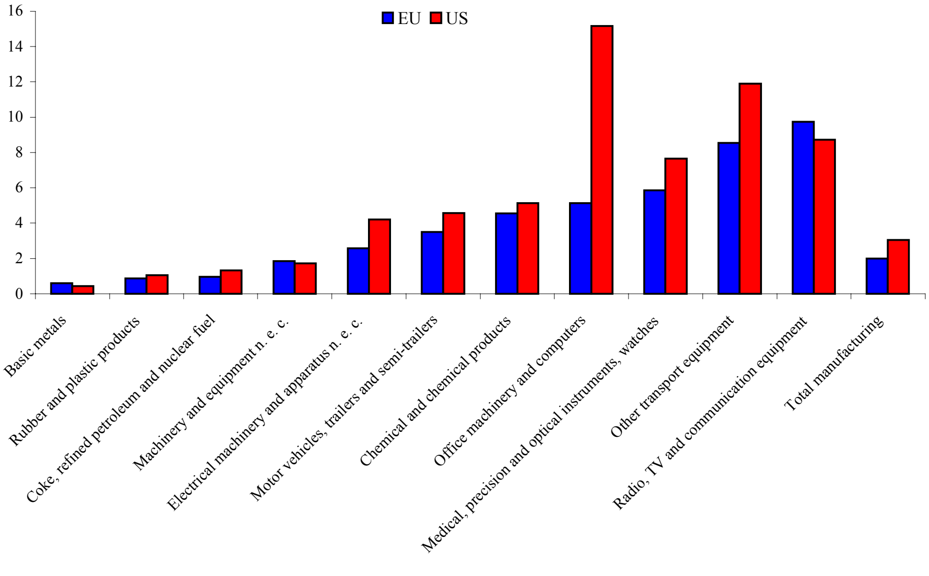
[57] These were telecom equipment, motor vehicles bodies, weapons and ammunition, and aircraft and spacecraft.

Graph IV.7: Research intensity across sectors in the EU and the US

Low R&D sectors



High R&D sectors



Note: Research intensity is measured as R&D expenditure as percent of production (average 1990/1997).

Source: WIFO calculations using EUROSTAT (New Cronos) and OECD (STAN) data.

- **Research intensity and productivity growth**

Productivity growth in the 1990s and research intensity are significantly related across sectors (see Table IV.3). This holds for the EU as a whole and for the US, but not for the majority of the member countries individually. International spillovers in research could be one reason for the lack of correlation at country level. Research intensity does not relate closely to production growth – with the notable exceptions of Finland and Sweden. Lags do not change the closeness of the relation.[58]

Table IV.3: Correlation between production and productivity growth and research intensity across sectors (rank correlation coefficients, with p value in parentheses)

	Production				**Productivity**			
	Contemporaneous		**Lagged**		**Contemporaneous**		**Lagged**	
Belgium	0,4681		0,5031		0,5042		0,5076	
	(0,0280)	**	(0,0170)	**	(0,0167)	**	(0,0159)	**
Denmark	0,2410		0,1851		0,1508		0,1154	
	(0,2799)		(0,4097)		(0,5030)		(0,6092)	
Germany	- 0,0390		0,0412		0,1191		0,0977	
	(0,8633)		(0,8555)		(0,5974)		(0,6654)	
Spain	0,1530		0,2095		0,0548		0,0457	
	(0,4966)		(0,3494)		(0,8087)		(0,8398)	
France	0,3698		0,3902		0,5483		0,5731	
	(0,0902)	*	(0,0726)	*	(0,0082)	***	(0,0053)	***
Italy	0,0186		0,0186		0,0457		0,0887	
	(0,9344)		(0,9344)		(0,8398)		(0,6948)	
Netherlands	0,0954		0,0751		0,3642		0,3134	
	(0,6727)		(0,7398)		(0,0956)	*	(0,1556)	
Finland	0,4421		0,4071		0,0830		0,0491	
	(0,0394)	**	(0,0600)	*	(0,7134)		(0,8281)	
Sweden	0,5370		0,5618		0,3145		0,3710	
	(0,0100)	***	(0,0065)	***	(0,1540)		(0,0892)	*
United Kingdom	0,2784		0,2998		0,3123		0,3439	
	(0,2097)		(0,1752)		(0,1571)		(0,1171)	
Average over EU countries	**0,2535**		**0,2343**		**0,6894**		**0,6996**	
	(0,2549)		**(0,2939)**		**(0,0004)**	***	**(0,0003)**	***
Japan	- 0,0536		- 0,0243		0,3947		0,3913	
	(0,8126)		(0,9146)		(0,0691)	*	(0,0717)	*
US	0,3066		0,3427		0,4771		0,4579	
	(0,1652)		(0,1184)		(0,0247)	**	(0,0321)	**

Notes: Contemporaneous: production (productivity) growth 1991/1998 vs. research intensity 1991/1998; lagged: production (productivity) growth 1991/1998 vs. research intensity 1985/1995. For production (productivity) three indicators are combined: nominal production (STAN), nominal value added (New Cronos), real value added (New Cronos; WIFO estimate). * (**, ***) denotes significance at 10 % (5 %, 1 %) level.

Source: WIFO calculations using EUROSTAT (New Cronos) and OECD (STAN) data.

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[58] This is a usual finding in the presence of feedbacks and co-movements and given an “intrinsic” research intensity at a given level of aggregation (for lags to matter, a lower level of aggregation would be necessary).

Electronic equipment, instruments and computers are sectors with both high research intensity and high productivity growth.[59] Additionally, chemicals and motor vehicles are in the top third of the sectors for both indicators (see Graph IV.8). In the chemical sector, biotechnology undoubtedly accounts for these results. Leather and apparel and the food industry have low research intensities and low productivity growth.

Textiles combines low research and low production growth, and although apparent productivity is about average, competitive pressure has led to decreasing employment (- 3.9 % between 1991 and 1998). Other transport is the sector with the second highest research input but production and productivity increases are low, possibly reflecting the wide diversity of this sector (from aircraft and spacecraft to railways). In addition, the locations of research and production in this sector are not the same and are sometimes even outside Europe. Electrical machinery belongs to the top three sectors in research intensity and has a moderate position in productivity growth. Publishing and printing is a sector with low direct research intensity but is implementing new forms of technology at a very fast speed, via technology investments embodied in equipment and intermediate inputs. It is a high-growth sector, but its employment is also increasing, so that apparent productivity performance is below average (ranking the fourth lowest, as measured by real value added per employee).

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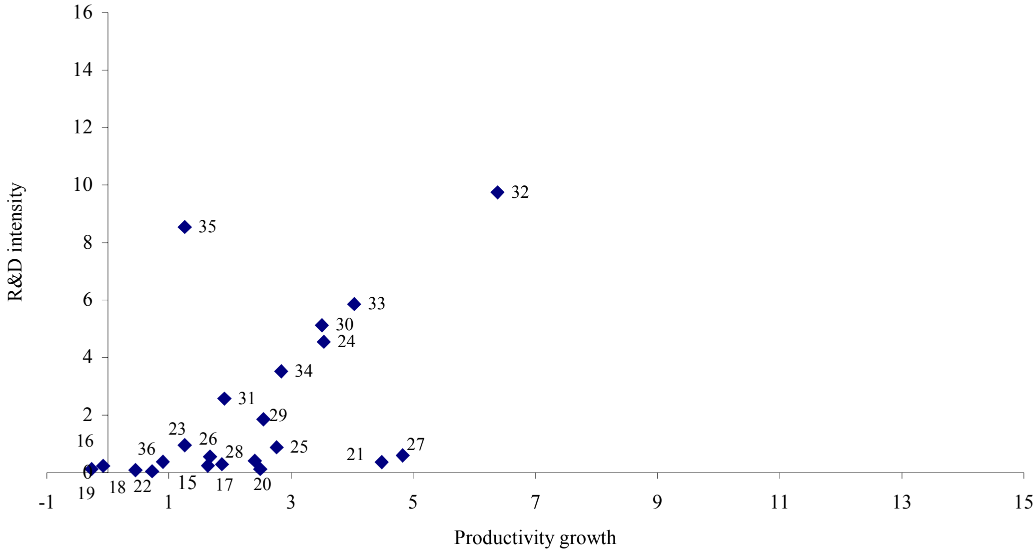
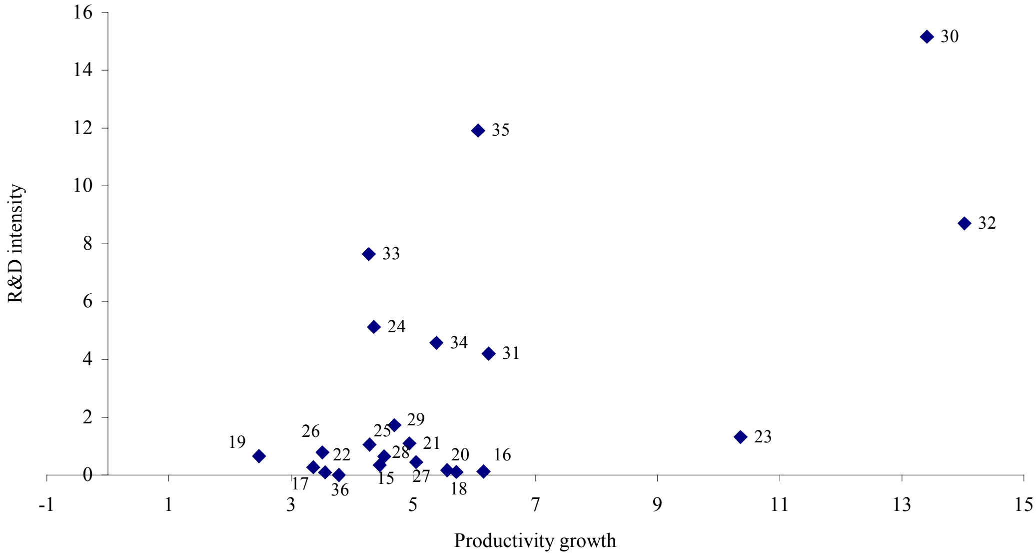
[59] The position varies according to the productivity indicator. For the combined indicator (production value, nominal plus real value added) these rank first, third and seventh among 22 sectors, respectively.

Graph IV.8: Sectoral productivity and research intensity in the EU and the US (in percent)

EU



US



15	Food products and beverages
16	Tobacco products
17	Textiles
18	Wearing apparel; dressing and dyeing of fur
19	Tanning and dressing of leather
20	Wood, products of wood and cork
21	Pulp, paper and paper products
22	Publishing, printing and reproduction
23	Coke, refined petroleum and nuclear fuel
24	Chemical and chemical products
25	Rubber and plastic products
26	Other non-metallic mineral products
27	Basic metals
28	Fabricated metal products
29	Machinery and equipment n. e. c.
30	Office machinery and computers
31	Electrical machinery and apparatus n. e. c.
32	Radio, TV and communication equipment
33	Medical, precision and optical instruments, watches
34	Motor vehicles, trailers and semi-trailers
35	Other transport equipment
36	Furniture; manufacturing n. e. c.

Source: WIFO calculations using EUROSTAT (New Cronos) and OECD (STAN) data.

Table IV.4 is a matrix classifying sectors according to productivity and research intensity in the EU and in the US. The purpose is to uncover regularities across these variables in the two regions. It is clear, to begin with, that high research intensity is not associated with low productivity growth either in the EU or in the US. In the EU, low research intensity is not associated with high productivity growth either. However, this is so in two sectors (tobacco products and wearing apparel and dressing and dying of fur) in the US.

Electronic equipment displays high research intensity and high productivity growth in 10 of 11 EU countries. This favourable position is attained five times for instruments and three times for other transport. For motor vehicles, chemicals and office machinery, the matrix contains two entries. On the other hand, in at least three countries, food, wood products, and pulp and paper combine low research intensity and low productivity growth. Publishing and printing is an exception in that six countries research intensity and productivity growth are low, but production growth is high.

Table IV.4: Research intensity and productivity growth: sectoral evidence

EU	Low productivity growth	High productivity growth
Low research intensity	Food products and beverages Tanning and dressing of leather Wearing apparel; dressing and dyeing of fur Publishing, printing and reproduction	
High research intensity		Radio, TV and communication equipment Medical, precision and optical instruments, watches Office machinery and computers Chemical and chemical products Motor vehicles, trailers and semi-trailers

US	Low productivity growth	High productivity growth
Low research intensity	Food products and beverages Textiles Publishing, printing and reproduction Furniture; manufacturing n. e. c.	Tobacco products Wearing apparel; dressing and dyeing of fur
High research intensity		Office machinery and computers Other transport equipment Radio, TV and communication equipment Motor vehicles, trailers and semi-trailers Electrical machinery and apparatus n. e. c.

Note: A sector is included in a box if, during the 1990s, its research intensity is in the lower or upper tercile (upper: top seven) of the sectors and its productivity growth is in the lower or upper tercile.

Source: WIFO calculations based on EUROSTAT (New Cronos) and OECD (STAN) data.

4.4. Productivity growth in 3–digit industries

This section extends the study of the patterns of productivity growth across the EU and the US to the 3-digit industry level. In the 1980s, productivity growth across industries in the EU differed significantly from the pattern observed in the US. However, the 1990s witnessed a convergence in the industry hierarchy of productivity growth, as shown by a positive and significant correlation between the two regions' productivity growth at industry level[60]. This similarity became more evident in the second half of the 1990s, and the correlation between the respective EU and US variables reached its highest value in the last years of the decade. The results, based on rank correlation coefficients, are presented in Table IV.5. Even the acceleration in productivity is significantly related, at least at 2-digit level.

Table IV.5: Correlation between productivity growth in the EU and the US

	Rank correlation between productivity growth in EU and the US across sectors and industries					
	Sector level			**Industry level**		
	Correlation		**p-value**	**Correlation**		**p-value**
Periods						
1986/1990	- 0,3416		0,1197	0,0826		0,4165
1991/1995	0,5234	**	0,0124	0,0418		0,6813
1996/1998	0,5539	***	0,0075	0,2429	**	0,0154
1991/1998	0,5088	**	0,0156	0,2170	**	0,0310
1986/1998	0,4749	**	0,0255	0,2712	***	0,0066
Acceleration second half minus first half	0,4241	**	0,0492	0,0824		0,4175
Individual years[1]						
1987	0,3645	*	0,0953	0,2512	**	0,0121
1988	0,1226		0,5866	0,1400		0,1669
1989	0,0493		0,8274	0,1045		0,3032
1990	0,6900	***	0,0004	0,2739	***	0,0061
1991	0,6499	***	0,0011	0,1490		0,1410
1992	- 0,0731		0,7446	0,1082		0,2862
1993	0,1795		0,4242	0,0532		0,6008
1994	0,1454		0,5185	0,2127	**	0,0345
1995	0,0419		0,8531	0,0868		0,3928
1996	0,5336	**	0,0105	0,2646	***	0,0081
1997	0,7672	***	0,0000	0,4908	***	0,0000

[1] Three-year moving average (e.g. 1987: growth between 1986 and 1988).

Note: * (**, ***) denotes significance at 10 % (5 %, 1 %) level.

Source: WIFO calculations based on EUROSTAT (New Cronos) data.

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[60] The rank correlation is 0.51 for sectors and 0.22 for industries (both significant at the 5 % level).

Several factors are behind these findings. Technology–driven industries, which had a disappointing productivity performance in the 1980s, started to experience a reversal of fortune in the early 1990s. In the EU, during this period, productivity in these industries was growing slowly (see Graph IV.6), possibly as a result of slowness in the adoption of new technologies and timid structural reforms, and partly reflecting the impact of the recession of the early 1990s and the recurrent ERM crises. Competitive pressures, on the other hand, led to an increase in apparent productivity in capital–intensive industries. In the second half of the 1990s productivity increased the most in technology–driven industries, in both the EU and the US, but at a significantly higher rate in the latter. The weak similarity in the early 1990s was probably a reflection of the macroeconomic difficulties experienced in Europe, but in the second half of the decade technological forces appear to have played a crucial role in determining the pattern.

As already mentioned, the impact of technology–driven industries on overall productivity is greater in the US than in the EU. First, productivity increased faster in these industries; second, in the beginning of the 1990s, the share of technology–driven industries was 22 % in the EU and 26 % in the US; and, third, the productivity lead of the US – however difficult it may be to measure productivity levels – was particularly large in these industries, so that the dynamics of this sector took place on top of a strong starting position.

Table IV.6: Industries with high productivity growth in the EU (top 25)

Nace Rev.1		Growth of productivity EU				Share of value added EU 1990	Growth of productivity US				Share of value added US 1990	Top 25 in EU and US	
		1991/1998		1996/1998			1991/1998		1996/1998			1991/1998	1996/1998
		% p.a.	Rank	% p.a.	Rank	%	% p.a.	Rank	% p.a.	Rank	%		
272	**Tubes**	8,0	1	8,8	6	0,5	4,9	37	10,1	24	0,3		YES
247	**Man-made fibres**	7,0	2	1,0	64	0,3	6,4	17	12,3	10	0,6	YES	YES
322	**TV, and radio transmitters, apparatus for line telephony**	7,0	3	16,4	1	1,5	11,0	3	13,8	9	1,7	YES	YES
342	**Bodies for motor vehicles, trailers**	6,4	4	13,5	2	0,5	8,5	6	17,0	4	0,7	YES	YES
211	**Pulp, paper and paperboard**	6,1	5	4,1	31	1,6	5,6	23	10,7	21	2,4	YES	YES
323	**TV, radio and recording apparatus**	6,0	6	6,2	16	0,8	1,5	91	- 0,2	96	0,1		
284	**Forging, pressing, stamping and roll forming of metal**	5,4	7	7,7	8	0,7	4,7	43	8,3	47	0,6		
343	**Parts and accessories for motor vehicles**	5,4	8	4,7	28	1,8	5,4	25	9,7	28	1,8	YES	
271	**Basic iron and steel, ferro-alloys (ECSC)**	5,3	9	1,2	63	2,5	7,5	9	10,7	20	1,0	YES	YES
321	**Electronic valves and tubes, other electronic comp.**	5,1	10	5,5	20	0,7	16,0	1	23,3	2	2,6	YES	YES
273	**Other first processing of iron and steel**	5,1	11	5,5	21	0,4	6,9	14	11,7	14	0,5	YES	YES
223	**Reproduction of recorded media**	4,9	12	6,5	14	0,1	- 2,8	99	- 3,3	98	0,0		
296	**Weapons and ammunition**	4,8	13	10,7	3	0,2	6,9	15	9,3	34	0,4	YES	
241	**Basic chemicals**	4,7	14	0,4	73	4,7	4,6	45	8,9	40	4,6		
202	**Panels and boards of wood**	4,7	15	7,9	7	0,3	7,1	12	7,7	55	0,4	YES	
176	**Knitted and crocheted fabrics**	4,5	16	6,2	17	0,1	4,8	39	9,5	32	0,1		
332	**Instruments for measuring, checking, testing, navigating**	4,4	17	6,1	18	1,3	6,3	18	9,1	36	2,9	YES	
201	**Sawmilling, planing and impregnation of wood**	4,3	18	9,5	5	0,4	8,4	7	15,1	7	0,5	YES	YES
244	**Pharmaceuticals**	4,2	19	3,6	36	2,6	4,2	58	9,1	38	2,9		
275	**Casting of metals**	4,1	20	5,1	24	0,8	4,6	44	6,4	66	0,7		
274	**Basic precious and non-ferrous metals**	3,9	21	2,3	51	1,1	3,5	70	3,2	90	1,2		
297	**Domestic appliances n. e. c.**	3,9	22	3,0	43	0,9	4,7	41	9,0	39	0,6		
156	**Grain mill products and starches**	3,8	23	3,6	38	0,4	8,6	5	12,0	13	1,1	YES	YES
335	**Watches and clocks**	3,7	24	2,9	45	0,1	0,8	94	11,6	16	0,1		YES
300	**Office machinery and computers**	3,5	25	7,0	10	2,1	13,4	2	25,1	1	2,4	YES	YES
	Subtotal of 25 high productivity growth sectors					26,3					30,3	14/25 Y	12/25 Y
	Total manufactuirng	**2,6**		**3,0**		**100,0**	**5,5**		**9,9**		**100,0**		

Source: WIFO calculations based on EUROSTAT (New Cronos) data.

Among the top 25 industries in both regions, three are electronic industries (equipment, computers, valves and tubes) and two are motor-vehicle industries (bodies for motor vehicles and parts and accessories for motor vehicles). Weapons and ammunition, and instruments are other high–technology industries in which productivity increased substantially both in the EU and in the US (see Table IV.6). Most other industries in the top 25 group are capital–intensive industries, ranging from man–made fibres to steel and pulp and wood. Technology–driven industries with high productivity increases in the EU which are not among the industries with high productivity growth in the US are pharmaceuticals, electronic apparatus, and recorded media. In general, of the 25 industries with the highest productivity increases in the 1990s in the EU, 14 are also among the first 25 in the US.[61] The similarities at the lower end of the spectrum are less marked. Of the 25 industries with the lowest productivity increases in Europe, only 10 are in the same group in the US, among which are five textile industries, oils and fats and motorcycles.

Comparison of the individual countries with the EU average shows that patterns of productivity growth have become similar across Member States. In 11 countries during the 1990s, the ranks in each country are significantly related to the corresponding EU ranks.[62] The only countries where the correlation is not significant are Denmark, Ireland and Finland. In the case of France, Spain, the Netherlands and Austria, the correlation is significant both for sectors (2-digit level) and for industries (3-digit level). Three small countries (Belgium, Portugal and Sweden) have, together with two large countries (France and Spain), the closest conformity to EU productivity growth patterns.[63]

If there is a strong pattern of variation in productivity growth across industries, countries with a higher share of industries that have experienced high productivity growth should themselves experience higher productivity growth. This is to some extent the case. For example, if the US had had the EU production structure, its increase in productivity would have been slower by half a percentage point in the 1990s. The reason is that the high productivity growth in technology–driven industries would have had less weight compared to the actual US data. However, if the EU had had the US production structure, it would not have had a higher productivity increase since several of the capital–intensive industries, in which productivity increases in the EU were specifically strong, would have had less weight. According to the same hypothesis, Greece (because of its high share of capital–intensive industries) and Ireland (because of its greater share of technology–driven industries than the US) would have registered the greatest reduction in productivity growth, while the highest gains would have been achieved in the Netherlands and Belgium.

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[61] Of the 25 industries with the highest productivity increases in the EU between 1996 and 1998, 12 belong to the top 25 group in the US.

[62] The selection criterion is the rank correlation for productivity growth (combined indicator) at the 90 % level of significance at a minimum of one level of aggregation (2– or 3–digit level).

[63] The relation between country and EU performances in productivity growth remains close when working with the short period 1996 to 1998, and is better when using the acceleration of productivity growth during this period vs. the first half of the nineties. Only four countries exhibit no significant relation between own acceleration of productivity and that of the EU: Belgium, Ireland, the Netherlands and Greece.

Table IV.7: Industry taxonomy

Industries classified according to inputs used

Mainstream manufacturing		**Marketing–driven industries**	
1730	Finishing of textiles	1510	Meat products
1770	Knitted and crocheted articles	1520	Fish and fish products
1750	Other textiles	1530	Fruits and vegetables
1760	Knitted and crocheted fabrics	1540	Vegetable and animal oils and fats
2120	Articles of paper and paperboard	1550	Dairy products; ice cream
2430	Paints, coatings, printing ink	1560	Grain mill products and starches
2510	Rubber products	1570	Prepared animal feeds
2520	Plastic products	1580	Other food products
2610	Glass and glass products	1590	Beverages
2660	Articles of concrete, plaster and cement	1600	Tobacco products
2680	Other non-metallic mineral products	1910	Tanning and dressing of leather
2720	Tubes	1920	Luggage, handbags, saddlery and harness
2870	Other fabricated metal products	1930	Footwear
2910	Machinery for production, use of mech. power	2210	Publishing
2920	Other general purpose machinery	2220	Printing
2930	Agricultural and forestry machinery	2230	Reproduction of recorded media
2950	Other special purpose machinery	2450	Detergents, cleaning and polishing, perfumes
2960	Weapons and ammunition	2820	Tanks, reservoirs, central heating radiators and boilers
2970	Domestic appliances n. e. c.		
3110	Electric motors, generators and transformers	2860	Cutlery, tools and general hardware
3130	Isolated wire and cable	3350	Watches and clocks
3140	Accumulators, primary cells and primary batteries	3630	Musical instruments
		3640	Sports goods
3150	Lighting equipment and electric lamps	3650	Games and toys
3540	Motorcycles and bicycles	3660	Miscellaneous manufacturing n. e. c.
3550	Other transport equipment n. e. c.	**Capital-intensive industries**	
Labour-intensive industries		1710	Textile fibres
1720	Textile weaving	2110	Pulp, paper and paperboard
1740	Made-up textile articles	2310	Coke oven products
1810	Leather clothes	2320	Refined petroleum products
1820	Other wearing apparel and accessories	2410	Basic chemicals
1830	Dressing and dyeing of fur; articles of fur	2470	Man-made fibres
2010	Sawmilling, planing and impregnation of wood	2630	Ceramic tiles and flags
2020	Panels and boards of wood	2650	Cement, lime and plaster
2030	Builders' carpentry and joinery	2710	Basic iron and steel, ferro-alloys (ECSC)
2040	Wooden containers	2730	Other first processing of iron and steel
2050	Other products of wood; articles of cork, etc.	2740	Basic precious and non-ferrous metals
2620	Ceramic goods	3430	Parts and accessories for motor vehicles
2640	Bricks, tiles and construction products	**Technology–driven industries**	
2670	Cutting, shaping, finishing of stone	2420	Pesticides, other agri-chemical products
2810	Structural metal products	2440	Pharmaceuticals
2830	Steam generators	2460	Other chemical products
2840	Forging, pressing, stamping and roll forming of metal	3000	Office machinery and computers
		3120	Electricity distribution and control apparatus
2750	Casting of metals	3210	Electronic valves and tubes, other electronic comp.
2850	Treatment and coating of metals		
2940	Machine-tools	3220	TV, and radio transmitters, apparatus for line telephony
3160	Electrical equipment n. e. c.		
3420	Bodies for motor vehicles, trailers	3230	TV, radio and recording apparatus
3510	Ships and boats	3310	Medical equipment
3520	Railway locomotives and rolling stock	3320	Instruments for measuring, checking, testing, navigating
3610	Furniture		
3620	Jewellery and related articles	3330	Industrial process control equipment
		3340	Optical instruments and photographic equipment
		3410	Motor vehicles
		3530	Aircraft and spacecraft

Source: DEBA and COMPET. WIFO calculations.

4.5. Concluding Comments

During the 1990s, manufacturing production and labour productivity growth in the EU were far below the rates recorded in the US, marking a reversal of the situation compared to the second half of the 1980s. An acceleration took place in the second half of the 1990s both in the US and in the EU, though more markedly in the US.

Innovation, leading to new products and production processes, is an important determinant of productivity improvements and economic growth. But innovation is also a complex process intertwined with factors such as the strength of the knowledge base, institutional arrangements, qualification of the labour force, openness of the economy and overall ability to take on board improvements achieved in other countries or sectors. Other than through own innovation, an economy may also improve its performance as a result of innovation diffusion or through technology embodied in inputs and new capital goods, which in turn may magnify the benefits of own research efforts. Indicators proxying different aspects that facilitate innovation and growth are indeed shown to be related to productivity and economic performance in manufacturing. The relationship is not necessarily significant for each indicator separately, conceivably due to the complex nature of innovation, the complementarity required between certain factors, and the multiple roads to innovation and growth.

In the 1990s, EU technology-driven industries experienced the highest productivity growth, followed by capital-intensive industries, where this high growth took place mainly in the first half of the decade. In the US, technology-driven industries took the lead in productivity growth in every sub-period.

The good performance of capital-intensive industries in the EU during the first half of the 1990s is most probably the result of the restructuring that took place in these industries and hints at the importance of embodied technology in innovation diffusion and its effect on economic performance.

In the 1990s, research intensity and productivity growth are significantly related across sectors, both in the US and within the EU, though not in each Member State individually. This relationship reveals the role of research efforts for innovation and performance; on the other hand, the lack of such relationship at country level may be a sign of international spillovers at work.

In terms of patterns of productivity growth, there appears to have been increasing convergence between the US and the EU. While in the 1980s the US hierarchy of productivity growth across industries was significantly different from that in the EU, in the 1990s these patterns became more and more similar. This is partly the result of the lag, relative to the US, in productivity performance of technology-driven industries. In the EU, it was not until the second half of the 1990s that technological forces appear to have played a determining role in the industrial pattern of productivity growth; while competitive forces, driving the restructuring of capital-intensive industries, are most likely behind the developments of the first half of the decade.

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ANNEX IV.1:

FACTORS CONTRIBUTING TO GROWTH: A COMPARISON ACROSS THE MEMBER STATES

This annex presents country profiles combining information on the forces behind growth, as presented in section IV.2, with results indicating the impact of research on productivity from section IV.3 and the specialisation of national industries explored in previous Competitiveness reports.[64] A graph ("cobweb") for each Member State summarises information on these indicators and on innovation and performance assessments by the European Commission[65]. Each variable is standardised, so that points outside the unit circle indicate a performance above the average of the EU Member States (see Table A IV.1.2 for the definition of variables).

Drawing on the trends in the indicators used in these country profiles in the 1990s, section 2 investigates whether Member States have converged over this period.

- Country profiles

Belgium

Belgium's growth performance in total economy output is close to the EU average. Labour productivity grew at a higher than average rate and its level is one of the highest within the EU. These good performances have also been achieved in the manufacturing sector.

Belgium spends relatively less than the EU average on research and close to the average on education. Innovation expenditure in manufacturing is also low. ICT expenditures are close to the EU average but ICT-producing industries are less present than elsewhere. Patenting is low. The excellent productivity performance can probably be explained by intense competitive pressure due to the high degree of trade integration. The presence of enabling capabilities in manufacturing and a well-educated labour force contribute too.

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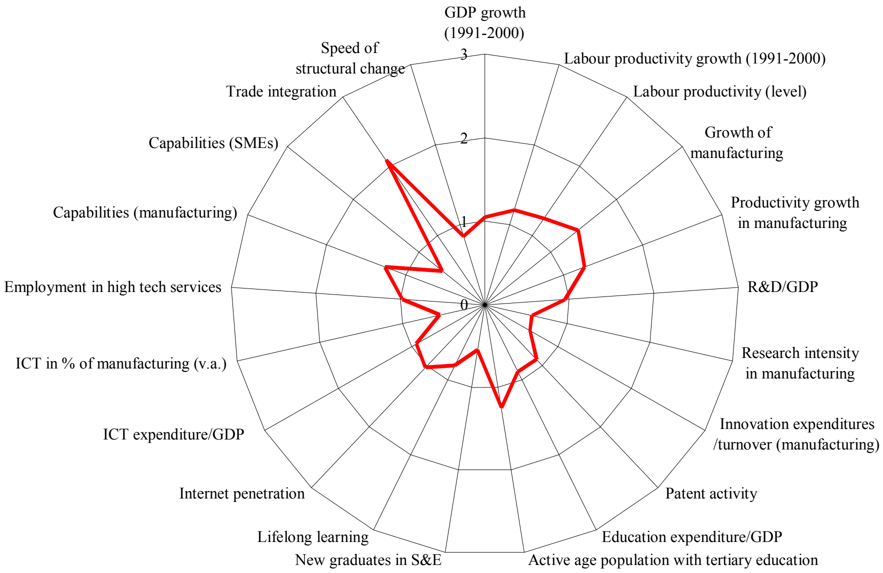
[64] See European Commission (1999), European Commission (2000A, 2000B), Aiginger et al. (1999) and Aiginger (2000).

[65] European Commission (2001A, 2001B).

Graph A IV.1.1: Country profiles: Belgium



Note: Each indicator outside the unit circle shows a superior performance of the country relative to EU average.

At manufacturing level, the industrial structure is rather traditional in the sense that capital intensive and low-skill industries have high shares. Belgium maintained its position in the textile sectors. The chemical sector provides 17 % of value added and is the largest industrial sector. Exports in pharmaceuticals are booming and its market share in Europe has increased from 6.3 % to 9.6 %. Food is the second largest sector, vehicles the third. Significant inroads in technology-driven industries can be observed in the production of audio and video apparatus.

Belgium is one of the countries in which research intensity and growth across sectors appear to be related[66]. The two sectors leading in research intensity - other transport and electronic equipment - are growing fast; the same is true for instruments and office machinery. Food, textiles, and pulp and paper, on the other hand, are industries with low research and low growth. Publishing and printing is an industry with low research intensity and high growth; this may be due to embodied technology in inputs and equipment. Leather and footwear have high and increasing levels of research in Belgium – in contrast to other countries - but productivity growth did not increase.

Denmark

Both total economy and manufacturing growth in Denmark were above average, specifically in the first half of the 1990s.

Denmark displays a good research and education performance, especially in terms of lifelong learning. However, the supply of new Science and Technology graduates is low. ICT expenditures indicate a diffusion of these technologies in the economy, a fact confirmed by the level of Internet penetration. Innovation expenditures are high

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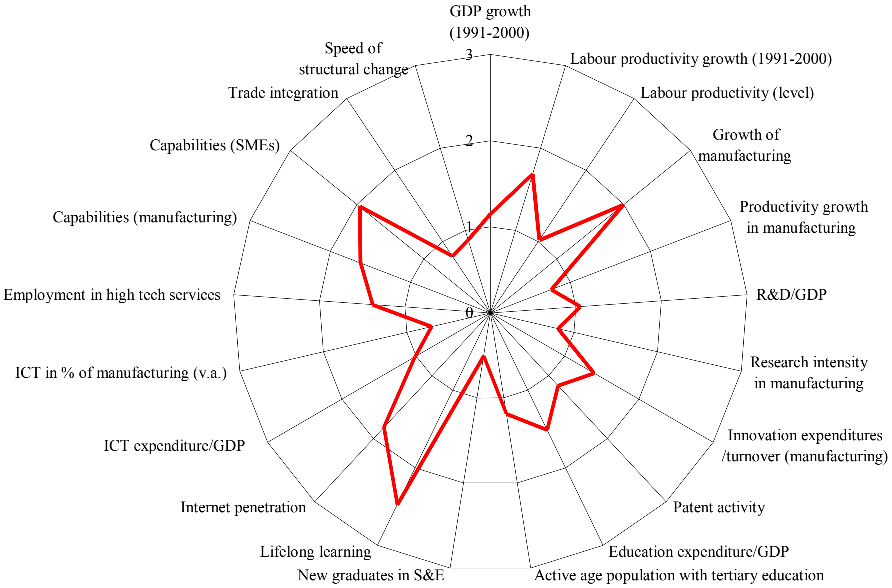
[66] Rank correlation between these two variables is positive and statistically significant.

and innovation capabilities are well developed; SMEs capabilities are the highest in the EU.

Graph A IV.1.2: Country profiles: Denmark



Note: Each indicator outside the unit circle shows a superior performance of the country relative to EU average

Denmark has a rather small industrial sector but presents a strong development of high-technology services. At manufacturing level, the share of skill-intensive and marketing-driven industries is high. The importance of marketing-driven industries is due to the food sector, which accounts for 19 % of output and 23 % of exports. The second largest sector is machinery. A specialisation in wood products and furniture is also apparent. Denmark has a rather low share of capital-intensive and technology-driven industries. High tech industries with relatively large export shares are pharmaceuticals and medical equipment. The fastest growing industries are wood products, tobacco and motor vehicles.

In Denmark, research intensity and production or productivity growth across industries do not appear to be related. Instruments, chemicals (specifically, the pharmaceutical industry) and electronic equipment are research-intensive and fast growing. Food and pulp and paper are low on both accounts. Office machinery and the other industries (including furniture) are research-intensive, but post low growth. On the contrary, wood, publications, and motor vehicles have high growth rates, but are not research-intensive.

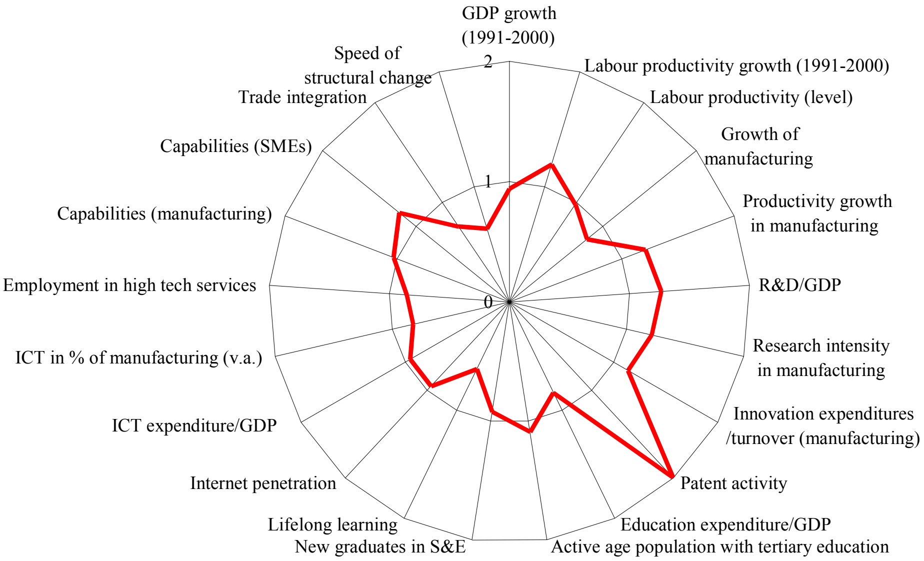
Germany

Germany's growth pattern reflects the problems and progress of unification. Growth was above average in the first half of the nineties, but fell below the EU average during the second half. Productivity in manufacturing accelerated, reflecting restructuring and internationalisation of firms.

Germany scores high in research indicators. However, its R&D ratio has decreased in the 1990s. The presence of innovation capabilities in SMEs is another strong point.

Germany has a good supply of human capital but lifelong learning is lagging behind. The diffusion of information and communication technology is slower than average.

Graph A IV.1.3: Country profiles: Germany



Note: Each indicator outside the unit circle shows a superior performance of the country relative to EU average.

Germany accounts for 30 % of the value added of European manufacturing. The trade balance amounts to more than three quarters of the EU trade surplus. Employment in medium-high and high technology industries is strong but it is below the EU average in high technology services. Germany's strength is in skill-intensive and mainstream industries. The largest sectors in production and exports are machinery, vehicles, and chemicals, which together provide 50 % of exports. In some of the technology-driven industries, Germany's export shares are below average and have declined in the telecom industries. Aircraft and spacecraft, instruments, and electronic components increased their shares. Apart from motor vehicles, the highest degree of specialisation is in machine tools, electrical apparatus, and measuring and musical instruments.

Research intensity and production or productivity growth across industries do not appear to be related in Germany[67]. This may be due to the fact that restructuring affected productivity more than research activity. Many firms began to outsource and became multinationals. For all five industries that lead in research, production growth is not above average. Electronic equipment and chemicals have high research intensity but low production growth. Vehicles, which rank sixth in research intensity, increased production, but do not rank high in productivity growth. On the other hand, food and printing are growing fast – with virtually no research activity –though with low productivity growth.

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[67] Rank correlations are practically zero.

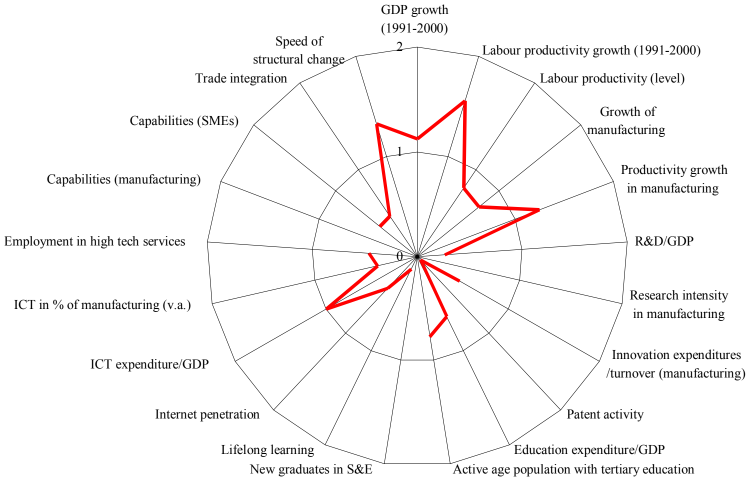
Greece

Greece is catching up, albeit slowly and not without some turbulence. Production, as well as labour productivity, increased in the 1990s slightly faster than the EU average. Productivity in manufacturing grew faster despite slow output growth, reflecting the increased competitive pressure.

Greece is below the EU average in most indicators of research and ICT. It has a relatively high share of higher educated population of working age and its education expenditure is increasing though it is still below average.

Greece has the smallest share of manufacturing in GDP of all European countries. The highest rate of growth (in capital-intensive sectors like petroleum, basic metals, textiles and wood) was achieved with employment decreasing by about 5 % p.a. Productivity growth was low in two sectors which are large in Greece, namely food and wearing apparel. The share of low-skill industries is by far the largest and is still increasing, as is the share of marketing-driven industries.

Graph A IV.1.4: Country profiles: Greece



Greece has less capital inflow and higher extra-EU exports than any other Member State.[68] The breakdown of Yugoslavia has increased transport and transaction costs with core European countries. The transformation of former socialist countries has increased competitive pressure but also provided new market opportunities, bringing faster than average structural change.

Spain

Spain's GDP grew faster than the EU average while growth in manufacturing was approximately at par. This coincided with a significant reduction in unemployment with, as a consequence, low to negative productivity growth rates.

Spain is among the weaker countries with respect to indicators for research and human capital and displays low ICT use. Exports are growing by 10 % p.a., led by

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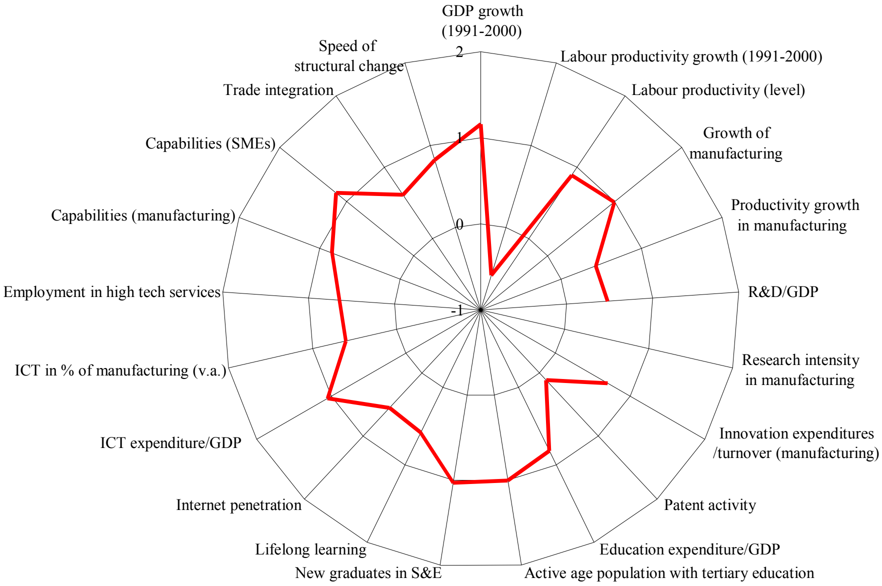
[68] Extra-EU exports made up 50 % of total exports in 1998, singularly high for member countries. This reflects high and growing trade shares with Cyprus, Bulgaria, Macedonia and Turkey, as well as with other Eastern European countries and Russia.

intra-EU exports. The share of industry in GDP is now below average. Productivity and wages are low.

In manufacturing, three well represented sectors – food, apparel and leather – exhibited a sluggish performance in productivity. Two capital-intensive (basic metals and chemicals), and two high tech industries (computers and medical equipment) increased productivity sharply.

Graph A IV.1.5: Country profiles: Spain



Note: Each indicator outside the unit circle shows a superior performance of the country relative to EU average.

The car industry doubled its production share and is now the second largest industry in terms of both exports and production. Food is also an important sector for exports: fish, fruits and vegetables have double-digit shares in European exports. Chemicals are now third in production and exports. The high shares of pharmaceutical, audio and video apparatus and medical equipment industries reflect successful clusters of high-tech industries, often around subsidiaries of multinational firms, which supply leading technologies.

There appears to be no relation between research intensity and production or productivity growth.[69] Among the research-intensive sectors only office and electrical machinery posts high growth; in chemicals, other transport and electronic equipment, neither production nor productivity grew fast. Food and apparel combine low research intensity with low productivity growth. Textiles and basic metals combine high productivity growth with low research activity.

France

Production growth was below the EU average in the first half of the 1990s and about average during the second half. Labour productivity growth was well below average. Manufacturing growth was slightly lower than the EU average - as is the case for

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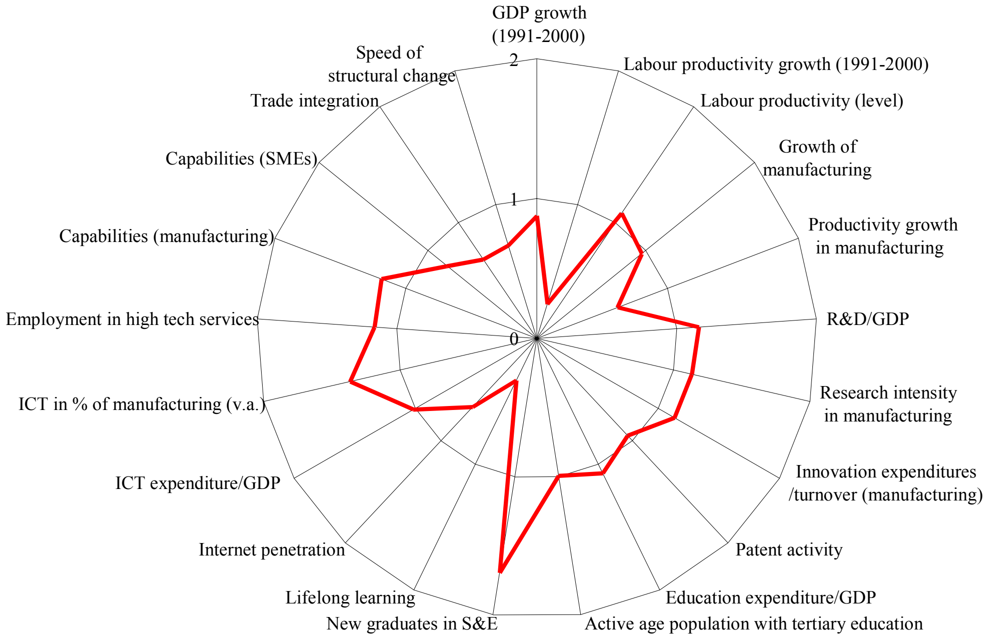
[69] The two rank correlations across industries are positive but not statistically significant.

most large countries. The share of manufacturing in total production declined to 18.5 %.

France is strong in research and innovation outlays, but the trend of research expenditure relative to GDP is downward. Indicators of human capital show a position slightly above the European average. New graduates in Science and Engineering are far above the EU average but efforts in life-long learning are lower than average. The ICT producing sectors as well as high technology services are well developed.

Graph A IV.1.6: Country profiles: France



Note: Each indicator outside the unit circle shows a superior performance of the country relative to EU average.

In general, the industrial structure of France is closer to the European structure as a whole than to that of other large countries. The share of technology-driven industries is high in France, as is the share of industries characterised by high inputs from knowledge-based services. France's two largest industrial sectors - chemicals and food – are growing fast. Motor vehicles and machinery are the third and fourth largest sectors. Cars and other transport are well represented in exports, and together account for more than one quarter of total exports. The highest export shares are in food and electrical machinery.

The specific success of France in aircraft and spacecraft can be seen in the "other transport" sector: France accounts for 18 % of value added and 45 % of total European exports, reflecting trans-European projects in spacecraft and aircraft. Productivity is increasing in this sector, as it is in chemicals and plastics.

Research intensity and production, as well as productivity growth appear to be linked.[70] Four of the five research-intensive sectors in France are also high growth

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[70] Rank correlations across sectors are positive and statistically significant in both cases.

sectors with rapidly increasing productivity (instruments, electrical equipment, other transport and chemicals); the exception is office machinery, where research is high but production is decreasing a probable sign of delocalisation. Food is a low-research sector with small increases in productivity. Publishing and printing combines low research with about average production growth, but has below average productivity increases.

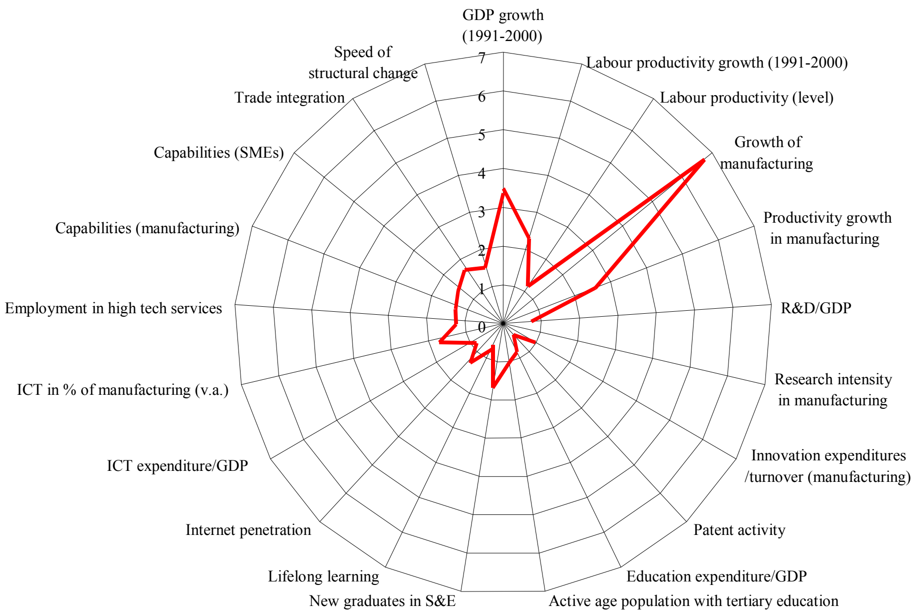
Ireland

Growth of real GDP was 8 %, about half of which was due to productivity growth. Two thirds of the double-digit (11.2 %) growth in manufacturing resulted from productivity growth. Both production and productivity growth in the manufacturing sector accelerated in the second half of the1990s. GDP per capita caught up with the EU average in 1997.

Ireland still has low levels of public R&D and education expenditure. However, business R&D is moving closer towards the EU average, even though multinational firms still perform a larger share of research in their home country, as compared to production. Skills are highly rated, due to an efficient education system and the supply of new graduates in science & technology is the third strongest. Ireland has a large share of ICT-producing industries. Average innovation expenditures (compared with a fast increasing turnover) are complemented by higher rates of innovation based on co-operation and on continuous research at firm level, as expressed by the capabilities indicators.

Ireland has built its remarkable catching up process on its attraction of foreign capital, but has ingeniously connected inward investments with local strengths. It has attracted dynamic high-tech industries, developed programmes to upgrade qualifications and to cluster firms around the subsidiaries of multinational firms. The supply of skilled labour has been a contributing factor.

Graph A IV.1.7: Country profiles: Ireland



Note: Each indicator outside the unit circle shows a superior performance of the country relative to EU average.

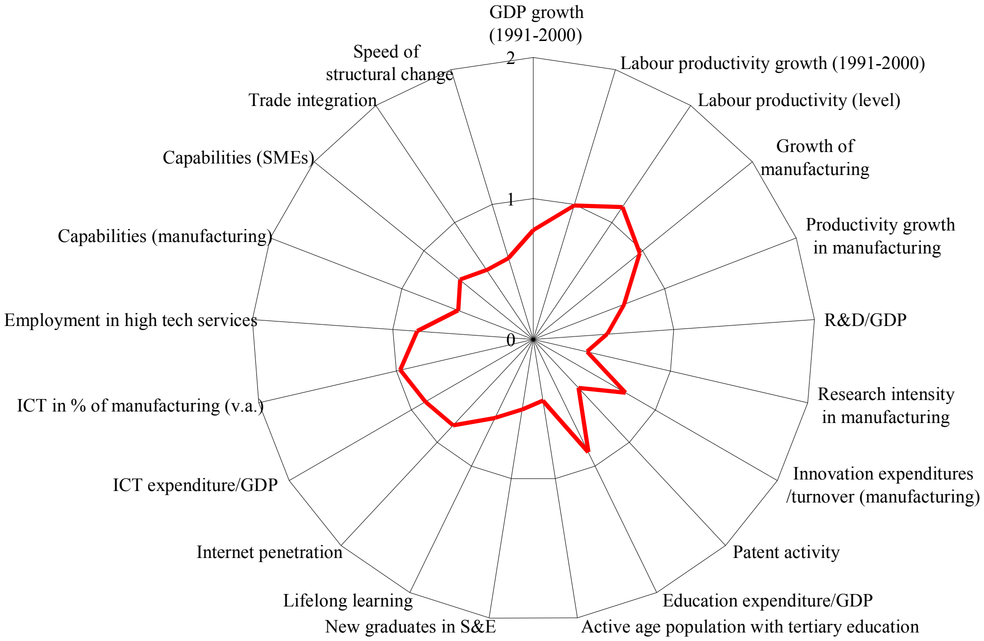
The share of manufacturing is rising and, at 32 %, is now by far the highest in Europe. Exports, specifically to the US, Japan and Switzerland, are rising but the share of extra-EU exports is still below average. Ireland produces 1.7 % of total European manufacturing, and export shares have doubled, now reaching 3 %. The ratio of exports to production is the highest of all the Member States. Value added per employee is also the highest among EU countries. The share of production in marketing-driven and technology-driven industries is high. Chemicals is the largest sector, with basic chemicals and pharmaceuticals each accounting for about 15 % of Irish exports. Computers rank second in exports and telecom equipment third. 15 % of EU computer exports and 10 % of chemicals come from Ireland.

Italy

Despite sluggish overall growth, labour productivity grew parallel to that of other EU countries. In manufacturing, productivity growth was lower than the EU average during the1990s, specifically in the second half, when production fell by one percentage point and productivity by two percentage points below the EU average. Italy is one of the four European countries with a deceleration in productivity growth.

With respect to almost all the variables that are believed to facilitate innovation and growth, Italy is consistently below the European average. This is specifically the case for indicators of research, human capital and new technologies. An exception is ICT production. The share of the economically active population having higher education is particularly low relative to the EU average.

Graph A IV.1.8: Country profiles: Italy



Note: Each indicator outside the unit circle shows a superior performance of the country relative to EU average.

Italy produces about 12 % of European manufacturing output. The export ratio and openness are below average, reflecting strong domestic demand for consumption and investment goods. Italy has a two-tier industrial structure. On the one hand, the share of labour-intensive and low-skill industries is larger than in most other Member States; on the other hand, high-skill and mainstream industries are also strong. Technology-driven and marketing-driven industries are under-represented. Italy has a large textile sector, with high export unit values indicating high fashion products.[71] Machinery - a skill-intensive, mainstream sector - is the largest single sector, followed by chemicals in production and by cars in exports.

Productivity rose in electronics and computers, as well as in basic metals, paper and metal products. In the textile industries, productivity actually decreased, but real term figures underestimate the upgrade in quality. In machinery, productivity increased slightly. Thus, though the pattern for productivity growth across industries is similar to that of other countries, average growth is lower. Employment in Italian manufacturing remained fairly stable, despite the very slow growth in output. Italy has the slowest speed of change of industrial structure.

Three of the five leading research-intensive sectors in Italy do not translate high research into productivity growth. Other transport has a particularly low level of productivity growth; motor vehicles have increased production at a below-average rate of growth in productivity. Research activity and productivity are high in

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[71] The textile industries account for 12 % of production and 17 % of Italian exports. These shares have decreased slightly. Since, however, in other countries this sector has contracted (with some fragmentation and outsourcing), Italy is now the leader in textile exports, supplying 25 % of total exports. Italy is specialised in high quality, fashion products and enjoys above average unit values in textiles, leather products and apparel.

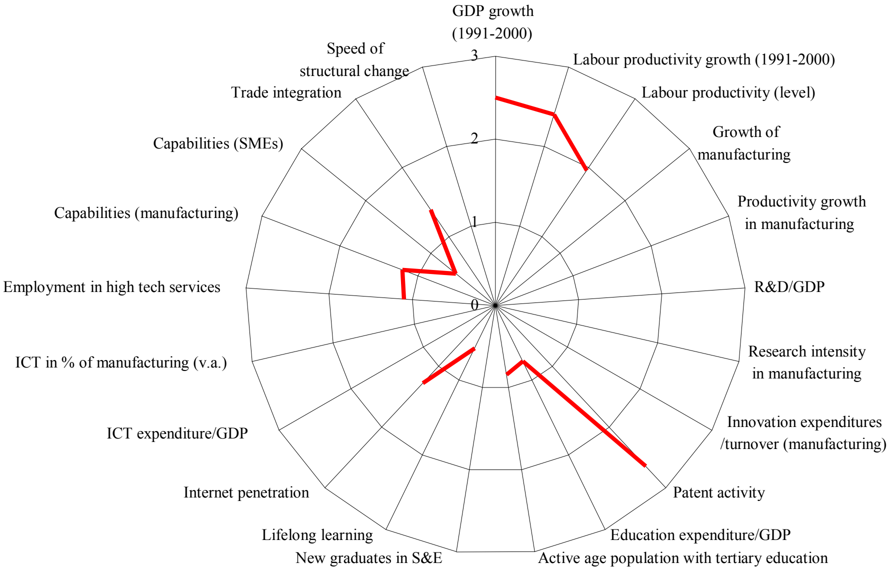
electronic equipment and in office machinery. The food industry and the textile industries rank low in both areas, with the exception of apparel, where production growth is about average. Publishing has low growth in productivity and production - the latter in contrast to other countries. High growth, despite low research intensity, characterises the wood, pulp and paper and fabricated metal sectors.

Luxembourg

Data availability is a recurrent problem when assessing Luxembourg's performance.[72] Luxembourg's GDP per capita is almost double the EU average and the highest in the OECD area. Production and productivity growth were more than twice the EU average.

Capabilities in manufacturing are above the EU average.

Graph A IV.1.9: Country profiles: Luxembourg



Note: Each indicator outside the unit circle shows a superior performance of the country relative to EU average.

Luxembourg has the highest contribution from the services sector to the economy among OECD countries. Financial services and communications were the main engines of growth.

Luxembourg traditionally has a strong position in basic metals, but the share of this formerly dominant sector is declining. The steel industry accounts now for 13 % of total value added, down from 41 % in 1985. Rubber and plastic are the second strongest sector with a fairly constant share of value added of about 14 %. Fabricated metals and chemicals grew at annual rates of around 10 %. Machinery is the most important engineering industry; several food industries and printing have increased their shares, thus broadening the industrial base. The overall share in European manufacturing increased slightly. Employment in manufacturing remained stable

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[72] The low number of enterprises raises problems of confidentiality at more detailed levels of analysis. R&D statistics are not available either.

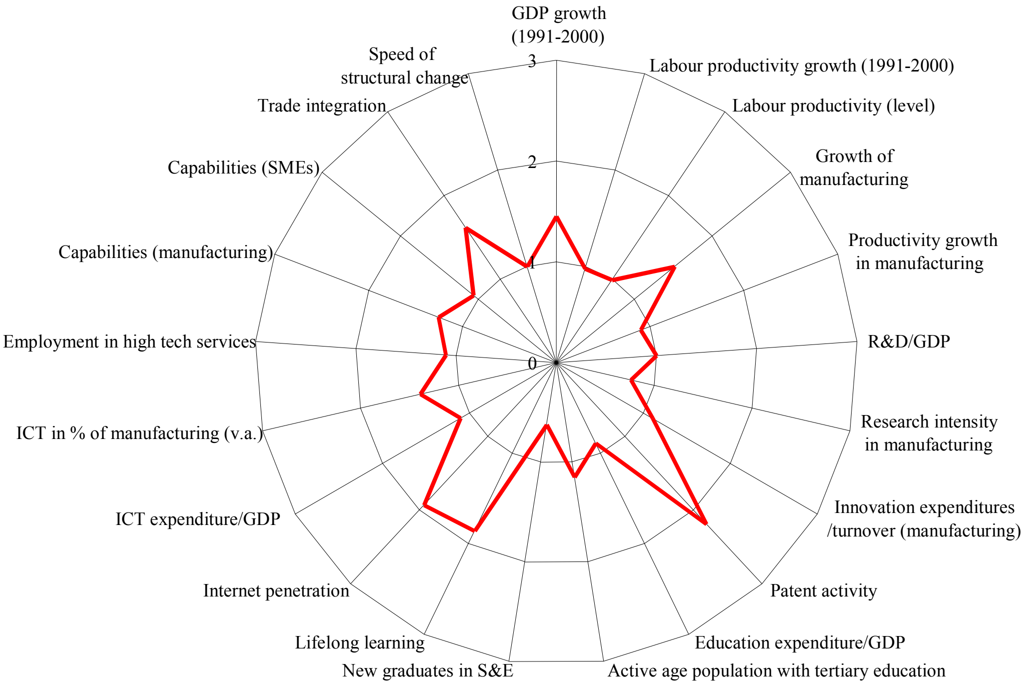
over the period 1995- 2000, while it declined in most other Member States. The jobs lost in the steel industry were partly compensated for by job creation in chemical industry, metal products, food and investment industries.

The Netherlands

In the 1990s, production grew above the EU average, while productivity growth was slightly lower than average.

Research and development expenditures are close to the EU average and patenting is very strong. There is a mixed picture as far as human capital is concerned, with below average numbers of graduates in science and engineering, average public outlays, and well above average performance in lifelong learning practice. The development of ICT-producing sectors is above average and the diffusion of these technologies in the economy is strong.

Graph A IV.1.10: Country profiles: Netherlands



Note: Each indicator outside the unit circle shows a superior performance of the country relative to EU average.

The share of capital-intensive and low-skill industries is somewhat higher than the average, and so is the share of marketing-driven industries. Technology-driven industries have a lower than average share, as do skill-intensive industries, while industries characterised by high inputs from knowledge-based services are very important. The largest sectors are chemicals and food. Food accounts for 14 % of total European exports, although this share is declining. The publishing industry is in third place and has raised its share of value added. The tobacco industry accounts for the highest share in EU exports - for which the Netherlands provides one third of European exports - and the petroleum industry contributes one fifth.

At the manufacturing level, research intensity is rather low. However, it is complemented by higher than average innovation expenditure and a strong presence of innovation capabilities. Office machinery posts high levels of research and high growth in production and productivity. High rankings in both research and growth can also be seen in the car industry and in electronics. On the other hand, electrical machinery and chemicals do not translate research intensity into production growth - in the case of chemicals; this is perhaps due to the lower share of pharmaceuticals. Tobacco and pulp and paper are capital-intensive industries with high productivity growth.

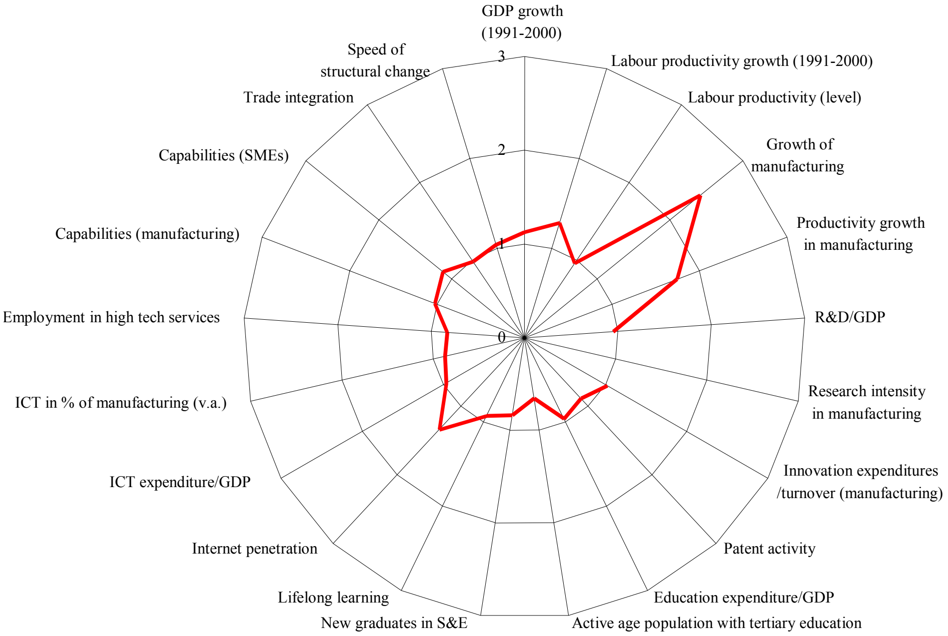
Austria

Following a period of above average growth, Austria's performance drew closer to EU average during the 1990s. The manufacturing sector increased its share in European production and ranks fourth among EU countries in growth of output and productivity.

Austria traditionally has a deficit in R&D and has now come close to the EU level. Innovation capabilities are above average. Austria is moderately well placed with respect to most human capital and ICT indicators.

The privatisation of manufacturing firms speeded up in the mid-1990s, after a period of heavy losses. The liberalisation of telecom and privatisation started rather late.

Graph A IV.1.11: Country profiles: Austria



Note: Each indicator outside the unit circle shows a superior performance of the country relative to EU average.

The share of manufacturing in total production is rather large; its share in European value added rose from 2.2 % to 2.8 % Productivity growth is specifically high, partly in the wake of privatisation and the restructuring of formerly nationalised or bank-owned firms, and partly due to the successful positioning of medium-sized firms in market niches. The export ratio is high, becoming more dynamic owing to the increasing trade surpluses with the accession countries in Central and Eastern

Europe, as well as to exports to the US. The degree of openness is high, even when compared to other small countries.

The production structure remains centred around traditional positions and the share of technology-driven industries is rather low. The largest sector is machinery. Motor vehicles are second in exports; Austria supplies parts to European and US car manufacturers. Above average market shares are posted by traditional strongholds such as the pulp and paper industry, the leather industry, metal products, and basic metals. In none of the technology-driven industries does Austria have significantly above average shares, possibly reflecting insufficient research efforts.

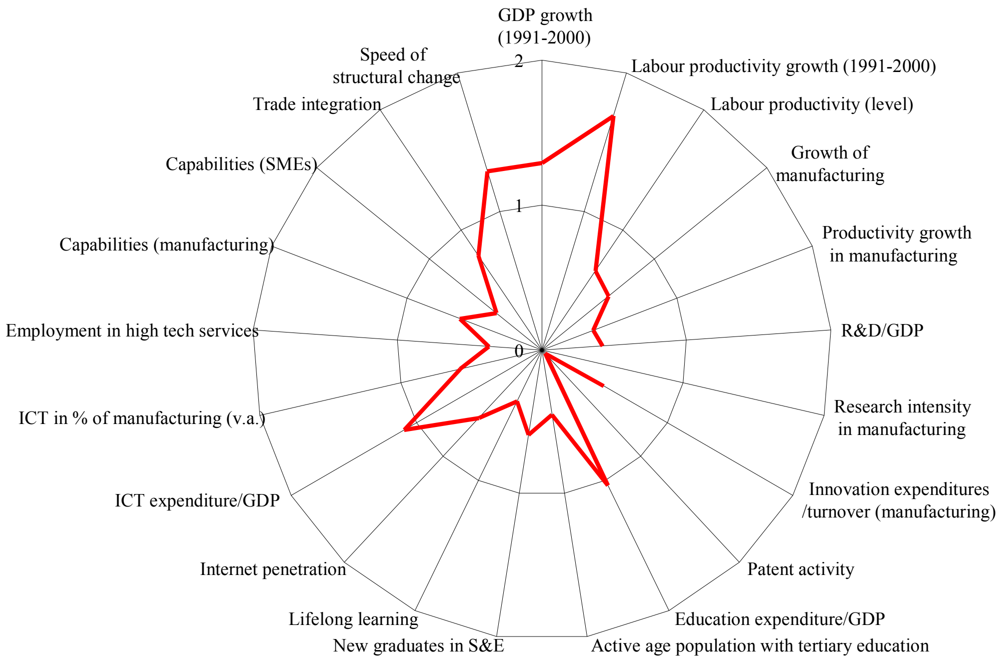
Portugal

The Portuguese economy is catching up, especially since the second half of the 1990s. Productivity is the lowest among Member States, but is increasing fast. Research efforts, both public and at business level, are still very low in comparison with the EU average. Expenditure on education is above average. The same applies to ICT, with relatively high expenditures but low penetration levels.

The industrial sector is large, accounting for 23 % of GDP. The development is driven by European integration; the intra-EU share of exports is the largest among Member States, and is growing faster than extra-EU exports. Despite Portugal's rising share in European exports, the trade deficit doubled over the last decade and amounts to nearly one half of exports.

In the sectors with larger shares than in the EU, such as food and textiles, there has been virtually no increase in productivity. By contrast, productivity increased at double-digit annual rates in basic metals and pulp and paper. Motor vehicles and other transport are catching up in productivity and display stable employment. A high productivity increase was also apparent in office machinery, albeit from a very low level.

Graph A IV.1.12: Country profiles: Portugal



Note: Each indicator outside the unit circle shows a superior performance of the country relative to EU average.

The share of Portugal's textile sectors - textiles, apparel, and leather - decreased from 24 % to 19 %; nevertheless, this share is still the second largest after that of Greece. Cars are now the largest export industry. Telecom equipment has attained the fifth largest export share; tobacco, wood (specifically cork), and made-up textiles are industries with high export shares. In general, low-skill and labour-intensive industries still dominate. The structure is adapting towards European demand, specifically by increasing shares of skill-intensive and mainstream industries. Portugal attracts foreign investments amounting to up to 3 % of GDP.

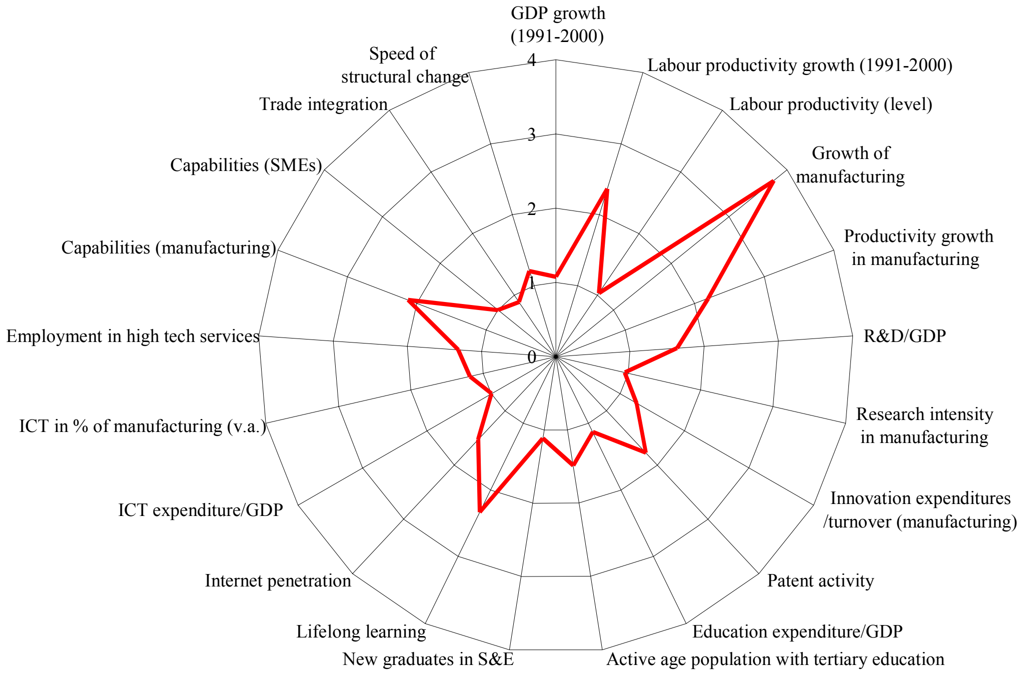
Finland

In the early 1990s, Finland was hit by a financial crisis and by the collapse of its export markets in the Soviet Union. As a result, GDP growth was negative for three consecutive years. In the second half of the 1990s, growth accelerated rapidly, making up for lost ground. Productivity growth for the entire decade is far above the European average. Finland's performance with respect to research, formation of human capital, development of ICT-producing sectors and innovative capabilities is consistently above average. Finland gave priority to research - even during its crisis years- and is now one of the countries with the best performance in research and ICT. Finland focuses on academic research at a limited number of locations and has reinforced engineering-oriented disciplines. The liberalisation of telecommunications started early, with competition in long-distance telephony introduced in the 1980s. Early and well operated programmes brought the information society into schools, the government and institutions.

The share of manufacturing in GDP in Finland is the second largest (26 %) and, in contrast to other countries, it did not decline between 1985 and 1998. Productivity increased fastest in electronics, basic metals, and paper and wood industries.

Electronic equipment jumped from 15th to 2nd place in production. Finland increased market shares in electrical machinery and in printing and publishing, while maintaining strongholds in capital-intensive industries; pulp and paper is still the most important sector, and accounts for one third of exports. The "forestry cluster" has increased its share in value added, partly through complementary services and technology centres.

Graph A IV.1.13: Country profiles: Finland



Note: Each indicator outside the unit circle shows a superior performance of the country relative to EU average.

Research intensity and production growth appear to be related across sectors[73]; this relation is less clear with respect to productivity growth, conceivably because of the role of capital-intensive industries where, typically, productivity improvements do not rely on own research but rather on embodied technology. Research is concentrated in the high tech sectors. In electronics, electrical machinery, and instruments high levels of research effort coincide with high productivity growth; in chemicals and in office machinery, high levels of research did not result in fast growing production and productivity. Productivity has also increased in Finland's traditional areas of strength: pulp and paper, the wood industry and basic metals are all among the top five sectors with regard to productivity growth. In these sectors, research intensity is lower than in other Finnish industries, but higher in Finland than in the EU.

Sweden

Sweden faced a severe financial crisis in the early 1990s that led to a long period of contraction of the economy. Production growth fell below the EU average, although,

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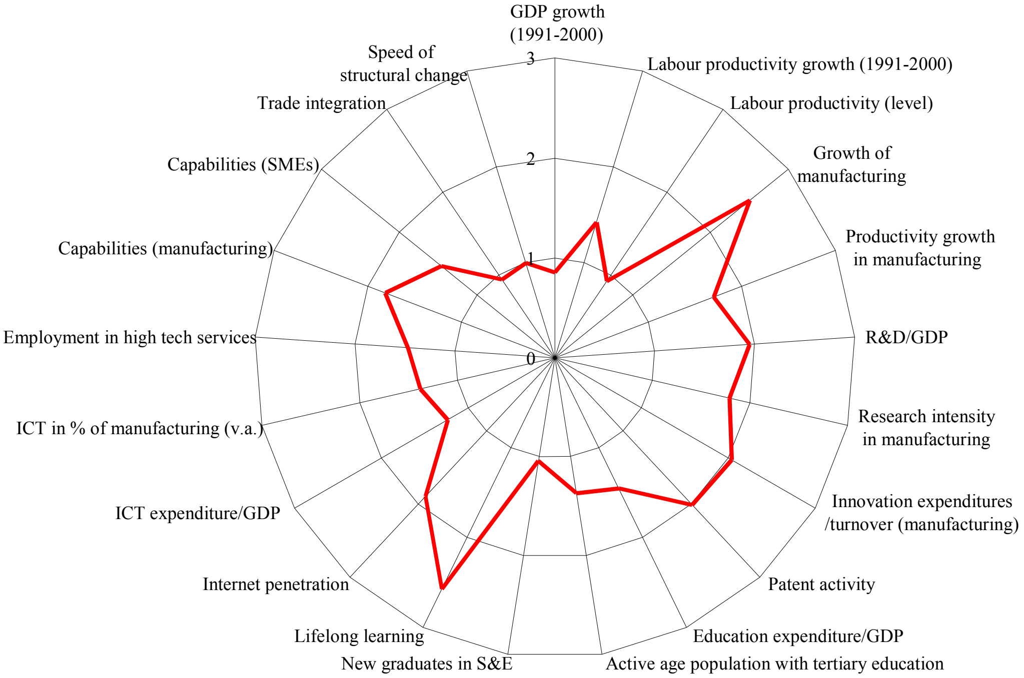
[73] The rank correlation is positive and statistically significant.

over the decade, productivity growth was higher than the EU average. Growth of manufacturing is above average and the productivity increase is the third highest.

Sweden is among the top countries for most of the factors facilitating innovation and growth and has improved in most of them, even though high performances had already been achieved at the beginning of the 1990s in research, education and ICT use.

Graph A IV.1.14: Country profiles: Sweden



Note: Each indicator outside the unit circle shows a superior performance of the country relative to EU average.

The highest increase in productivity occurred in two traditionally strong sectors. In electronic equipment, where Sweden share of production is 10 percentage points above the EU average, productivity increased by 10.3 %. This sector now accounts for 15 % of exports, which is as much as wood and paper together. In motor vehicles, productivity rose by 4.3 %. In both sectors, productivity rose faster than the EU average. In other industries, productivity increases guaranteed continued competitiveness in tough markets: basic metals, apparel and tobacco. Machinery and motor vehicles are the largest sectors in Sweden. Pulp and paper is third, but its production share decreased (in contrast to Finland). Basic metals have high market shares, and the trend is on the rise. Extra-EU exports have grown faster than intra-EU exports. Sweden has a large share of capital-intensive industries and the share of technology-driven industries is increasing fast, as is that of industries characterised by high inputs from knowledge-based services. Sweden has the lowest share of low-skill industries, reflecting its former high wage position.

In Sweden, research intensity and production, as well as productivity, growth across sectors are clearly related.[74] Other transport and cars are research-intensive sectors.

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[74] The two rank correlations are both strongly positive and statistically significant.

For motor vehicles, as well as for electronic equipment and for office machinery, high levels of research are combined with high growth in productivity. Productivity growth in traditional strongholds is apparent in basic metals, but not in pulp and paper or in wood.

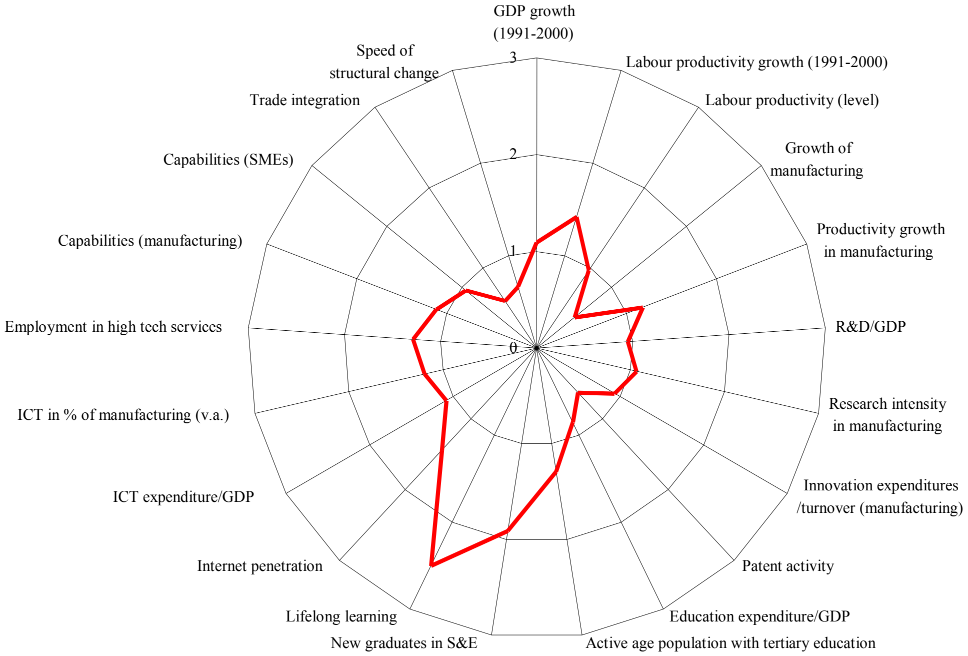
United Kingdom

In the 1990s, the United Kingdom reversed its growing productivity gap in manufacturing vis-à-vis other advanced countries, though output growth remained lower.

In the United Kingdom, research indicators are comparable to the EU average, but as in other large countries R&D expenditures relative to GDP have declined. The United Kingdom ranks high in both the production and use of ICT. Public expenditures on education are below average but the supply of skills is among the best.

The United Kingdom produces 15 % of European manufacturing output, the second largest production share among Member States. The United Kingdom enjoys the second highest unit value of exports, reflecting structural change towards industries characterised by high inputs from knowledge-based services. It also takes advantage of its position as the headquarters and export hub for high-technology products. Marketing-driven industries have a significantly higher share in the United Kingdom than in the EU. Food is still the largest sector in production; followed by chemicals, machinery, and vehicles. A clear and increasing specialisation of the United Kingdom can be observed in printing and publishing, which now amounts to 8 % of production; more than 20 % of European production and exports in this sector come from the United Kingdom. High market shares have also been attained in office machinery and telecom equipment.

Graph A IV.1.15: Country profiles: United Kingdom



Note: Each indicator outside the unit circle shows a superior performance of the country relative to EU average.

In the United Kingdom, research intensity and productivity growth across sectors do not appear to be related. Electronic equipment, chemicals and instruments are sectors with high research intensity, and high growth. Other transport has the highest research intensity, but low growth in production and productivity; electrical machinery has the fourth highest research intensity and the second lowest level of growth in productivity. In general, capital-intensive industries like oil, chemicals and food, have high productivity growth.

- Convergence of underlying forces across Member States

The trend in the 1990s in the variables used as proxies for the forces facilitating innovation and growth and presented in the country profiles gives a rough idea of whether Member States have converged in terms of these underlying forces. Indeed, in a majority of cases there is convergence, both as a reduction of the dispersion of performances[75] and as a reduction of the relative distance between the leading and the "trailing" group of countries. Each group is composed of five countries - not necessary the same at either point in time. The points in time are not the same for all indicators, depending on the length of the time series. In the case of Internet penetration, the period is just one year, yet the converging pattern is very strong. Table AIV.1.1 summarises the information on convergence/divergence of the different indicators across Member States.

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[75] Measured by the coefficient of variation.

Table A IV.1.1: Convergence of underlying forces within the EU

1. Converging	2. Diverging	3. Unclear trend
♦ Population having attained secondary education ♦ Population having attained tertiary education ♦ Number of publications / resident ♦ Lifelong learning (1996-2000) ♦ Internet penetration (Oct. 1999-Oct. 2000) ♦ ICT expenditure/GDP (1991-2000) ♦ PCs/100 population (1995-1999)	♦ Patent activity (1996-1999) ♦ Employment in high tech services (1995/97-1999) ♦ ICT in % of manufacturing (v.a.) (1991-1998)	♦ R&D/GDP (1991-1999) ♦ Research intensity in manufacturing (result varies according to years) ♦ Education expenditure/GDP (1995-1998)

The indicators relative to ICT penetration are converging faster. Two of the three diverging indicators refer to structural features that may be self-reinforcing (specialisation, concentration), while in the third case (patents) the leaders increased their advantage. As for the two measures of research intensity, there is a stabilisation of relative distances, but greater dispersion in the case of the R&D to GDP ratio and no clear pattern for R&D in manufacturing. Finally, spending in education behaves in the same way as total R&D.

The lower performance group shows little tendency to vary; it consists mainly of the southern EU countries. Sweden, Denmark, Finland, and the Netherlands tend to share the top places, followed by the UK, Germany, France and Luxembourg[76]. Again, for most of the indicators the (relative) distance between top and low performers tends to decrease over time. And, in balance, decreases in the coefficient of variation are much stronger than increases, underlining the dominant trend of convergence.

The EU is closing the gap with the US for a few indicators only

A comparison can be made with the US for some of the above indicators. The EU has improved its position in most of the cases, although not decisively. The gap in ICT spending has been reduced substantially, as the improvements on Internet and PC penetration confirm. However, with regard to the development of the ICT-producing sector the situation has worsened. The EU is catching up with the US in publications, in secondary and tertiary education attainment and in patents.

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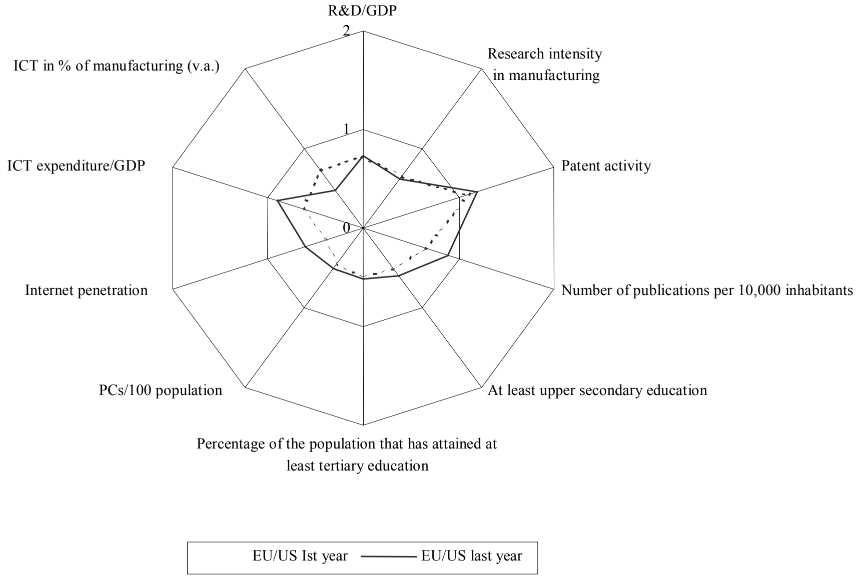
[76] When data permit its ranking.

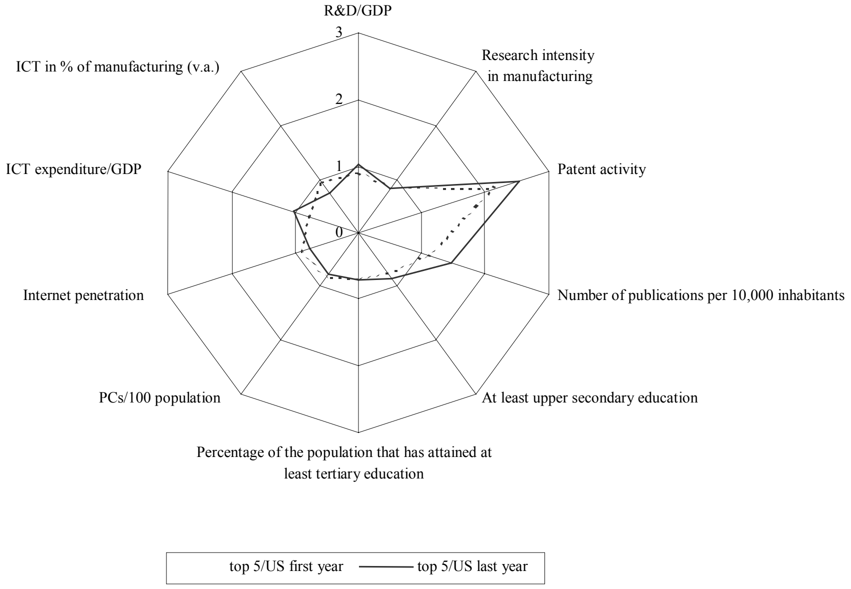
Graph A IV.1.16: Comparison with the US over time



Notes: Each indicator outside the unit circle shows a superior performance of the EU relative to the US. The *first* and *last* year are not the same for all indicators; they depend on the length of the time series

The picture is definitely better for the leading EU countries. They have surpassed the US in patents, publications, ICT diffusion and total research and development spending.

Graph A IV.1.17: Comparison of the top EU performers with the US over time



Notes: Each indicator outside the unit circle shows a superior performance of the top five EU countries relative to the US. The *first* and *last* year are not the same for all indicators, they depend on the length of the time series. The top five EU countries vary according to the indicator.

Table A IV.1.2: Indicators for the country profiles

Indicator	Definition	Source	Reference year(s)
GDP growth	Growth rate of GDP at constant prices (base year 1995)	EUROSTAT ESA 95	1992-2000
Labour productivity (level)	GDP (in PPS) per person employed	EUROSTAT ESA 95	2000
Labour productivity growth	Annual average growth rate of above	DG ENTR calculation	1991-2000
Growth of manufacturing	Real growth of manufacturing (production index)	EUROSTAT	1991-2000
Productivity growth in manufacturing	Production index employment	-	1991-2000
R&D/GDP	Total R&D expenditure as a percentage of GDP	EUROSTAT, OECD	1999
Research intensity in manufacturing	R&D expenditure as a percentage of value added in manufacturing	OECD, STAN	
Innovation expenditures /turnover (manufacturing)	Total innovation expenditure as a percentage of sales in manufacturing	EUROSTAT, Community Innovation Survey	1996
Patent activity	Number of European and US patent applications per million inhabitants, by country of origin	EPO and USPTO	1999
Education expenditure/GDP	Total public expenditure on education as a percentage of GDP (private expenditure not taken into account)	Joint UNESCO/OECD /EUROSTAT questionnaire on education statistics	1998
Active age population with tertiary education	Percentage of working age population with some form of post-secondary education	Eurostat, Labour Force Survey	2000
New graduates in S&E	New graduates (all post-secondary) in Science and Engineering as a percentage of population aged 20-29	EUROSTAT	1999
Lifelong learning (adult participation in)	Percentage of population aged 25-64 participating in education and training (adult participation in training 4 weeks prior to the survey)	Eurostat, Labour Force Survey	Spring 2000
Internet penetration	Percentage of citizens aged 15 or more with home Internet access	DG INFSO, EUROBAROMETER	oct-00
ICT expenditure/GDP	ICT expenditure as a percentage of GDP (current prices). ICT comprises information and telecommunications technology equipment, software and services	EITO, EUROSTAT	2000
ICT in % of manufacturing (v.a.)	Share of ICT sectors (OECD definition) in total manufacturing (nominal value added)	OECD	
Employment in high tech services	Percent of total employment in high-tech services (post and telecommunications, information technology incl. software development and R&D services - NACE 64, 72 and 73).	EUROSTAT, Labour Force Survey	1999 data
Capabilities (manufacturing)	Arithmetic average of two indicators: percentage of manufacturing firms engaged continuously in R&D and percentage of manufacturing firms involved in innovation cooperation	EUROSTAT, Community Innovation Survey	1996
Capabilities (SMEs)	Arithmetic average of two indicators: percentage of manufacturing SMEs innovating in-house and percentage of manufacturing SMEs involved in innovation cooperation	EUROSTAT, Community Innovation Survey	1996
Trade integration	(Total imports of goods + total exports of goods) / (2*GDP)	EUROSTAT (COMEXT), UN (COMTRADE)	2000
Speed of structural change		European Commission (2000A)	

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ANNEX IV.2:

R&D AND GROWTH PERFORMANCE: EVIDENCE FROM EUROPEAN AND US FIRMS IN THE 1990S[77]

This annex studies the contribution of R&D to firm performance using a sample of 2167 large, publicly traded firms in Europe and the US. Data show that firms that report R&D are growing faster and have higher productivity. The econometric analysis indicates that the impact of research on production is significant and robust, and estimates the rate of return on R&D at approximately 12 %.

The database used- Global Vantage- provides information on company accounts, sampled from a wide range of manufacturing sectors, for the United States and twelve EU countries covering the period 1989-1998.[78]

Table A IV.2.1: Distribution of firms in the sample, 1990-1998

	All firms		R&D firms		Non R&D firms	
	absolute	% of sample	absolute	% of sub-sample	absolute	% of sub-sample
Belgium	39	1,8	6	0,6	33	2,8
Denmark	48	2,2	13	1,3	35	3,0
Germany	266	12,1	96	9,3	170	14,6
Greece	25	1,1	8	0,8	17	1,5
France	214	9,7	54	5,2	160	13,7
Ireland	154	7,0	10	1,0	144	12,4
Italy	82	3,7	7	0,7	75	6,4
Netherlands	73	3,3	18	1,7	55	4,7
Austria	34	1,5	11	1,1	23	2,0
Finland	51	2,3	36	3,5	15	1,3
Sweden	74	3,4	39	3,8	35	3,0
UK	305	13,9	155	15,0	150	12,9
EU-12	**1 365**	**62,1**	**453**	**43,8**	**912**	**78,4**
US	833	37,9	581	56,2	252	21,6
Total	**2 198**	**100,0**	**1 034**	**100,0**	**1 164**	**100,0**

Note: The sample excludes firms with large discontinuities in the data, generally caused by mergers; all firms that reported non-zero R&D expenditures in one or more years in the 1990-1998 period are classified as R&D firms.

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[77] This annex is based on Wieser, R. (2001), The Impact of R&D on Output and Productivity: Firm Level Evidence, Background Report, European Commission, DG Enterprise, Brussels.

[78] There is no information on R&D expenditures for firms in Spain, Luxembourg and Portugal. The original data was restricted to 2 167 firms due to omissions and questionable data on certain variables and in response to merger and acquisition problems (outliers).

Table A IV.2.1 presents the distribution, in the sample, of R&D reporting and non-reporting firms across countries. 47 % of firms report R&D expenditures of which about 56 % are from the US, 15 % are from the UK and 29 % are from the other EU countries.[79]

Table A IV.2.2 presents the average, lower quartile, median and upper quartile of employment, sales, gross physical capital, R&D expenditures and R&D intensities for the European and US firms in 1994/1995. European firms in the full sample are, on average, only slightly smaller than the US firms (in terms of average employment, average sales and average physical capital stock). However, European firms that report R&D expenditures are much larger than the corresponding US firms. European R&D firms have, on average, 25 600 employees, against 14 600 in the US. Furthermore, in Europe, R&D firms are more than twice as large as non–R&D firms, whereas in the US sample they are roughly similar in size. Additionally, in Europe, average R&D expenditures of R&D firms are considerably higher than in the US. These observations suggest that small European firms active in research are not adequately represented in the sub–sample of R&D reporting firms.

Also, average R&D intensity (R&D/sales) is higher in the US (4.8 % compared 3.6 % in Europe). However, if the firms' disclosure decision depends positively on the importance of R&D activities (measured by the R&D/sales ratio),[80] then the "true" average R&D intensity of European firms might be even smaller. Finally, the size distributions in both samples are highly skewed (in most cases the mean is above the third quartile). Hence, even after outlier corrections, large firms in both regions heavily dominate the sample.

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[79] For the purpose of the following descriptive analysis, no distinction is made between firms whose R&D is reported as "zero" and firms whose R&D is just "missing". All such firms are treated as not having reported positive R&D. However, there may be a selection bias in the data, and this is accounted for in the econometric model.

[80] This is one of the conclusions reached in Gaeremynck – Veugelers (2000).

Table A IV.2.2: Sample characteristics of key variables, 1994–1995

Variable	EU-12			US		
	All firms	R&D firms	Non R&D firms	All firms	R&D firms	Non R&D firms
N	1.365	453	912	833	581	252
Employment (thousands)						
Average	12,3	25,6	5,9	12,5	14,6	7,8
Lower Quartile	0,8	1,1	0,7	1,0	10,0	1,2
Median	2,2	5,2	1,9	3,1	3,3	2,8
Upper Quartile	8,7	21,8	6,5	10,0	12,0	6,9
Sales (millions of dollars)						
Average	2.160	4.570	1.050	2.274	2.766	1.210
Lower Quartile	103	156	106	152	146	157
Median	307	728	278	473	501	414
Upper Quartile	1.324	3.605	1.011	1.539	1.870	909
Physical Capital (millions of dollars)						
Average	821	1.747	402	853	1.035	436
Lower Quartile	26	40	28	34	33	39
Median	89	206	83	128	142	112
Upper Quartile	398		328	512	623	328
R&D (millions of dollars)						
Average		199			119	
Lower Quartile		3			4	
Median		13			14	
Upper Quartile		71			45	
R&D/sales						
Average		3,6			4,8	
Lower Quartile		1,0			1,2	
Median		2,2			2,8	
Upper Quartile		4,7			6,4	

Notes: for all variables, average for 1994–1995; physical capital refers to property, plant and equipment (gross of depreciation); R&D refers to research and development expenditure.

Table A IV.2.3 presents annual median growth rates of major variables for the two types of firms, in Europe and in the US, during the 1990s. R&D firms display higher labour productivity growth, as well as more capital deepening than non–R&D firms in both regions. While the physical capital stock grew significantly faster in R&D firms, there was no statistically significant difference in employment growth.[81]

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[81] The significance of observable differences in the growth rates of the variables is evaluated using the *Mann-Whitney U* test statistic.

Another important observation is that R&D firms in the US exhibit higher growth in all variables, compared to European R&D firms, during all the periods under consideration. Growth in R&D expenditures by US firms was almost twice that of European firms, and labour productivity increased annually by 1.6 percentage points more in the US.[82]

Table A IV.2.3: Median annual growth rates – non parametric tests for significant differences in growth rates

Variables	EU-12		US	
	Non R&D	R&D	Non R&D	R&D
sales	**2.6**	**4.0**	**5.3**	**6.8**
US vs. EU	*	*	*	*
Non R&D vs. R&D	*	*	*	*
employees	**1.9**	**1.3**	**2.3**	**2.3**
US vs. EU	n.s.	*	n.s.	*
Non R&D vs. R&D	n.s.	n.s.	n.s.	n.s.
physical capital	**3.2**	**4.6**	**5.8**	**7.0**
US vs. EU	*	*	*	*
Non R&D vs. R&D	*	*	*	*
labour productivity (sales/employee)	**1.1**	**2.7**	**3.3**	**4.3**
US vs. EU	*	*	*	*
Non R&D vs. R&D	*	*	*	*
capital deepening (phys. cap./empl.)	**1.1**	**2.7**	**3.4**	**4.0**
US vs. EU	*	*	*	*
Non R&D vs. R&D	*	*	*	*
R&D		**4.1**		**7.8**
US vs. EU		*		*

Note: * denotes statistical significance at the 5 % level; n.s. = not statistically significant.

Estimating a Cobb Douglas production function linking output growth to the growth rates of physical capital and labour, as well as the R&D intensity at the beginning of the period provides estimates of the contribution of R&D to output growth.[83]

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[82] However, this last observation might be partly due to the under–representation of small, fast growing firms in the European sample; see the discussion on sample selection below.

[83] The measure of output is “net sales or revenue”, physical capital is measures as “net property, plant and equipment”, employment is “average number of employees” and R&D intensity is “research and development expenses” divided by sales.

One important econometric problem in estimating the relationship between R&D and productivity is the selectivity bias. Given the large number of European firms that do not report R&D expenditures, it is likely that some bias exists, at least in the European sample.[84]

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[84] European firms are in most cases not forced to disclose their R&D activities in their official accounts; compared to the EU, the reporting rules for R&D expenses are less liberal in the US. This bias problem was addressed using the Heckit method, where first a selection equation, relating the reporting probability to a set of variables (capital, labour, firm size, cash flow, industry and geographic dummies) is estimated, which is then used in the regression equation linking R&D to output growth. The estimated probability of reporting R&D expenditures depends negatively on employment growth and on European country dummies and positively on the size of firms and on the research intensity of the industry but it does not depend on cash flows. In other words, disclosure of R&D is more likely for large, slowly growing R&D intensive firms from the US. Thus, what is noticeably missing from the data are small, fast growing European firms with above average productivity, given the level of R&D intensity.

Table A IV.2.4: Output growth and R&D intensity (nominal): Heckit results

Coefficients (Standard Errors)									
Specification	Independent Variables							inverse Mills ratio	Chi^2 - Test
	Physical Capital	Employment	Research Intensity	Industry Research Intensity	Country Research Intensity	EU Research Firms' Dummy	EU Dummy		
1 Basis	**.26**	**.61**	**.12**					**- .02**	**2.47**
	(.052)*	(.049)*	(.048)*					(.016)	(.116)
2 Intra-Industry Spillovers	**.26**	**.61**	**.11**	**.02**				**- .01**	**8.10**
	(.050)*	(.053)*	(.048)*	(.060)				(.004)*	(.004)
3 Inter-Industry Spillovers	**.26**	**.60**	**.12**		**.14**			**- .02**	**.17**
	(.062)*	(.071)*	(.061)**		(1.195)			(.054)	(.680)
4 Country Effects	**0,27**	**.60**	**.14**			**- .06**	**- .00**	**- .01**	**1.01**
	(.024)*	(.027)*	(.041)*			(.105)	(.007)	(.011)	(.313)

Notes:* (**) denotes statistical significance at the 5 % (10 %) level.

Estimates using Heckman full maximum-likelihood estimation with Huber/White/sandwich estimator of the variance.

The variables physical capital and employment are the respective mean logarithmic growth rates over the period 1991-1998. Research intensity is reported R&D averaged over the years 1991-93, divided by average sales 1991-1998. Industry research intensity is industry R&D outlays divided by nominal production at industry level (NACE 2-digit); average 1990-98 using OECD-ANBERD. Country research intensity is industry R&D outlays/nominal production at country level; average 1990-98. The EU research firms' dummy represents R&D from EU firms in the sample. The EU dummy takes the value one for EU firms' observations.

The inverse Mills ratio is an additional regressor (in essence, an omitted variable); a significant coefficient implies sample selection. The likelihood ratio test is an equivalent test for sample selection

Table IV.2.4 presents the basic results regarding the contributions of R&D capital to output (total net sales). Four specifications of the estimating equation were used:

- In Specification 1 (Basis) the independent variables are the growth rates of physical capital and labour and research intensity; the estimates are all statistically significant at the 5 % level and reveal important effects on total net sales, while the estimated rate of return on R&D is 12 %.[85]

- Specifications 2 (Intra-industry Spillovers) includes a spillover variable, constructed as the industry R&D in percentage of the industry's production value, meant to capture intra-industry spillovers. The regression shows that this intra-industry effect is not statistically significant.

- In Specification 3 (Inter-industry Spillovers), the industry–wide R&D intensities are aggregated for the individual countries to measure inter–industry effects. Again, the spillover effect is not statistically significant in this specification.

- Specification 4 (country effects) addresses the relative impact of R&D activities carried out by firms in the two regions (the US and the European countries as a whole). Although the estimated rate of return on R&D is lower for European firms (8 % compared to 14 % in the US), the coefficient is not statistically significant at the usual levels.

To examine robustness, these estimations were performed using real values with the Heckit method and also using OLS for both nominal and real values. The estimates for the private rates of return remain significant and are of rather comparable magnitude in all specifications. This is also true for the estimates of labour and physical capital input. Furthermore, no single specification reveals significant country effects. However, the OLS results point to high and significant spillovers (both intra– and inter–industry) when output growth is measured in nominal values.

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[85] Adding industry dummies to this specification does not change the estimates.

CHAPTER V:
THE COMPETITIVENESS OF EUROPEAN BIOTECHNOLOGY: A CASE STUDY OF INNOVATION

This chapter reviews the state of innovation and production systems in European biotechnology and, in particular, its innovative capacity and related factors [86]. As such, biotechnology cannot be considered as an industrial sector but rather as a set of technologies developed in the field of life sciences. Its applications span over a number of other industrial or service sectors, and agriculture. This direct link with science makes innovative capacity a major determinant of competitiveness.

While large biotechnology firms are undoubtedly important[87], the emphasis of the chapter is on the role of the small and medium, research-intensive companies, which have emerged from the new opportunities opened up by the life sciences. In this chapter they are referred to as dedicated biotechnology firms (DBFs).

Inevitably, comparisons with the US biotechnology industry are made throughout. One notable difference between Europe and the US in the 1990s has been that, while in the US a new research–intensive industry in the life sciences has continued to develop, there has not been a comparable specialisation in entrepreneurial biotechnology in Europe (see also Gambardella, Orsenigo, Pammolli, 2001). Partly reflecting this difficulty in developing an industry of DBFs, the perception has emerged that the US has a competitive advantage over Europe in biotechnology.

The US have pioneered the rise of an effective division of labour between smaller and larger companies, which possess different comparative advantages in the "exploration" and "exploitation" of new innovation opportunities (March, 1991). Europe has been less effective in facilitating the growth of research–intensive DBFs. While large multinationals, such as biopharmaceuticals and agri-food, may not need local technology suppliers, the presence of a local industry of research–based firms and technology suppliers is critical, because the industry is, by itself, a powerful source of growth and social progress. The US biotechnology industry has, over the past two decades, created a large number of new jobs, and at least a dozen new world–class companies (e.g. Amgen, Chiron, Genzyme, and others), along with several new ones in the new tool technologies (e.g. Incyte, Millennium, Celera, Human Genome Sciences, and others). It has also produced a substantial stream of revenues, mostly in the form of royalties from licences or R&D contracts and collaborations.

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[86] There are several statistical and methodological problems that affect the quality and reliability of data concerning the European biotechnology industry. This chapter uses data from the BID (Biotechnology Industry Databank) of the University of Sienna, as well as statistics collected by publicly funded organisations such as the US National Science Foundation in the US and NUTEK in Sweden, from the most important patent offices, and from commercially available databases such as Windhover, Recombinant Capital, Pharmaventures and Bioscan. Reports and data from commercial sources like Ernst&Young, Decision Resources, SRI, McKinsey, the European Venture Capital Association, have also been used. For a detailed description of the data used in this Report, see the background study "Innovation and Competitiveness in Biotechnology: a European Perspective", July 2001, prepared for the present Report by a team of researchers coordinated by Prof. Fabio Pammolli and Dr. Massimo Riccaboni at the University of Siena (see Allansdottir et al., 2001).

[87] These are the agri-seed firms such as Syngenta, Aventis, and Advanta, large chemical firms such as BASF, and large pharmaceutical firms like Astra- Zeneca, Novartis, Aventis, and GlaxoSmithKline.

As in many other technologies, innovation in biotechnology was first undertaken not by incumbents but by new companies. In the US, biotechnology was the motive force behind the first large–scale entry into the pharmaceutical industry since the early post-World War II period. Entry rates soared in 1980 and remained at a very high level thereafter, but with waves linked to both the stock market performance and to the appearance of successive new technologies. Despite the high rates of entry of new firms into biotechnology, it took several years before the industry started to have an impact on the pharmaceutical and agri-food markets. Many of the early research efforts proved to be dead-ends and/or much more difficult to develop than expected.

These companies were primarily university spin-offs and were usually formed through collaboration between scientists and professional managers, backed by venture capital. Their specific skills related to knowledge of new techniques and to research capabilities in that area. The "function" of this type of national biotechnology firms has been to mobilise fundamental knowledge created in universities and to transform it into commercially useful techniques and products.

Section V.1 reviews the recent evolution of industrial biotechnology in Europe and the contribution of the new DBFs that entered the industry during the 1990s. Section V.2 provides a detailed analysis of R&D activities and research collaborations of European biotechnology companies. Section V.3 analyses the essential features of biotechnology clusters in Europe and the position of European biotechnology firms in the context of the international division of labour within the field. Section V.4 reviews briefly the institutional, legal, and cultural factors that have an impact on the evolution and performances of the biotechnology industry and Section V.5 surveys the adoption of biotechnology by large European firms. The final section V.6 summarises the main findings.

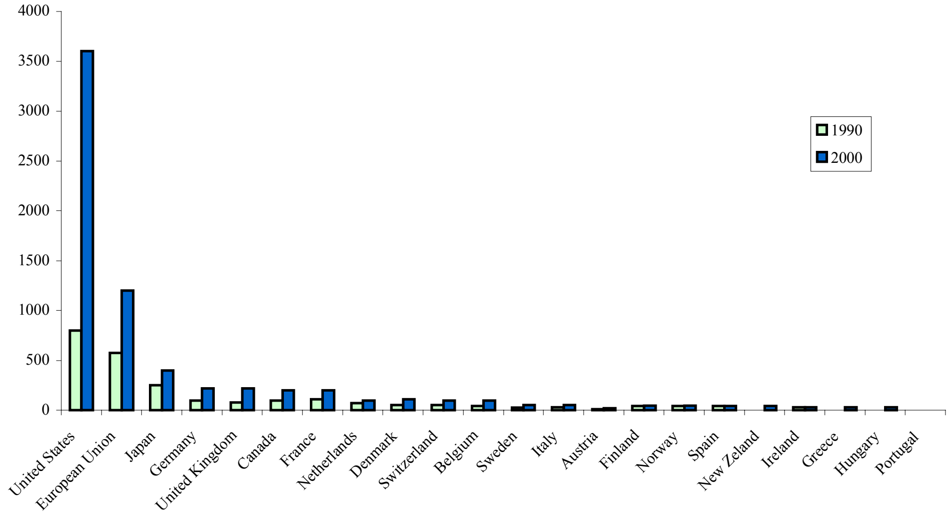
5.1. Innovation activities of the European biotechnology industry

This section provides an overview of the innovative performance of industrial biotechnology in Europe, on the basis of patent data and patent citations. A traditional indicator of innovative performance, patents are even more important in the context of biotechnology where they often represent the only tradable asset.

5.1.1. General observations and comparisons with the US

The available empirical evidence shows that the US is and continues to be the most important locus of innovation in biotechnology (see Graphs V.1 and Graphs V.2), followed by Japan, Germany, the UK and France.

Graph V.1: Biotechnology patents granted by the USPTO, 1990 and 2000 (in hundreds)



Source: OECD, calculations based on data from USPTO and EPO

Graph V.1 gives an account of the dominance of the US in biotechnology inventions. From 1990 to 2000, the US share in all biotechnology patents granted by the USPTO[88] increased by nine percentage points. The share of Japan declined by 11 %. A modest increase occurred in the case of Denmark (1.1 %), while Germany's share declined by 1.2 % The shares of all other European countries have remained generally stable over the last decade. Between 1990 and 1997, national shares of biotechnology EPO patent applications[89] have been stable (see Graph V.2), with the exception of Japan, which saw a decline of 6 %. The UK shows the best performance with an increase of 2.1 %.

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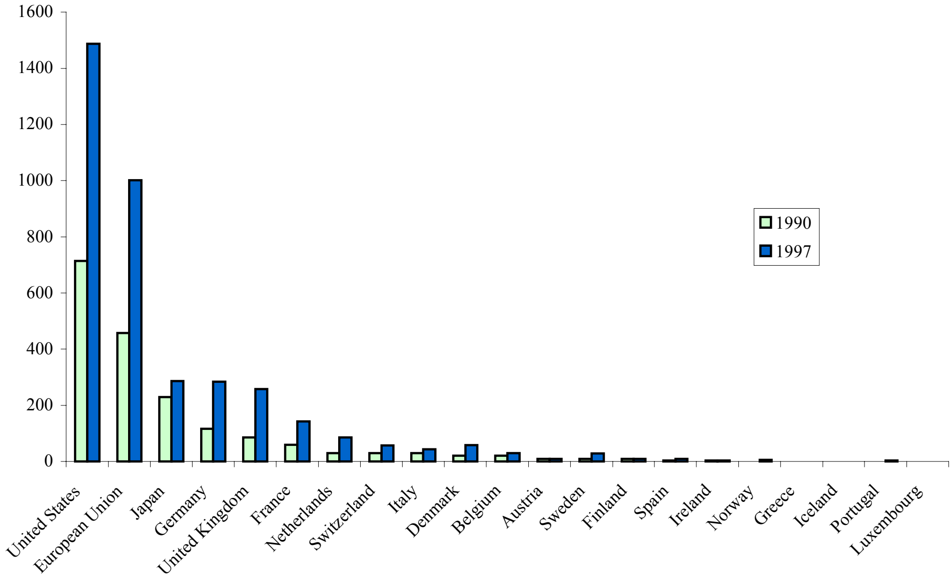
[88] Biotechnology patents are covered by class 435 of the USPTO classification system ("molecular biology and microbiology"). For a complete definition of class 435 see http://www.uspto.gov/web/offices/ac/ido/oeip/taf/moc/435.htm.

[89] European biotechnology patents are covered by 5 IPC codes: C12M: Apparatus for enzymology or microbiology; C12N: Micro-Organisms or Enzymes; compositions thereof; C12P: Fermentation or enzyme-using processes to synthesise a desired chemical compound; C12Q: Measuring or testing processes involving enzymes or micro-organisms; C12S: Processes using enzymes or micro-organisms to liberate, separate, or purify a pre-existing compound or composition. For complete definitions of these IPC codes, see http://classifications.wipo.int/fulltext/new_ipc/index.htm.

Graph V.2: Biotechnology patent applications to the EPO for priority years 1990 and 1997 (in hundreds)



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

Patent citations data provide a better measure of the potential technological and economic value of innovative activities than patent counts. Citations are a measure of the importance or impact of inventions and a proxy for knowledge flows among patenting institutions. Widely cited patents tend to be “seminal” patents, i.e. key inventions to which further patents must refer. Moreover, high citation rates have been shown to correlate with the economic value of patents. Thus, a high number of citations received by a given firm or country can be interpreted as a measure of the quality and relevance of its innovative activities.

Allansdottir et al. (2001) show that the share of citations to US patents is substantially higher (around 55 %) than the share of US patents in total patents, suggesting that on average US patents are more important. Moreover, among European nations only UK patents show a higher share for citations than for patent counts. On the basis of a subset of “highly cited” patents (i.e. patents receiving at least 10 citations not counting self–citations) in the period 1978 – 1995 (with citations up to 1997) the US lead increases further to 65.4 %.

National biotechnology firms (DBFs) hold a disproportionate share of these highly cited patents (48 %), and US DBFs account for more than 80 % of highly cited patents of DBFs. In Europe (including Switzerland), around 65 % of the highly cited patents belong to large incumbent firms and around 20 % to DBFs (almost all of them British). Considering the top 20 institutions in terms of patent citations, eleven are American (four DBFs, three incumbents, four universities and other research organisations), two are, respectively, German, British and Japanese, while Switzerland, France and Denmark are represented with one institution. Almost all of these European institutions are large corporations, the only exceptions being one British DBF and one French public research organisation.

Finally, the US appears to be more specialised in the pharmaceutical segment of biotechnology. The US share in highly cited agri–food patents is 13.5 % compared to a total of 17 %. However, only two European countries have agri–food patents, Germany (35 %) and the UK (33 %), among their total highly cited patents.

The importance of biotechnology depends to a considerable extent on the size and the growth of downstream industries, which demand biotechnology products and technologies (see also Gambardella, Orsenigo, Pammolli, 2001). Table V.1 shows, over a period of twenty years, the shares on GNP of the most important industries related to biotechnology: food, chemicals, and pharmaceuticals, for the US, Japan, and four major European countries: Germany, France, the UK and Sweden.

Table V.1: International patterns of specialisation in related industries: share of food, pharmaceutical and chemical industries in GNP, 1978-1997

		Average share of GDP (%)		
		1978-1985	1986-1993	1994-1997
United Kingdom	Food	19,11	17,97	17,00
	Chemicals	19,03	18,00	19,66
	Pharmaceuticals	1,50	2,14	2,78
Germany	Food	14,46	12,82	11,77
	Chemicals	20,31	17,71	18,61
	Pharmaceuticals	1,11	1,32	1,43
France	Food	17,79	17,01	16,68
	Chemicals	19,47	16,40	18,11
	Pharmaceuticals	1,65	2,24	2,65
Sweden	Food	4,06	2,78	2,81
	Chemicals	12,87	10,69	10,25
	Pharmaceuticals	0,85	1,67	2,72
US	Food	14,27	14,36	13,35
	Chemicals	19,42	16,69	16,59
	Pharmaceuticals	1,17	1,83	2,21
Japan	Food	11,07	10,90	11,11
	Chemicals	14,47	9,52	11,28
	Pharmaceuticals	1,26	1,42	1,56

Note: “ “Chemicals” excludes Drugs.

Source: OECD, STAN Database (2000).

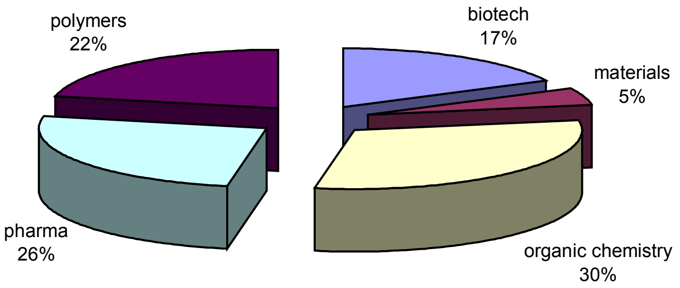
The data in Table V.1 show a continuous growth of the share of pharmaceuticals, while the shares of the food industry and of chemicals in GNP decreased significantly. The countries that recorded the highest growth in the GNP share of pharmaceuticals are the US and the UK, while Germany and Japan experienced a much slower growth. As for chemicals, the UK, Germany and France have the highest share in GNP.

5.1.2. R&D activities and research collaboration: Inter–country and inter–regional comparisons

Patent data provide important information about the geographical distribution of biotechnology research across macro-regions (Europe and the US) and across countries. The extent to which companies locate biotechnology research outside of their home country (internationalisation of research) is also important. To put the analysis in perspective, biotechnology is compared with four other branches of the chemical industry (materials, organic chemistry, pharmaceuticals, and polymers). It is assumed that the location of the inventors of the (97 785) patents and the location of the (7 264) chemical R&D laboratories coincide with the location of the inventive activity.

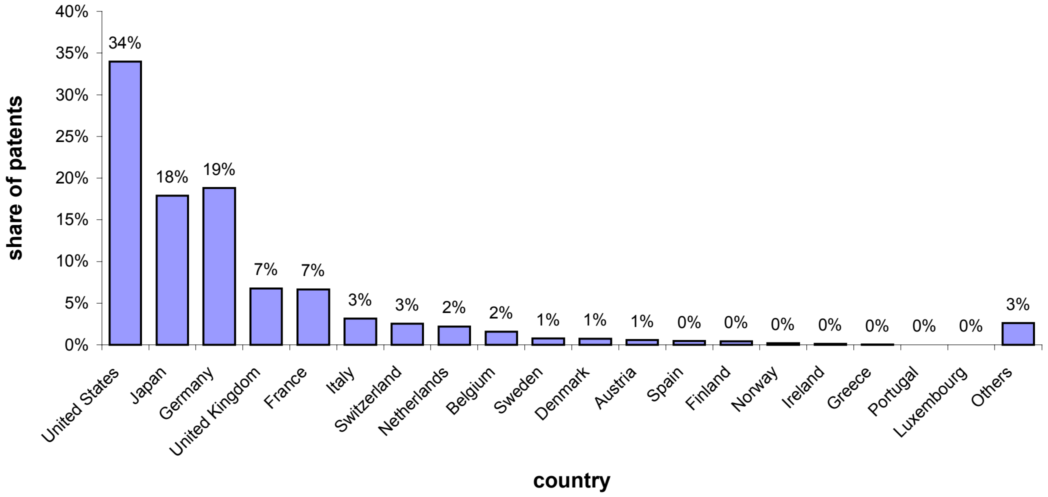
The data suggest that the US is comparatively more specialised in biotechnology innovations, and that smaller European countries show greater specialisation in biotechnology compared to larger European countries.

Graph V.3: Share of EPO patents by chemical class, 1987-1996



Graph V. 3 shows the sectoral break down of patents by chemical subsectors. In 1987–1996 biotechnology patents were 17 % of the total chemical patents, rising from 16 % in 1987–1991 to 19 % in 1992–1996. Clearly, these EPO patents include patents developed in Europe and in the US and Japan. Graph V. 4 shows the share of patents attributed to each country.

Graph V.4: Share of 1987-1996 EPO patents in chemicals by country of invention



The biotechnology patents invented in Europe represent 14.4 % of the total number of chemical patents invented in Europe, compared to 22.5 % of the EPO biotechnology patents invented in the US over the total number of chemical EPO patents invented in the US. This suggests that the US chemical companies are relatively more focused than European ones on biotechnology. To examine this issue further, the Revealed Technological Advantage Index (RTA) was computed for different countries. RTA is a country's share of all patenting in a given technology/sector relative to the share of patents in that technology/sector over all technologies/sectors, and it gives an account of the specialisation of a country or region in a technological field.[90] Table V.2 shows the Standardised Revealed Technological Advantage Index (SRTA) = (RTA-1)/(RTA+1), for Europe, the **US** and Japan. The standardised index varies between –1 (non-specialisation) and 1 (specialisation). The evidence in Table V. 2 suggests that the US has a stronger specialisation in biotechnology than Europe (and Japan). The biotechnology RTA index for the US is 0.13 compared to –0.09 for Europe, and –0.12 for Japan.

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[90] $\text{RTA} = (P_{ij} / \sum_J P_{ij}) / (\sum_i P_{ij} / \sum_i \sum_J P_{ij})$,

where P_{ij} denotes the number of patents in country/region i and sector j.

Table V.2: Standardised Revealed Technological Advantages of Europe, US and Japan in biotechnology, materials, organic chemistry, pharmaceuticals and polymers (97 785 patents in 1987-1996).

(RTA-1) / (RTA+1)					
Country	**Biotech.**	**Materials**	**Organic chemistry**	**Pharma**	**Polymers**
EU total (*)	- 0,09	0,01	0,06	0,02	- 0,05
US	0,13	- 0,06	- 0,08	0,01	- 0,01
JP	- 0,12	0,08	0,01	- 0,11	0,15
OTHERS	0,22	0,02	- 0,08	0,11	- 0,39

Note: (*) This is EU-15 plus Switzerland (CH) and Norway (NO).

Source: European Patent Office (1998).

Table V. 3 reports the standardised RTA by individual European country. It suggests that it is the larger European countries that show no specialisation in biotechnology compared to the other branches of the chemical industry. The standardised biotechnology RTA for Germany (–0.31), Italy (–0.24), France (–0.03) and the UK (0.01) are negative or very close to zero. By contrast, the standardised biotechnology RTA for the smaller European countries – Denmark (0.41), Ireland (0.23), the Netherlands (0.15), Sweden (0.25), Finland (0.12) and Norway (0.45) – is positive and has a high value. Germany and the UK have dominated the traditional chemicals industry for many years, while Italy and France have also been important world–wide. The RTA results indicate that whereas the larger countries continue to focus their activities on traditional chemicals, smaller European nations have taken advantage of the new opportunities opened up by biotechnology research. Thus, the traditional dominance of the larger European nations in chemicals does not provide them with a critical advantage in the new biotechnology industry.

Table V.3: Standardised Revealed Technological Advantages of European countries in biotechnology, materials, organic chemistry, pharmaceuticals and polymers (97 785 patents in 1987-1996)

(RTA-1)/(RTA+1)					
Country	**Biotech.**	**Materials**	**Organic chemistry**	**Pharma**	**Polymers**
Germany	- 0,31	0,05	0,12	- 0,08	0,07
France	- 0,03	0,08	0,01	0,12	- 0,22
United Kingdom	0,01	- 0,14	0,04	0,16	- 0,37
Italy	- 0,24	- 0,07	0,00	0,09	0,05
Switzerland	- 0,17	- 0,40	0,25	- 0,06	- 0,27
Netherlands	0,15	0,16	- 0,14	- 0,18	0,15
Ireland	0,23	0,02	- 0,30	0,19	- 0,24
Belgium	0,02	0,14	- 0,23	0,06	0,12
Sweden	0,25	- 0,07	- 0,28	0,26	- 0,55
Denmark	0,41	- 0,29	- 0,12	0,06	- 0,80
Spain	- 0,02	- 0,21	0,19	0,05	- 0,54
Austria	0,34	0,19	- 0,19	- 0,10	- 0,16
Finland	0,12	- 0,08	- 0,29	0,01	0,18
norway	0,45	0,42	- 0,30	- 0,14	- 0,54
Greece	0,39	0,02	- 0,31	0,03	- 0,28
Luxembourg	- 1,00	0,31	- 0,24	- 0,14	0,42

Note: Portugal is excluded because it had too few patents.

Source: European Patent Office (1998).

The results shown by Tables V.2 and V.3 are confirmed by simple ratios of the total biotechnology patents over the total number of patents by country of invention. Table V.4 shows that 45.4 % of the total biotechnology patents in the sample were invented in the US and 36.5 % of biotechnology patents invented in Europe. However, in all chemical sectors the US share is 34.5 % while Europe's share is 44.8 %.

Table V.4: Share of patents by region of the assignee, region of the inventor and by sector (10 000 sample patents)

	Country of the assignee		
Country of the inventor	**EU**	**US**	**Total**
All chemical sectors			
EU	86.3 %	9.0 %	44.8 %
US	11.9 %	87.8 %	34.5 %
Total	98.2 %	96.8 %	79.3 %
Biotechnology			
EU	82.1 %	4.9 %	36.5 %
US	14.6 %	92.7 %	45.4 %
Total	96.7 %	96.6 %	81.9 %
Materials			
EU	90.7 %	8.0 %	44.9 %
US	7.8 %	90.1 %	30.9 %
Total	98.5 %	98.1 %	75.8 %
Organic chemistry			
EU	89.1 %	10.8 %	50.8 %
US	9.5 %	87.4 %	28.4 %
Total	98.6 %	98.2 %	79.2 %
Pharmaceuticals			
EU	85.0 %	11.5 %	47.3 %
US	13.3 %	86.2 %	36.0 %
Total	98.3 %	97.7 %	83.3 %
Polymers			
EU	85.4 %	8.3 %	40.1 %
US	12.9 %	84.6 %	33.5 %
Total	98.3 %	92.9 %	73.6 %

Source: European Patent Office (1998).

The data on the R&D laboratories also shed light on the comparative specialisation of European countries in biotechnology. Of the 7 264 chemical R&D labs in the sample, 32 % perform biotechnology research[91]. Smaller countries (Denmark, Finland, Ireland, and the Netherlands) are more focused on biotechnology than the larger countries (Italy, Germany, and France), thus confirming the results seen earlier.

Finally, in Europe about 72 % of the biotechnology laboratories are public (government research institutions, universities, and hospitals). This share is slightly lower in pharmaceuticals (71 %), and much lower in the chemical sectors (40 %). The evidence across countries is mixed. In Finland and in Ireland, 82.9 % and 80.6 % of the biotechnology labs are public. This percentage drops to 67.7 % in Denmark, and to 56.8 % in the Netherlands. It could be said, therefore, that the entry of Finland and Ireland is related to public funding and public research in biotechnology. By contrast, in the Netherlands and to some extent in Denmark, the share of activities in

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[91] Each R&D lab in our sample can perform more than one activity. For example, only one third of the 32 % of labs carrying out biotechnology research perform only biotechnology research. The other two thirds perform research in biotechnology and in one or more other chemical sectors.

biotechnology is more closely associated with private research. No single model emerges. Either private or public research can be the means by which newcomer countries can take advantage of the opportunities opened up by biotechnology.

The data can provide information on the extent to which patent assignees locate research activity in their home country. It is assumed that the locus of the innovative activity is the location of the inventors of the patent and that the location of the patent assignee is given by the nationality of the ultimate owner of the assignee[92]. The results show that, in general, the home country is the preferred location of inventive activities in all countries and sectors; and that biotechnology is a partial exception, with the European countries locating a sizeable share of their inventive activity in the US.

Table V.4 shows that European assignees invent 86.3 % of their chemical patents in Europe and US assignees 87.8 % of their patents in the US. When European companies locate their patenting activity outside Europe, they develop almost all of their “foreign” chemical patents in the US – the total share of patents by European assignees invented either in Europe or in the US is 98.2 %. Thus, the US is the favoured foreign location of the European assignees. Finally, there seems to be a fairly balanced interchange of research between the two continents in chemicals since the share of EPO patents by European assignees invented in the US (11.9 %) is very close to that of the EPO patents by US assignees invented in Europe (9.0 %).

As shown also in Table V.4 this pattern of cross-location between Europe and the US is also similar across the chemical subsectors with biotechnology being the only exception. The result that really stands out is the share of biotechnology patents by US assignees invented in Europe, which is only 4.9 %, while the share in the other direction is 14.6 %, suggesting that the US is an attractive location for biotechnology research by European assignees.

Therefore, the data do not show that European assignees perform a disproportionately large amount of biotechnology research in the US – they do almost as much biotechnology research in the US as they do in the other chemical sectors – but that Europe is not attracting similar levels of biotechnology research by US assignees. Even in pharmaceuticals, which is the closest to biotechnology, Europe attracts 11.5 % of the patents applied for by US assignees. The apparent European lack of attractiveness to US research seems to be specific to biotechnology.

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[92] The need to control for the ultimate owner of the assignees was the reason why the smaller sample of 10,000 patents was used here. It would be very difficult to examine the complete sample of 97 785 patents for the purpose of this Report.

Table V.5: Share of biotechnology patents invented by European assignees in the home country, in the US and in other European countries (sample of 10 000 patents in 1987-1996 in percent)

	Country of the assignee					
Patents	**Switzerland**	**Germany**	**France**	**Italy**	**Netherlands**	**UK**
• **invented in the home country**	30,6	76,2	81,5	73,3	70,7	76,9
• **invented in the US**	48,2	7,6	11,0	4,9	4,4	8,1
• **invented in the other EU countries**	18,4	11,2	4,2	21,8	24,8	12,8

Source: European Patent Office (1998).

Table V.5 shows the shares of biotechnology patents invented by European assignees in their home country, in the US and in European countries other than the home country. The table confirms that the assignees locate research largely in their home country, although inter–country differences exist. The most important difference is that Swiss assignees invent almost half of their biotechnology patents in the US, while assignees from all the other countries in Table V.5 (Germany, France, Italy, the Netherlands, and the UK) invent over 70 % of their biotechnology patents at home. Apart from the US, the latter countries have a sizeable share of biotechnology patents invented in other European countries and, moreover, these patents are not concentrated in the leading nations – Germany or the UK – but are spread across European countries. When Swiss multinationals are excluded from the sample, the share of biotechnology patents by European assignees invented in the US declines from 14.6 % to 11.3 %. This is closer to the similar share for the other chemical sectors presented in Table V.4.

5.1.3. *Division of innovative labour and markets for technology*

The ability of firms to access and make efficient use of markets for technology and networks of collaborative relations has become a crucial source of competitiveness in the new markets for technology (Arora, Fosfuri, Gambardella, 2001; Arora, Gambardella, Pammolli, Riccaboni, 2001). As a consequence, in the last 25 years, collaborations in biotechnology have increased dramatically world-wide (Science and Engineering Indicators, 2000; Orsenigo, Pammolli, Riccaboni, 2001).

The very existence of dedicated biotechnology firms (DBFs) depends on their ability to participate in networks of collaborative relations and markets for technology. Most exploit their basic competence and act primarily as research companies and specialised suppliers of high technology intermediate products, performing contract research for, and in collaboration with, established corporations in downstream sectors. Collaboration allows DBFs to survive and – in some cases – to pave the way for subsequent growth. First, collaboration with large companies clearly provides the financial resources necessary to fund R&D. Second, it provides the access to organisational capabilities in product development and marketing.

The latest generations of DBFs (and the new "stars" like Affymax, Incyte and Celera) were created on the basis of specialisation into radically different new technologies like genomics, combinatorial chemistry, bioinformatics and what is now called "platform technologies". These technologies are essentially research tools and their developers do not aim to become producers but providers of tools and services to corporations involved in drug discovery and development. They may thus be able to sell customised services to a wider range of potential buyers.

Established companies face the opposite problem. While they need to explore, acquire and develop new knowledge, they have the experience and the structures necessary to control testing, production and marketing. Confronted with expanding innovative opportunities, no individual company, irrespective of its size, can consider originating and controlling the whole relevant knowledge on its own. Thus, participation into the network of collaboration and in markets for technology becomes a crucial ingredient for sustained technological and economic performances.

Assessing the involvement of European firms and institutions in these networks is a crucial exercise for an evaluation of the state of the European biotechnology industry.

5.1.3.1. Collaboration across assignees

A review of the multiple assignee patents shows that in biotechnology the share of patents assigned to multiple assignees is higher than in the other sectors. On the basis of the 10 000 patent sample, there are 11.2 % biotechnology patents with multiple assignees against 8.9 % in pharmaceuticals, 5.4 % in organic chemistry, 3.8 % in polymers, and 3.1 % in materials[93]. Biotechnology appears to be more open to collaborations. This is still the case when it is compared to pharmaceuticals which is technologically closer to biotechnology and is a more collaborative field (8.9 % multiple assignee patents) than the other fields in traditional chemicals. Furthermore, the evidence suggests that there are no country–specific factors that could account for this.

5.1.3.2. Collaboration among inventors

Single inventors develop only 18.3 % of the sample's 97 785 chemical patents, the remaining (81.7 %) are developed by two or more inventors. Hence, while there are few patents with multiple assignees, there is a great deal of collaboration among individuals. These teams of inventors are mostly national. Overall, 90.8 % of the patents in the sample developed by multiple inventors refer to inventors from the same country.

To review further the question of the nature and characteristics of research teams in biotechnology patents a sub–sample of 4 649 patents from the EPO sample of 10 000 patents was selected on the basis of their having at least one inventor located in Europe. The focus on inventions carried out in Europe is related to the finding that

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[93] Overall in our sample of 10 000 patents, the share of single assignees is 93.2 %, for the same as in the 97 785 sample. This is suggestive of the comparability of the statistics computed by using either of the two samples. In this case, we are using the 10 000 sample because, as we shall see below, we need to use the information on the country of origins of the ultimate parent of the assignees.

Europe does not appear to be a very attractive location for biotechnology research. It is therefore interesting to understand in greater depth the characteristics of the research located in there.

The data show that single inventors develop 788 patents (16.9 %) and multiple inventors the remaining (83.1 %). Furthermore, there is no major difference across countries or sectors in the size of the research team.

Table V.6 reports the average number of supplementary classes of these patents. Again, this is broken down by sectors and by some leading countries. This table shows that the biotechnology patents by US assignees that were invented in Europe have a significantly higher degree of interdisciplinarity compared to the biotechnology patents by the other countries in the table (Germany, France and the UK). This suggests that the US assignees in Europe patent research outputs with a greater degree of generality compared to the others. The difference is particularly striking with Germany. The average number of IPC classes in German biotechnology patents invented in Europe is 1.8, compared to 2.7 for the US. The figures for France and the UK are respectively 2.4 and 2.5.

Table V.6: Mean number of supplementary classes by patent. Inter-country (country of the assignee) and inter-sectoral differences

Sectors	**Germany**	**France**	**UK**	**US**	**TOTAL**
Biotech	1.8 (0.17)	2.5 (0.18)	2.4 (0.18)	2.7 (0.3)	2.1 (0.08)
Materials	1.2 (0.19)	1.2 (0.31)	1.5 (0.38)	1.5 (0.54)	1.3 (0.13)
Organic chemistry	2.4 (0.07)	2.4 (0.13)	2.7 (0.15)	2.9 (0.21)	2.5 (0.05)
Pharma	1.7 (0.09)	1.2 (0.13)	1.5 (0.14)	1.2 (0.2)	1.6 (0.06)
Polymers	1.8 (0.09)	1.5 (0.19)	1.7 (0.23)	1.6 (0.26)	1.7 (0.07)
Average by country	2.0 (0.05)	1.8 (0.09)	2.0 (0.09)	2.3 (0.12)	2.0 (0.03)

Note: Standard errors in parentheses.

Source: Our elaboration from the EPO data.

The greater interdisciplinarity of the US biotechnology patents might reflect the fact that, for US assignees, patents in Europe are inventions patented abroad. Since patenting abroad is more costly, one may patent abroad only the more important patents, which are likely to be the more interdisciplinary ones. But Table V.6 shows that in biotechnology the US patents are relatively more interdisciplinary compared to other countries than are the US patents in the other sectors. For example, even in pharmaceuticals, which is the sector closest to biotechnology, the average number of IPC classes of the US patents is 1.2 as against 1.7 for Germany, 1.2 for France, and

1.5 for the UK. This suggests that US biotechnology patents invented in Europe may indeed be broader on average. Trajtenberg (1990) suggests that more general patents are also more cited, and they are more valuable. If so, this would indicate that US biotechnology research in Europe play a beneficial role, as US assignees are likely to perform research that leads to more valuable inventions than European assignees.

Finally, there is evidence that large firms are less involved in interdisciplinary biotechnology. This is consistent with the existing literature about this industry, which has stressed that competencies for producing innovations with greater breadth (and value) are often associated with smaller academic labs or smaller research-intensive firms (e.g. see Gambardella, 1995). In other words, it is the quality of the team rather than the size of the organisation that matters in this case. Moreover, biotechnology appears to be a more internationalised research process and this is consistent with the view that, as a modern science-based industry, its knowledge foundations are being developed in different areas on rather "global" basis.

5.1.3.3. Networks of collaborative relations

Table V.7 shows the nationality of origin and development of collaborative agreements (CA) in biotechnology for selected years. A crucial difference between Europe and the US becomes immediately apparent. The overwhelming majority of the biotechnology collaborative projects originate (70.07 %) and are developed (66.12 %) in the US. However, European biotechnology organisations have gradually increased their role both as originators (from about 14 % in 1990-94 to 20 % in 1998-00) and as developers (from 12.46 to 21.61 %) of new projects.

Table V.7: Number of organisations and number of originated and developed collaborative agreements (CAs), by nationality

Nationality		Number of Organizations						Number of CAs			
		EFs		DBF s		PRO s		as originators		as developers	
		No.	%	No.	%	No.	%	No.	%	No.	%
1990-1994											
EU-15	112	41	36,61	36	32,14	35	31,25	274	14,05	243	12,46
US	496	154	31,05	241	48,59	101	20,36	1 463	75,03	1 459	74,82
Japan	25	23	92,00	1	4,00	1	4,00	65	3,33	84	4,31
Other	93	31	33,33	36	38,71	26	27,96	148	7,59	164	8,41
Total	726	249	34,30	314	43,25	163	22,45	1 950	100,00	1 950	100,00
1995-1997											
EU-15	226	89	39,38	95	42,04	42	18,58	510	17,90	553	19,41
US	652	196	30,06	338	51,84	118	18,10	1 989	69,81	1 830	64,23
Japan	47	41	87,23	6	12,77	0	0,00	61	2,14	173	6,07
Other	195	59	30,26	73	37,44	63	32,31	289	10,14	293	10,28
Total	1 120	385	34,38	512	45,71	223	19,91	2 849	100,00	2 849	100,00
1998-2000											
EU-15	447	117	26,17	223	49,89	107	23,94	838	20,19	897	21,61
US	1 124	334	29,72	587	52,22	203	18,06	2 819	67,91	2 629	63,33
Japan	81	64	79,01	8	9,88	9	11,11	119	2,87	212	5,11
Others*	313	78	24,92	151	48,24	84	26,84	375	9,03	413	9,95
Total	1 965	593	30,18	969	49,31	403	20,51	4 151	100,00	4 151	100,00
1990-2000											
EU-15	785	247	31,46	354	45,10	184	23,44	1 622	18,12	1 693	18,92
US	2 272	684	30,11	1 166	51,32	422	18,57	6 271	70,07	5 918	66,12
Japan	153	128	83,66	15	9,80	10	6,54	245	2,74	469	5,24
Others*	601	168	27,95	260	43,26	173	28,79	812	9,07	870	9,72
Total	3 811	1 227	32,20	1 795	47,10	789	20,70	8 950	100,00	8 950	100,00

Note: *Argentina, Australia, Bermuda, Brazil, Canada, China, Costa Rica, Croatia, Cuba, Czech Republic, Egypt, Hong Kong, Hungary, Iceland, India, Indonesia, Israel, Malaysia, Mexico, New Zealand, Norway, Philippines, Poland, Puerto Rico, Russia, Singapore, Slovenia, South Africa, South Korea, Switzerland, Taiwan, Thailand, Yugoslavia.

EFs: established firms; DBFs: dedicated biotechnology firms; PROs: public research organisations.

Source: BID, University of Siena.

In the second half of the 1990s, the number of DBFs rose in Europe but remained substantially unchanged in the US. However, European DBFs are still not as active in the networks of division of innovative labour. Age is not the only factor underlying the lower participation of European DBFs in markets for technology. The background study contends that the following structural differences between Europe and the US may affect the collaborative capabilities of DBFs.

- American DBFs develop a larger share of projects originated by domestic public research organisations (PROs) and DBFs and by European DBFs than their European counterparts. In Europe, DBFs tend to be replaced as developers by established companies. Interestingly enough, the only exception is for projects originated by European PROs, which are developed mainly by co-localised DBFs or by European PROs.

- European PROs increased their relationships with both European and American DBFs in the period 1996-2000. On the contrary, US-based PROs collaborate more and more directly with established companies and act more frequently as developers of projects originated by DBFs. In general, universities and research institutes increasingly reach out and collaborate with delocalised partners both as originators and as developers. European DBFs do not seem to be able to attract US established pharmaceutical companies as developers of projects originated in Europe, and they turn in preference to European partners.

- Only a minority of European DBFs in Europe participates as developers in collaborative projects originated by other organisations. Established companies have the lion's share of bio-pharmaceutical products in Europe.

- European companies tend to access markets for technologies later on during product development (clinical research and marketing), while they are less active in the early stages of research. Product innovation in therapeutic biotechnology is highly dependent on both the originator and developer capabilities of US companies. European DBFs, still young and small, do not take part in the division of innovative labour in product development, particularly with American PROs and established companies.

- Finally, PROs in Europe tend to be focused on the generation of new research opportunities, while they tend to be absent from the downstream stages of product development.

5.2. Characteristics of the new European biotechnology industry

It was suggested in the previous section that European biotechnology is lagging significantly behind the US. However, encouraging signals related mainly to the good performance of some small (mainly northern) European nations and to a recent impressive increase in the number of DBFs was also stressed. This section examines the characteristics of European DBFs.

DBFs are widely considered to be the most efficient available organisational solution for the development of innovative activities in biotechnology:

- First, DBFs are fundamental organisational devices for exploring an enormous, quickly expanding and incredibly complex space of new innovative opportunities.

- Second, they perform a crucial function of transforming fundamental scientific knowledge into technological and commercially valuable knowledge. They intermediate in the transfer of knowledge from universities to established large corporations which cannot be always at the forefront of scientific discovery but which have the downstream capabilities needed for commercialisation (Orsenigo, 1989; Henderson, Orsenigo and Pisano, 1999).

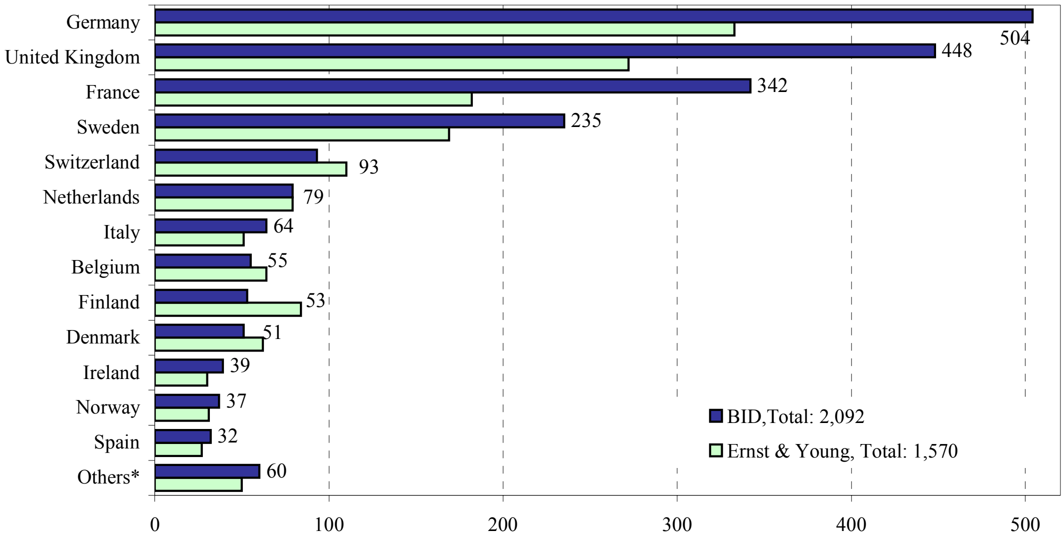
- Third, DBFs promote and are crucial agents in the process of division of labour in innovative activities that emerges in response to the increasingly codified and abstract nature of the knowledge bases on which innovations draw (Arora, Gambardella, 1994; Gambardella, 1995).

5.2.1. *The structure of the industry*

This section uses data from the Biotechnology Information Databank (BID), maintained at the University of Siena, which includes 3669 organisations active in biotechnology. Among them, there are 2092 independent dedicated biotechnology firms (DBFs). More specifically, there are 1730 core biotechnology firms (according to the OECD classification) and 362 specialised suppliers. Detailed data for each of these have been collected.

Graph V.5 shows the number of independent dedicated biotechnology firms in major European countries at the end of year 2000. The data do not consider public research organisations, or companies whose main activities are in fields other than biotechnology, or biotechnology divisions of larger firms. They represent the 'inner core' of the European national systems of innovation in biotechnology. According to the data collected in BID, Germany leads the league with more than 500 small independent dedicated biotechnology firms (DBFs), followed closely by the UK. Taken together, Germany and the UK account for about one half of the total number of DBFs in Europe registered in the database. France ranks third with 343 biotechnology companies, followed by Sweden.

Graph V.5: Number of independent DBFs (December 2000)



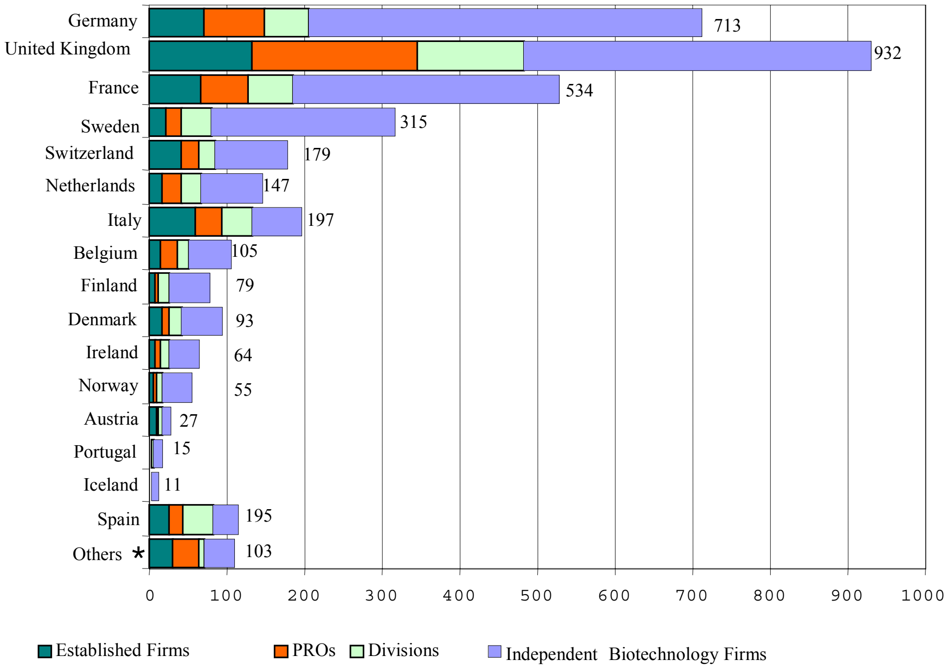
Note: *Others: Austria, Czech Republic, Estonia, Hungary, Iceland, Lithuania, Luxembourg, Poland, Portugal, Romania, Russia, Slovakia.

Source: BID, University of Siena.

If one calibrates the number of DBFs using population or GDP numbers, a clear representation emerges, with Sweden ranked first according to both measures, followed by Switzerland, Ireland, Finland, and Denmark. The UK, Germany and France have similar values, while Italy and Spain have the lowest ratios.

Graph V.6 shows the European biotechnology innovation and production systems in terms of the types of active organisations. There are important differences in the composition of the industry across European countries. In particular, the UK differs from Germany, both because of the high number of divisions of companies focused on biotechnology and because of the higher number of large firms. Moreover, in the UK one observes a higher number of non-industrial research institutes in the fields of molecular biology and biotechnology. In Italy and Spain the number of DBFs is particularly low when compared to the number of large firms or of divisions of large firms.

Graph V.6: Number of organisations active in biotechnology by type (December 2000)

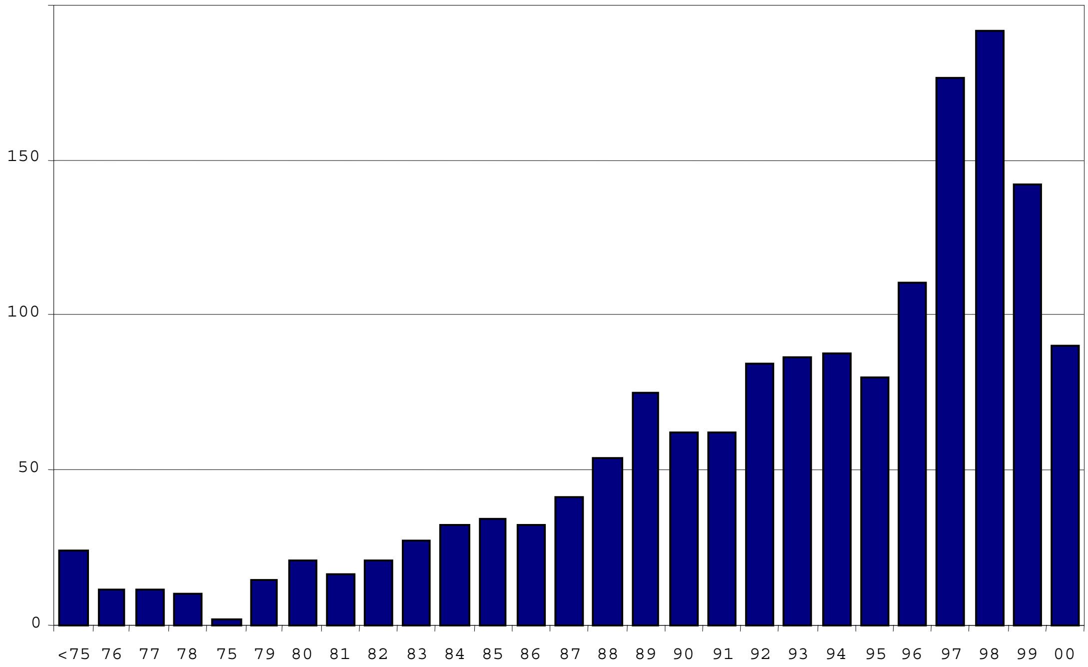


Note: *Others: Czech Republic, Estonia, Hungary, Lithuania, Luxembourg, Poland, Romania, Russia, and Slovakia.

Source: BID, University of Siena.

Graph V.7 shows the distribution of currently existing European DBFs by year of foundation. Peak years of entry were 1997 and 1998. In 1999 and 2000, after a 4–year period of intense entry, in which the overall number of EU biotechnology firms almost doubled, the rates of company formation decreased. This slowdown is not corroborated by the Ernst & Young data. If it were confirmed, it could be similar in nature to the one observed in the US at the beginning of the Nineties and it could prefigure a period of stabilisation, consolidation, and selection, with mergers, acquisitions, and exit offsetting new company formation. As a consequence, the impact of intense entry on the long–term evolution of the industry is not known, and the industry seems to be far from any equilibrium configuration.

Graph V.7: European dedicated biotechnology firms: Distribution by year of foundation (firms per year)



Source: BID, University of Siena.

Table V.8 shows the distribution of currently existing dedicated biotechnology companies in Europe, by cohorts of entrants. It is clear that there are important differences in terms of the generational composition of DBFs in major European countries. Nordic countries like Sweden have experienced a relatively stable pace of entry of new firms, while in other countries, particularly Germany, the upsurge of the number of new firms has occurred in the last five years. At present, Germany accounts for a third of the total number of new European firms (i.e. those which entered the industry after 1995), followed by UK and France. The three countries, taken together, account for more than three quarters of the new biotechnology firms that entered the industry between 1996 and 2000.

Table V.8: European dedicated Biotechnology Firms: distribution by cohorts of entrants

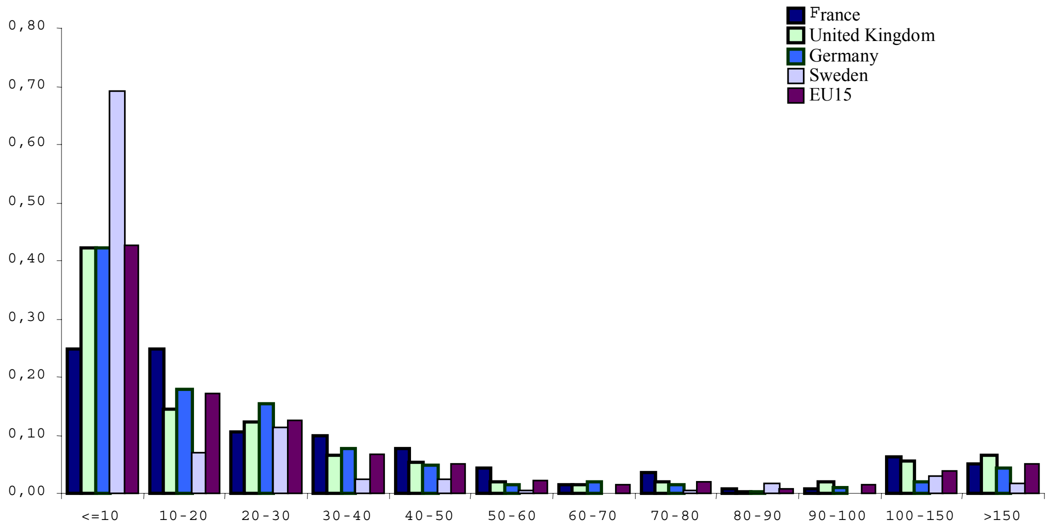
	EU-15		**United Kingdom**		**Germany**		**France**		**Sweden**		**Others***	
	No.	**%**	**No.**	**%**	**No**	**%**	**No.**	**%**	**No.**	**%**	**No.**	**%**
below 91	600	31,09	147	32,81	102	20,24	112	32,18	89	37,87	150	37,97
91-95	487	25,23	113	25,22	114	22,62	86	24,71	61	25,96	113	28,61
above 95	843	43,68	188	41,96	288	57,14	150	43,10	85	36,17	132	33,42
Total	1930	100,00	448	100,00	504	100,00	348	100,00	235	100,00	395	100,00

Note: *Others: Austria, Belgium, Denmark, Finland, Ireland, Italy, Luxembourg, Netherlands, Portugal, and Spain

Source: BID, University of Siena.

Graph V.8 shows the size distribution of European DBFs, in December 2000, divided into classes according to the number of employees. As is evident, most European DBFs are either micro or small research–intensive firms. Only approximately 10 percent of active European DBFs have more than 50 employees, while the majority (about 57 %) has less than 20 employees94. It is worth noting that despite general similarities in the shape of business size distributions, European national systems of innovation in biotechnology rely on quite different mixtures of small and medium biotechnology companies. Surprisingly enough, when compared to general figures about business firm size in manufacturing, the size of French DBFs is well above the mean for EU–15, while the opposite is true for Sweden. Moreover, while UK and Germany look similar in terms of shares of micro business units in the total number of firms active in biotechnology, Germany has a higher proportion of firms in the middle size range (10 to 50 employees), compared to the UK, which relies upon a higher number of medium and large DBFs.

Graph V.8: European Dedicated Biotechnology Firms: distribution of employment by size class



Source: BID, University of Siena.

The sustained flow of entry shown in Graph V.7 has changed the relative importance of agri–food and pharmaceuticals as areas of application. The share of new DBFs that entered the agri–food industries declined from 1995, from about 15 % to less than 5 % in the year 2000; this fall is likely to reflect regulatory factors and growing public opposition to genetically-modified crops. During this time, the number of dedicated biopharmaceutical companies rose from 35 % to more than 50 % of the

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[94] Presumably, the real number of small biotechnology companies is even higher. In particular, some of the youngest firms have barely enough people to run early-stage research activities, not revealing themselves through alliances, venture capitalist, company Internet sites, participation in public programs, surveys, directories and the like. Moreover, the BID also includes about 40 virtual companies (0 employees), concentrated mainly in Sweden. Virtual companies have been excluded from the analyses discussed in this chapter.

total number of new firms. Thus, the dramatic increase in the number of European DBFs from 1996 to 2000 reflects, to a large extent, the entry of new DBFs that entered the industry to exploit the therapeutic application of genomics and new techniques, such as combinatorial chemistry and bio-informatics, which can be used to improve and speed up the development of new therapeutic treatments.

Table V.9 summarises the technological profiles of EU DBFs according to broad areas of interest in biology, chemistry and medicine. It shows the existence of differences among European countries concerning the areas of specialisation of national DBFs in main fields of application.

Table V.9: European Dedicated Biotechnology Firms: distribution by areas of activity

Country	Therapeutics		Diagnostics		Agriculture		Food		Veterinary		Environnent		Total	
	No.	**%**	**No.**	**%**	**No.**	**%**	**No.**	**%**	**No.**	**%**	**No.**	**%**	**No.**	**%**
EU-15	809	40,03	415	20,53	282	13,95	228	11,28	137	6,78	150	7,42	2021	93,35
Germany	221	44,56	123	24,80	63	12,70	35	7,06	27	5,44	27	5,44	496	22,91
United Kingdom	185	39,36	96	20,43	55	11,70	45	9,57	31	6,60	58	12,34	470	21,71
France	150	35,05	68	15,89	77	17,99	73	17,06	39	9,11	21	4,91	428	19,77
Sweden	79	48,77	22	13,58	21	12,96	10	6,17	17	10,49	13	8,02	162	7,48
Switzerland	35	53,85	14	21,54	9	13,85	4	6,15	3	4,62	0	0,00	65	3,00
Italy	37	34,58	22	20,56	18	16,82	19	17,76	3	2,80	8	7,48	107	4,94
Other	30	37,97	16	20,25	4	5,06	14	17,72	10	12,66	5	6,33	79	3,65
Total	**874**	**40,37**	**445**	**20,55**	**295**	**13,63**	**246**	**11,36**	**150**	**6,93**	**155**	**7,16**	**2165**	

Note: Other: Czech Republic, Estonia, Hungary, Iceland, Lithuania, Norway, Poland, Portugal, Romania, Russia, and Slovakia.

Source: BID, University of Siena.

German biotechnology companies are active mainly in human health care (therapeutics and diagnostics), Swedish firms concentrate on human and animal therapeutics, while France, Italy, and Switzerland have a higher proportion of companies active in agri-food. A large proportion of French and German DBFs entered the industry, both in pharmaceuticals and agri-food, to explore the commercial value of recent technological advances at the lowest levels of the organisation of the living organisms in genomics, proteomics and bioinformatics. The UK keeps a strong technological basis in cell and tissue engineering, process biotechnology, instrumentation, and devices. Moreover, new UK DBFs are more active in combinatorial chemistry and in other general–purpose research techniques applied to drug discovery and development. Italy's specialisation is in targeting sub–cellular organisms, while Swedish companies tend to focus mainly on manufacturing of biomaterials and on innovative technologies in drug discovery, such as combinatorial chemistry and chiral synthesis.

Table V.10: European Dedicated Biotechnology Firms: distribution by technological field

Country	Cell and Tissue Culture and Engineering		Subcellular Organisms		DNA		Proteins and Molecules		Process Bio-technology		Chemical Synthesis[1]		Bio-informatics		Other Devices[2]		Analysis[3]		Total	
	No.	**%**	**No.**	**%**	**No.**	**%**	**No.**	**%**	**No.**	**%**	**No.**	**%**	**No.**	**%**	**No.**	**%**	**No.**	**%**	**No.**	**%**
EU 15	436	18,72	189	8,12	349	14,98	504	21,64	218	9,36	177	7,60	126	5,41	233	10,00	97	4,16	2329	92,53
Germany	93	14,03	60	9,05	114	17,19	170	25,64	38	5,73	62	9,35	44	6,64	50	7,54	32	4,83	663	26,34
United Kingdom	117	22,90	30	5,87	60	11,74	87	17,03	53	10,37	34	6,65	25	4,89	88	17,22	17	3,33	511	20,30
France	82	16,94	41	8,47	85	17,56	107	22,11	61	12,60	36	7,44	30	6,20	24	4,96	18	3,72	484	19,23
Sweden	47	26,26	7	3,91	20	11,17	24	13,41	14	7,82	20	11,17	12	6,70	19	10,61	16	8,94	179	7,11
Switzerland	25	22,32	5	4,46	11	9,82	17	15,18	11	9,82	4	3,57	7	6,25	27	24,11	5	4,46	112	4,45
Italy	24	21,24	16	14,16	13	11,50	18	15,93	16	14,16	8	7,08	3	2,65	14	12,39	1	0,88	113	4,49
Other[4]	16	21,05	4	5,26	13	17,11	19	25,00	8	10,53	4	5,26	5	6,58	5	6,58	2	2,63	76	3,02
Total	**477**	**18,95**	**198**	**7,87**	**373**	**14,82**	**540**	**21,45**	**237**	**9,42**	**185**	**7,35**	**138**	**5,48**	**265**	**10,53**	**104**	**4,13**	**2517**	

Notes:
1. Chemical Synthesis: Includes Combinatorial Chemistry, Chiral Chemistry, Molecular Synthesis.
2. Others Devices: Includes Medical Equipment, PCR.
3. Analysis: Environmental and Agri-Food Test.
4. Other: Czech Republic, Estonia, Hungary, Iceland, Lithuania, Norway, Poland, Portugal, Romania, Russia, Slovakia.

Source: BID, University of Siena.

Finally, Table V.10 shows the extent to which biotechnology applications and research technologies are integrated at the firm level in key European countries. French and British companies have the highest degree of integration between technologies and applications. The higher level of integration of UK firms could well reflect a difference in the composition of industry in terms of cohorts of entrants, since the UK has a higher fraction of early entrant DBFs, which had sufficient time to implement their technologies in specific domains of application.Conversely, German firms and a significant fraction of Swedish firms, in particular, tend to be vertically specialised either in terms of technologies or domains of application.

5.3. Geographical clusters in European biotechnology

5.3.1. Clustering

In the US, biotechnology has been characterised, historically, by a relatively high concentration of firms, employment and activities in a restricted number of regions, mainly in San Diego, the Bay Area, Boston, Seattle, New Jersey, the New York metropolitan area and the Houston area in Texas. Based on this, economists, analysts and policy–makers have argued that spatial concentration of innovative and industrial activities is fundamental for successful development of biotechnology. To this effect, policies have been devised (e.g. the German BioRegio Program) with the explicit aim of supporting not so much the birth of new DBFs but rather the development of clusters of biotechnology activities.

Why is such concentration observed? As this is fundamentally a science-based technology, involving abstract and codified knowledge, it should in principle be available to everybody. What forces lead to the agglomeration of biotechnology activities in specific clusters? Different explanations have been suggested.

- The (partially) tacit nature of knowledge means that personal contacts, imitation and frequent interactions are necessary for knowledge transmission. These are clearly possible at lower cost for firms located within the same city or region. The transmission of tacit knowledge requires mutual trust, a sharing of language and culture and intense non-business relations are aspects which are made easier by co-location.

- Discoveries in this technological area are characterised by high degrees of natural excludability, i.e. techniques for their replication are not widely known and anyone wishing to build on new knowledge must gain access to the research team or laboratory setting having that know–how. In these circumstances, inventor–scientists tend to enter into contractual arrangements with existing firms or start their own firm in order to extract the supranormal returns from the fruits of their intellectual contribution. And they tend to do so within commuting distance of their laboratories.

- However, empirical evidence suggests that there might be a threshold effect: local sources of knowledge are key in determining success in the development of new products and processes only in areas with a large accumulation of knowledge (Silicon Valley). Innovations by firms located in other areas depend on distant relationships with universities and other high–technology firms (suppliers and customers) located elsewhere, especially in urban centres.

Trying to draw some conclusions from this discussion, it would appear that clustering might be the outcome of different factors, but mainly:

- the existence of a strong critical mass of scientific knowledge, in absolute terms: in other words, excellence in scientific research is a basic precondition for attracting innovative activities. Where this is lacking, firms (incumbents and/or prospective entrepreneurs) might look for other locations for tapping the relevant knowledge. Moreover, diversity is also important. Insofar as innovation rests on the integration of different fragments of knowledge, the presence of a diversified scientific base becomes a key issue.
- The existence of a strong and diversified industrial base, with accumulated capabilities and organisational structures enabling them to actually participate in the network of cognitive and social relationships that are necessary to get access to, absorb and integrate the new knowledge and, on these bases, to engage in successful innovative activities.
- The existence of specific and often formal organisational devices (including markets for know-how) that allow flows of knowledge to take place.

5.3.2. Geographical concentration of biotechnology in Europe: Evidence from patent data

Table V.11 shows the regional distribution of the 4 649 patents invented in Europe from our sample of 10 000 chemical patents and lists the top 20 among the 146 European regions[95].

The top 20 regions (13.7 % of the total number of regions) account for 77.5 % of the sample of chemical patents invented in Europe. The top 10 regions (6.8 % of the total) host 59.5 % of these patents. The distribution of chemical patents across European regions is highly concentrated[96].

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[95] Based on the Eurostat classification at the NUTS1 and NUTS2 level.

[96] Paci and Usai (1998) and Caniels (1999) report similar results for total patenting activity in Europe.

Table V.11: Distribution of patents across European regions (region of the inventor): cumulative frequencies and Herfindahl index. top 20 regions (10 000 patent sample in 1987-1996)

Biotechnology		Materials		Organic chemicals		Pharmaceuticals		Polymers	
Regions	Cum. Freq.	Regions	Cum. Freq.	Regions	Cum. Freq.	Regions	Cum. Freq.	Regions	Cum. Freq.
South East Engl. (UK)	8,6	Nordrhein-Westfalen (D)	14,3	Nordrhein-Westfalen (D)	15,3	Nordrhein-Westfalen (D)	12,9	Nordrhein-Westfalen (D)	20,8
Île de France (F)	15,9	Hessen (D)	22,3	Hessen (D)	24,9	Île de France (F)	23,7	Rheinland-Pfalz (D)	33,9
Bayern (D)	21,5	Île de France (F)	29,0	Rheinland-Pfalz (D)	34,4	South East Engl. (UK)	31,5	Hessen (D)	40,5
Hessen (D)	26,9	Rheinland-Pfalz (D)	34,4	Switzerland	42,2	Hessen (D)	37,0	Switzerland	44,2
West-Nederland (NL)	31,5	West-Nederland (NL)	39,3	South East Engl. (UK)	49,5	North West Eng. (UK)	41,7	Rhône-Alpes (F)	47,9
Switzerland	35,6	North West Eng. (UK)	43,8	Île de France (F)	55,7	Switzerland	46,2	Lombardia (I)	51,5
Eastern (UK)	39,5	Vlaams Gewest (B)	47,8	Lombardia (I)	59,8	Lombardia (I)	50,5	Île de France (F)	54,8
Nordrhein-Westfalen (D)	42,9	Baden-Württemberg (D)	51,8	Sachsen-Anhalt (D)	62,6	Rheinland-Pfalz (D)	54,6	Sachsen (D)	57,6
Københavns amt (DK)	46,2	Sachsen (D)	55,4	Rhône-Alpes (F)	65,5	West-Nederland (NL)	57,7	West-Nederland (NL)	60,4
Baden-Württemberg (D)	49,2	Zuid-Nederland (NL)	58,5	Sachsen (D)	68,2	Baden-Württemberg (D)	60,4	Zuid-Nederland (NL)	62,9
Niedersachsen (D)	52,0	North East Eng. (UK)	61,6	Baden-Württemberg (D)	70,9	Sachsen-Anhalt (D)	62,7	Sachsen-Anhalt (D)	65,4
Vlaams Gewest (B)	54,5	Bayern (D)	64,3	Bayern (D)	73,0	Bayern (D)	65,1	North West Eng. (UK)	67,9
Ostösterreich (A)	56,6	Niedersachsen (D)	67,0	West-Nederland (NL)	75,1	Berlin (D)	67,3	Vlaams Gewest (B)	70,1
Rhône-Alpes (F)	58,6	Sachsen-Anhalt (D)	69,2	Vlaams Gewest (B)	77,2	Vlaams Gewest (B)	69,3	Bayern (D)	72,3
Berlin (D)	60,4	Rhône-Alpes (F)	71,4	Sachsen (D)	78,7	Eastern (UK)	71,2	Région Wallonne (B)	74,4
Lombardia (I)	62,2	South East Engl. (UK)	73,7	Alsace (F)	80,2	Lazio (I)	73,0	Emilia-Romagna (I)	76,4
Alsace (F)	63,8	Ostösterreich (A)	75,0	Eastern Eng. (UK)	81,5	Rhône-Alpes (F)	74,7	Baden-Württemberg (D)	78,3
Uusimaa (FIN)	65,5	Bruxelles (B)	76,3	Berlin (D)	82,9	Hamburg (D)	75,9	South East Engl. (UK)	80,1
Stockholm (S)	67,1	Région Wallonne (B)	77,7	Scotland (UK)	83,9	North East Eng. (UK)	77,1	Niedersachsen (D)	81,5
Comunidad de Madrid (E)	68,6	Haute-Normandie (F)	79,0	Cataluña (E)	84,7	Sachsen (D)	78,2	Bruxelles (B)	82,9
Herfindahl index	**0,03**		**0,05**		**0,07**		**0,05**		**0,08**

There are many German regions among the top 20, ranging from five in biotechnology to nine in pharmaceuticals. This is consistent with the well–known leadership of Germany in chemicals, although the smaller number of German regions among the top 20 regions in biotechnology confirms earlier remarks about its lower specialisation in this field. Other studies show that, in general, many of the most innovative European regions are in Germany (Paci and Usai, 1998). Overall, 52 % of the patents invented in the top 20 regions were invented in Germany, followed by France (with 13.8 % of the patents in the top 20 regions), the UK (13.8 %), the Netherlands (5.3 %) and Italy (4.6 %).

Although the data in Table V.11 show that patenting concentrates geographically in all five chemical branches, biotechnology shows the least geographic concentration. In the sample, the top 20 regions account for 68.6 % of the biotechnology patents invented in Europe. There are some regions that appear in all five listings in the top 20 positions. These are South–East England, Île de France, Bayern, Hessen, West-Netherland, Nordrhein-Westfalen, Baden-Württemberg, Vlaams Gewest and Rhône-Alpes. There are other regions, such as Rheinland-Pfalz and Sachsen, which are in the top 20 in all the chemical sectors, except in biotechnology.

There are also regions that are ranked in the top 20 in biotechnology, but that are not among the top 20 in any of the other four chemical fields. This suggests a peculiarity of biotechnology within the overall chemical sector, and in particular that biotechnology is a technology which facilitates the entry of new actors. Specifically, it is opening up opportunities for regions that have not been active in developing innovations in the traditional branches of the chemical sector, including pharmaceuticals. The new regions in our top 20 for biotechnology are Københavns in Denmark, Uusimaa in Finland, Stockholm in Sweden, and the area around Madrid in Spain. This suggests that biotechnology offers opportunities for new entries in technologically dynamic fields.

5.3.3. *Clusters of biotechnology activities in Europe*

Data on firms and research centres in the BID database permit identification of the principal biotechnology clusters in Europe. These are presented in the detailed Annex-Graphs V.1 to V.6. The data show that a process of clustering is taking place in Europe where a small number of local clusters are capturing a dominant majority of biotechnology firms and of public research organisations.

Some of these clusters (i.e. Oxford, Cambridge, Munich and Stockholm) are older and can rely upon sound research background and high international reputation, coupled with a critical mass of both young and established spin–off companies and international contacts. Other biotechnology clusters – the Medicon Valley between Copenhagen and Lund, the German bio-regions of Rhine/Neckar and Rhineland, and French districts – are younger. They took off during the 1990s, mainly thanks to a supportive policy environment, availability of public and private finance, new infrastructures, the presence of large companies active in related downstream industries and institutes of research in biomolecular biology, biomedical sciences and biochemistry. Biotechnology activities in Germany, UK, France, Sweden and Switzerland are concentrated in a handful of clusters. Apparently, most of the factors that contribute to the growth of the national systems of innovation and production in biotechnology are local in nature. Annex Graphs V.1 to V.5 provide a descriptive atlas of biotechnology regions in Europe.

- In the UK, British DBFs are clustered in East Anglia (Cambridge), south-east England (Oxfordshire, Greater London, Surrey), and Central Scotland – see Annex Graph V.2. In particular, most of the activities around the Oxford and Cambridge campuses as well as within the City of London are to be found within a radius of 10 kilometres. In addition to the university, Oxford includes other prestigious research organisations and hospitals (John Radcliffe Hospital, AEA Technology, MRC Radiobiology Institute, and Wellcome Trust Human Genetics Center). Also, a number of well-known Oxford spin–offs are located along the A34 corridor from Oxford to Didcot (i.e. Oxford GlycoSciences, Oxford Asymmetry, Powderject Pharmaceuticals).

- Around the university campus in Cambridge are located other leading institutes (Laboratory of Molecular Biology, the Babraham Institute, the Sanger Centre, and the European Bioinformatics Institute) as well as 27 % of UK DBFs with a large variety of technological and business profiles.

- A large variety of actors – public research organisations (Imperial College, Medical Research Council, University College), research hospitals (Guy's and St Thomas' Hospital), venture capitalists, headquarters of the main pharmaceutical and chemical enterprises and new biotechnology firms – are located in London.

- On 20 November 1996, the German Federal Ministry for Education, Science, Research and Technology announced the three winners of the BioRegio contest. Munich, Rhine/Neckar and Rhineland received an extra DM 50 million of federal funding over the next five years and at least the same amount from industry. Also as a consequence of this program, German DBFs tend to be located in Bayern, Baden–Württenberg, Rheinland-Pfalz, Nordrhein–Westfalen, and Berlin (see Annex Graph V.3). Many of the new DBFs benefited from the BioRegio program and located their activities close to leading institutes of research. The key Swiss clusters are Basel and Zurich. All these clusters emerged in the last five years, thanks to both strong public and private support and world–class local research institutes, particularly in small molecule discovery and computational chemistry.

- Annex Graph V.4 shows the high concentration of French biotechnology firms in Paris, the second largest cluster in terms of number of DBFs in Europe after Cambridge (Mytehlka, Pellegrin, 2001). According to BID data, about 30 % of French biotechnology firms are located in Paris trailed by a group of French regions (Alsace, Rhone–Alpes, Midi Pyrennees, Auvergne, Bretagne and Aquitaine) that have been catching up in the last five years (see France Biotech, 2000). Here again, in a 10 km^2 area one can find a heterogeneous set of both public and private biotechnology organisations.

- Finally, Annex Graph V.5 shows two large Nordic clusters. The Novum Biopark in Stockholm is closely related to the Karolinska Institute Complex, which has a long tradition of excellence in medical and biological fields. The southern one is called Medicon Valley and grew up between Copenhagen and Lund–Malmö, especially after the construction of the bridge between Denmark and Sweden. Almost all biotechnology firms in Sweden are located in four major regions: Stockholm-Uppsala, Skåne - which is the southern region including Lund and

Malmö- Gothenburg and Umeå (Vinnova, 2000), while in Denmark they are highly concentrated in the Sjælland Island.

- Other fast-growing clusters are in Finland (Helsinki, Turku, Tampere, Kuopio, Oulu), in the Netherlands (Zuid-Holland Region) and in Lombardia (Milan).

This data review suggests two remarks. First, clustering would seem to be strongly related to the presence of heterogeneous and interconnected prestigious research institutions. And, secondly, the main clusters are not simply characterised by dense internal or local relations, but also by the ability to establish strong and varied external ties with other clusters.

European clusters such as Cambridge, Oxford and Karolinska show a remarkable degree of organisational heterogeneity and internal interconnectivity, comparable to that which characterises the most important clusters in the US. The Swedish collaborative network presented in Annex Graph V.6 shows the central role of the Karolinska complex (Karolinska Institute and KaroBio) in the middle between the Astra and Pharmacia stars of international contacts. The most important cluster of Swedish biotechnology firms around Karolinska is brought into closer connection by diverse organisations located outside Sweden. The density of the Swedish national innovation network is greatly increased by the inclusion of diverse organisations from other geographical locations. Moreover, the Swedish picture emphasises the central role that small science–based firms can play in reaching out to other areas.

This model suggests that successful systems of innovation in biotechnology appear to grow from “old” regional clusters, developed around the strength of scientific expertise, the integrative capabilities of established pharmaceutical companies, and the dynamic role of small firms. These clusters have become over time both internally denser and much more outward–oriented.

In the second model of EU clusters (many French and Germans regions) networking is not yet developed to the same extent. They seem to lack interdisciplinary teams and the connections across stages of the R&D process that dense webs of local relations among hospitals, university labs and firms make possible. These difficulties, together with the centralisation and bureaucratisation of some of the relevant evaluation and selection processes, could constitute an inherent element of fragility for some of the younger clusters in continental Europe.

The tendency towards clustering is accompanied by a parallel process of increasing openness of the original clusters, a process also noted in the US. Recent trends suggest a combination of an increasing number of collaborations and a decreasing proportion of local connections (Owen-Smith, Riccaboni, Pammolli, Powell, 2001).

5.4. Institutional factors affecting Europe’s industrial competitiveness in biotechnology

The commercial development of European biotechnology, as already indicated previously, is lagging significantly behind the US. Despite encouraging signs of dynamism – especially by the small Northern European countries – and a wave of entries of new DBFs – especially in Germany – innovative activities remain far below US levels. European companies make significant use of American research while US firms do not seem to make as much use of European research. The new

European DBFs are much smaller than their American counterparts, much less active in the global network of collaborative relations and in the markets for technology, and mainly present in platform technologies.

One explanation for this may be that US firms enjoy first–mover advantages. In technologies where innovative activities are often characterised by increasing returns, first–mover advantages are an important phenomenon and are likely to provide long–lasting and difficult-to-erode leadership. European DBFs may have simply been pre-empted by their American counterparts, while the excellence of the American scientific research system has attracted financial and human resources from all parts of the world, further strengthening the US leadership in biotechnology. However, other variables have likely played a role. With biotechnology being fundamentally science–based and characterised by rapid innovation, it is possible that, at least partially, first–mover advantages may not be sustainable. Under these circumstances, catching–up and forging ahead – at the firm and country level – might be possible.

This section reviews some major institutional determinants of industrial competitiveness in biotechnology that might have hindered the development in Europe. In particular, the role of the following variables, known to contribute to competitiveness and growth in biotechnology and in the life sciences, will be examined:

- The size and the structure/organisation of the biomedical education and research systems;
- Basic institutions governing labour markets for skilled researchers and managers, as well as corporate governance and finance;
- Intellectual property rights and patent law, with particular reference to their role in the functioning of markets for technologies.

5.4.1. *The structure of the research system*

5.4.1.1. Funding

Biomedical research is expensive and public money always played an important role in supporting this field. With the advent of biotechnology the cost of research increased further, thus making a strong support even more necessary in maintaining high quality competitive research.

Molecular biology was developed predominantly in the US and in the UK, even though significant research groups were active in many other European countries. After World War II, US support for research in life sciences literally exploded. Public funding of biomedical research in the post–war period increased dramatically in Europe as well, but total spending remained significantly lower than in the US. The sheer size of resources devoted to biomedical research in the US in the post–war era explains much of the American leadership in life sciences.

Table V.12 provides an indication of the relative importance of public funding for biotechnology in OECD countries other than the US. In absolute PPP$ terms Germany spends the most on biotechnology, followed by the UK and France. The median contribution of government budgets dedicated to biotechnology is 3.5 %, with a considerable spread, ranging from 0.4 % in Italy to 13.8 % in Belgium, 10.1 % in Canada and 8.1 % in Finland.

Table V.12: Public funding of Research and Development in biotechnology (1997)

	Biotechnology R&D	**Total Government Budget Appropriations or Outlays for R&D (GBOARD)**	**R&D Biotech/R&D Overall**
	Million PPP$		**%**
Austria	16.8	1 146.5	1.5
Belgium	181.7	1 314.0	13.8
Canada	261.4	2 581.0	10.1
Denmark	45.2	945.6	4.8
Finland	94.5	1 165.0	8.1
France	560.0	12 683.1	4.4
Germany	1 048.2	15 595.7	6.7
Greece	6.5	430.9	1.5
Iceland	0.9	68.5	1.3
Ireland	15.0	229.9	6.5
Italy	32.1	7 329.6	0.4
Netherlands	78.0	3 069.9	2.5
Norway[1]	26.8 - 32.2	880.3	3 - 3.7
Portugal	19.2	781.9	2.5
Spain	15.5	3 202.6	0.5
Sweden[2]	65.6	1 795.2	3.7
Switzerland[2]	16.4	1 379.7	1.2
United Kingdom	705.1	9 055.7	7.8

Notes
1. These data are national estimates, hence the range.
2. GBOARD has been estimated.

Source: OECD, based on data from the European Commission (*Inventory of public biotechnology R&D programmes in Europe*, 2000), Eurostat, Statistics Canada, and national sources.

In the US, the funding of human health research has been traditionally attributed to the National Institutes of Health in Bethesda, Maryland. Every year the NIH Grants Office deals with thousands of applications from all over the World, which are evaluated with a peer- review system. In 1998 the budget for funding extramural research (NIH has is own direct funding system for intramural research which is about 40 % of the extramural budget) was of $ 8 billion. President Clinton took the commitment to double this budget for the year 2003. Thus, for the fiscal year 2000, NIH invested about $ 13.5 billion to fund 50 000 research projects world-wide.

On the other hand, the total budget of the 5th EU Framework Programme (1998-2002) is of about € 15 billion, comparable to the NIH budget for one year. Of this total, the amount of money dedicated to the Programme Quality of Life is € 2.4 billion. One must consider that this Programme is only partially devoted to biotechnology. The first prevision for the total budget of the 6th Framework Programme (2002-2006) is of € 17.5, i.e. exactly equal to the NIH budget for the year 2003 at the present exchange rate.

The total EU budget for research is only 4-5 % of the total research budget of all European nations together. The EU strategy has focused on supporting co-operative projects among EU Member States, the exchange of researchers, and the promotion of quality research in the most disadvantaged EU Member States. Recently, the European Commission introduced the new European Research Area concept and proposed a number of very large multi-centric projects for the next 6th Framework Programme, such as the Integrated Projects, the Centres of Excellence or the Clinical Trial Platform. This last project is aimed at supporting the development of new interventions against HIV/AIDS, malaria and tuberculosis in developing countries.

5.4.1.2. The institutional structure of research

The institutional structure of research – and of biomedical research in particular – evolved differently in continental Europe compared to the US (and partly to the UK).

- The structure of the funding system and the strategies of the funding agencies are crucially important. In the US, most of the funding is administered through the National Institute of Health (NIH). There is substantial integration between the production of biological knowledge concerning the nature and mechanisms of human diseases, clinical research, medical practice, and the discovery and development of new therapeutic treatments; and significant support towards fundamental science in universities and public research centres, widely disseminated through publication in the refereed literature. Moreover, the US system is characterised by a variety of sources of funding and selection mechanisms, which complement the role of the NIH and act according to different allocation principles (see Owen-Smith et al., 2001) Overall, the US research system achieves efficiency through competition among research units providing room, at the same time, for diversity and institutional flexibility.

- In Europe, funding tends to be administered mainly at national level, with strongly differentiated approaches and wide differences across countries. This is likely to have hindered the development of a critical mass, especially in smaller countries. In many cases, resources have either been spread over a large number of "small" laboratories, or they have been excessively concentrated in the few available centres of excellence. Funding from the various European programmes has only partially changed the situation. The absolute size and the higher degree of integration of the US research system, as opposed to the fragmented collection of national systems in Europe, amount to a fundamental difference.

5.4.1.3. The organisation and structure of universities

The US system is highly decentralised. Even public universities rely on diverse sources for funds, including state and national governments, foundations and corporate supporters, tuition revenues, and alumni gifts. Private universities, especially elite ones, are also supported by generous endowments.

The organisation of research and teaching has characteristics that facilitate flexibility and decentralisation but also integration of research. In the US and the UK, academic departments have long been the main organisational entities, while in Europe a single professor dominates. The departmental structure makes it easier to respond to the emergence of new disciplines, like computer sciences and biotechnology, both by integrating them into curricula in conventional programmes and/or by creating new departments and programmes.

It is possible to argue that the European model is characterised a high degrees of division of labour and specialisation between teaching and research institutions, whereas in the US the dominant model of post-graduate students being exposed to and trained to undertake scientific research within teams made up by students and professors within departments has been a more integrated one. In Europe, this separation might have had negative effects on both the quality of research and on the ability of academic institutions to interact with industry.

Despite national distinguishing characteristics, the structure of research systems in Europe is profoundly different from the Anglo–Saxon model.

- First, in Europe financing is considerably more centralised and, consequently, it entails more hierarchical control.

- Second, research institutions are far less interdisciplinary and flexible. In Germany, for example, a number of the highly prestigious Max Planck institutes are organised hierarchically around a single field, such as biochemistry, genetics, or immunology.

- Third, the integration of teaching with research has progressed far less than in the US (and, to some extent, the UK). Ph.D degrees are a relatively recent innovation in many continental European countries, and research has tended to be far more removed from teaching than in the US. Thus, for example, the diffusion of molecular biology into the general training in many European countries is a relatively recent phenomenon as compared to the US, and it has become only recently a standard part of the curricula of pharmacologists, pathologists and medical consultants, and plant biologists.

5.4.1.4. Diversity and integration among publicly-funded research organisations (PROs)

The research systems in the US and Europe are organised in qualitatively different ways and, hence, any comparison must be sensitive to differences in multiple dimensions.

Large and densely interconnected networks composed of tight, repeated interconnections among a diverse set of PROs characterise the US. Elite universities (Harvard, MIT), research institutes (the Dana-Farber Cancer Center), and hospitals (Brigham and Women’s and Massachusetts General) play central roles in innovative collaborations both within Boston and across US regions. In contrast, for example, the French and German national clusters show organisational homogeneity, do not include hospitals and have no identified universities97. The UK has a somewhat higher degree of organisational diversity, reflected in the presence of both government and non–profit research and funding agencies. Closely–knit regional networks such as those found in Boston help account for the global centrality of American PROs. Connections across US regions linking geographically dispersed universities to the National Institutes of Health illustrate a public research system that also reaches across regions and organisational forms.

The evidence suggests that national specialisation in Europe falls along scientific lines. In the US, there is abundant regional clustering but, unlike in the European case, agglomeration is not driven by scientific specialisation. Points of excellence develop in both the US and European systems, but in Europe those clusters are limited to narrower specialities and specific nations. The US represents a very different profile, characterised by diverse, substantively generalist research organisations connected both within and across key regional clusters[98] (see Owen-Smith et al. 2001).

This difference in the science base is critical, implying that increases in scale alone will not alter the focus of R&D efforts, because organisations typically engage in local searches, and would continue to patent in those areas in which they are most skilled. In essence, one reason for greater integration across and within US regions is the scientific overlap among generalist patentors. Alterations in the scale of patenting activity without corresponding shifts in this division of labour will not make the European system resemble its American counterpart. Instead, mere increases in scale might deepen specialisation and, perhaps, heighten fragmentation among European national research systems.

5.4.2. *Industry–university relations*

A further set of factors that explain the US advantage relate to the ability and willingness of the American academic system to interact with the industrial and commercial world. The key role acquired by scientific knowledge for technological innovation manifested itself in an unprecedented intensification of both industry–university ties and in the direct involvement of academic institutions and scientists in commercial activities. While both phenomena are not new, since the mid-1970s the drive towards an increasing commercialisation of the results of research accelerated dramatically, and patenting and licensing activities on the part of universities started to soar. The number of universities having established Offices for Technology Management also increased from 25 in 1980 to 200 in 1990. The creation of spin-offs became a distinct and crucial phenomenon of the American academic system. Increasingly, universities were assuming and were asked to assume the role of direct engines of (local) economic growth.

The emergence of the entrepreneurial university and the specific forms this process took in the US depend strongly on some general characteristics of the social, institutional and legal context, including the attitudes towards intellectual property

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[97] Scientists at the CNRS or Max Plancks may well have university laboratories, but the government institute is identified as their primary affiliation on the patents.

[98] For greater detail on the correspondence analysis used in this section, see the background study "Innovation and Competitiveness in Biotechnology: a European Perspective", op. cit.

rights and the availability of venture capital. There is high mobility between academia and the commercial world – and, more generally, there is an active labour market for scientists, technicians, and managerial experts – to a much more developed extent than in Europe. American university professors often participate in various ways in commercial activities, either retaining their academic affiliation or migrating back and forth between different affiliations. An alliance between scientific, organisational and entrepreneurial capabilities (together with a favourable attitude towards the establishment and enforcement of robust intellectual property rights) constitutes an essential pre–condition for growth in industry–university relations. It is possible to argue that a high degree of integration between research and teaching tends to favour further linkages, easier communication and more intense flows of knowledge and people between academia and the business world.

Conversely, the ties, bureaucracy, and hierarchies of its scientific institutions, at both the national and the European levels, strongly discourage labour mobility between academia and industry. As discussed by Soskice (1997), and Zucker, Darby and Brewer (1997), the organisation of labour and company law in Europe, combined with the organisational strategies of most large companies and with the structure of the academic labour market, constrains the development of US–style active labour markets, and makes it harder for companies to "hire and fire" personnel or rapidly cut non–performing assets. Moreover, though there is often some lateral movement between firms very early in a person's career, the vast majority of European employees build their careers within one firm and university.

Correspondingly, the structure of decision–making, remuneration, and career paths within firms and universities differ fundamentally from the US or UK model. Career paths, especially in universities, tend to be well-defined, incremental, and based on rank hierarchies. This structure works quite well in industries dependent on long–term investment strategies in relatively stable technologies, characterised by the diffusion of deep skills throughout the firm, but it creates fundamental obstacles to the creation of high–risk technology firms.

To the extent that innovation depends on the flow of knowledge between university labs, start–up research firms and large firms, joint research projects and strategic alliances facilitate this exchange of knowledge. Conversely, if the labour market does not support extensive lateral career mobility between academia and firms, these network externalities would be difficult to sustain (Soskice, 1997)[99].

In continental Europe, university–industry relationships have developed much more slowly[100] and even now – despite considerable progress – the situation remains unsatisfactory. Integration of research and teaching and collaboration with industry has been more frequent in the case of engineering schools and in selected disciplines in particular countries (chemistry in Germany). Unlike in the US, where universities have gradually extended their functions (an integrated model centred on universities),

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[99] There is interesting evidence in this respect that mobility of researchers between different institutional settings enhances both scientific research and commercial performance, not only in the US but also in European countries (Gittelman, 2000).

[100] More detailed information on the modalities and practices characterising industry-science relations in Europe can be found in the forthcoming report "Benchmarking Industry-Science relations – the role of framework conditions" cosponsored by the Austrian Federal Ministry of Economy and Labour and the European Commission.

continental Europe has leaned towards the development of various types of specialised institutions for technology transfer which act as intermediaries between research and industry (the institutional specialisation model).

Thus, there have been a large number of initiatives all across Europe aimed at establishing stronger links between industry and universities and at encouraging a more entrepreneurial attitude by universities. In practice, policies have been targeted mainly towards the setting up of specific devices to manage technology transfer, like science and technology parks or other such agencies, but their performance has so far been mixed.

5.4.2.1. A European paradox?

Despite the presence of centres of absolute excellence, scientific research in Europe seems to lag behind the US. If this were the case, it could have created a vicious circle, with a significant drain of human and financial resources from Europe to the US that contributes to further strengthen the American advantage.

There is now significant qualitative and quantitative evidence indicating that the R&D productivity of large firms, as well as the rates of formation of new firms, are highly correlated with the strength of universities and other research institutions in the underlying sciences (Ward and Dranove, 1995; Cockburn and Henderson, 1996; Zucker, Darby and Brewer, 1997; Swann and Prevezer, 1996).

However, there is less agreement about the existence of a direct link between the strength of the local science base and industrial and commercial performance. For example, the UK has been a leading location for a disproportionate share of the main research breakthroughs in biotechnology in the second half of 1900s, but much less so in the industrial application of such discoveries (Cooke, 2001). More generally, it is widely believed that scientific, but not industrial, research in Europe fares much better compared to the US – the so-called European paradox. In this view, competitive advantages cannot be explained by the strength of the local scientific base, since academic science is rapidly published and thus rapidly available across the world. Differential performance in industrial biotechnology is more likely explained by different institutional mechanisms favouring the rapid translation of scientific research into industrial R&D.

There is little empirical evidence in favour of or against the European paradox. There is some evidence that the formation of university spin–offs and the emergence of biotechnology clusters seems to depend less on the existence of academic research, as such, than on the presence of "star scientists" and cutting-edge research (Zucker, Darby and Brewer, 1997). Similarly, there is substantial – albeit largely anecdotal – evidence suggesting that successful experiences in industry–university ties in Europe take place in areas where concentration of world-class research in different fields of biotechnology is available (and where the need for explicit supporting policies is, as a consequence, less severe).

These observations support the notion that the absolute quality and "quantity" of scientific research and the coupling of scientific and organisational capabilities are essential pre–conditions for subsequent developments in industry–university relations. Indeed, the development of an entrepreneurial function within universities in the US has not substituted their traditional functions. Rather, the entrepreneurial function appears to be strongly complementary to and integrated with the other functions, primarily teaching. The US experience would seem to suggest, in this respect, that linkages with industry simply cannot develop without the constant mediation of teaching, as a stimulator of demand for relationships and an important source of absorptive capabilities within firms. In Europe, the presence of intermediary institutions might in some cases have paradoxically increased the distance between university and industry, introducing an additional layer in the relationship instead of favouring the development of organisational and integrative capabilities within firms and within academic institutions.

5.4.3. Financial markets and venture capital

The availability of venture capital is commonly invoked as a fundamental ingredient of American leadership in biotechnology. Clearly, venture capital played an enormous role in fuelling the growth of the new biotechnology firms. Venture capital is a long–standing institution in the US financial and innovative system. It was already active at the beginning of the 20th century and emerged as a vibrant industry with the electronic revolution in the 1960s. By contrast, in many European countries, the lack of developed capital markets for technology firms creates important barriers for prospective venture capitalists. It is worth recalling how venture capital plays a crucial role in bridging and complementing different constituents and roles within the system of biotechnological innovation.

Venture capital provides first of all finance to prospective academic entrepreneurs. Second, venture capital not only provides finance but also-and perhaps more importantly-managerial advice, organisational capabilities and “signals” to prospective investors about the potential of the new company. Contrary to the conventional stereotype of American financial institutions, venture capitalists are characterised by an extremely strong “hands-on” and “long-run” approach towards the companies they are financing. A significant number of doctorate holders in biology end up working in venture capital firms, and venture capitalists have to be part of the same network of conferences, literature, scientists, etc. Thus, venture capital mixes technology, academia and finance.

Lack of a developed venture capital market has restricted the start–up of biotechnology firms outside the US. In Europe, and despite various forms of intervention at the national and even local level aiming at fostering its formation, venture capital has only very recently begun to develop.

Nevertheless, in Europe there have been many other sources of funds (usually through government programmes) available to prospective start–ups. Moreover, survey results suggest that financial constraints did not constitute the main obstacle to establishing new biotechnology firms in Europe (Senker, 1998). Although venture capital played a critical role in the founding of US biotechnology firms, collaborations between the new firms and the larger established firms provided a potentially even more important source of capital. This raises the question of why prospective European start–ups could not turn to established pharmaceutical firms as a source of capital. A speculative but plausible answer could be that European companies tended to collaborate more with US biotechnology firms rather than

European firms[101]. Even in the absence of other institutional barriers to entrepreneurial ventures, start–ups in Europe might have been crowded out by the large number of US–based firms anxious to trade non–US marketing rights for capital (Henderson, Orsenigo, Pisano, 1999). Given the number of American DBFs in search of capital, European firms interested in commercialising biotechnology had little incentive to invest in local biotechnology firms.

Finally, the slow development of European venture capital for biotechnology could reflect less the inability or unwillingness of European financial institutions to fund new ventures and more a scarcity of "good" projects on the part of the industry. In partial support for this interpretation, it is worth recalling that several initiatives by both domestic and foreign investors to launch venture capital funds were attempted in Europe during the 1990s. Many of these funds, if anything, ended up investing in new biotechnology companies outside Europe. Conversely, foreign venture capital firms have funded some of the few experiences of successful European DBFs. Thus, the delayed development of venture capital in Europe seems to depend less on the lack of investors and funds than on the paucity of supply of promising start–ups based on solid scientific research.

The role of venture capital markets in sustaining small, young high–tech firms that do not meet strict creditworthiness institution criteria for funding new projects remains crucial in Europe. Recent evidence suggests that European venture capital markets are increasingly active in supporting small biotechnology companies in their innovative efforts. Yet, some potential drawbacks still persist at the interface between public and private financial markets and institutions, which need to be better co-ordinated for defining coherent incentive schemes for risk–taking innovative entrepreneurs.

Table V.13 shows that, during the period of unprecedented expansion in the European biotechnology industry (1996-2000), venture capitalists did not change their capital allocation from less research–intensive sectors toward biotechnology. While total investment rose from about € 6900 million to € 35000 million, most of it is devoted to traditional sectors (industrial machinery and equipment, fashion, leisure products) and to expansion and leverage buyouts. The main recipient of higher early–stage investment (seed and start–up financing, about 12 % more in 1996-2000) has been the ICT sectors. US data (Science and Engineering Indicators, 2000) for 1996-1998 show that the share of venture capital devoted to US biotechnology has been more than double, ranging from 6.1 % to 8.1 % as has the share of seed investment, which varied between 3.8 % (1996) and 4.6 % (1997)[102]. Moreover, unlike in Europe, the period 1996-98 was one of stability for the US biotechnology industry, and the proportion of venture capital disbursements to DBFs was far from its historical 1992 peak. As a result, despite recent growth, European DBFs have continued to attract only ¼ of the global venture capital investments in biotechnology during the last five years (Ernst & Young, 2001).

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[101] Indeed, most NBFs' strategies emphasised licensing product rights outside the US to foreign partners. Thus, to an even greater extent than many established US pharmaceutical firms, European firms were well positioned as partners for US NBFs.

[102] Original data provided by the Venture Economics Investor Service, Newark, NJ. Since data on US and European venture capital come from different sources, they are not strictly comparable (for a tentative comparison see National Science Foundation, 1998).

Table V.13: European venture Capital disbursements, by sector and financing stage, 1996–2000 (€1000)

	1996	**1997**	**1998**	**1999**	**2000**
By ector					
Biotech	182.355	250.348	346.354	643.838	1.017.185
	2,70 %	2,60 %	2,40 %	2,60 %	2,90 %
Hi-Tech	1.347.926	2.306.820	4.026.917	6.418.215	10.976.494
	19,60 %	23,90 %	27,80 %	25,60 %	31,40 %
Total	**6.878.646**	**9.654.942**	**14.460.781**	**25.115.694**	**34.985.753**
By stage					
Seed	68.992	85.137	169.271	467.536	819.680
	1,0 %	0,9 %	1,2 %	1,9 %	2,3 %
Start-up	375.430	625.953	1.468.511	2.771.872	5.843.723
	5,5 %	6,5 %	10,2 %	11,0 %	16,7 %
Expansion	2.712.015	3.375.956	4.334.539	7.432.678	12.986.306
	40,0 %	35,0 %	30,0 %	29,6 %	37,1 %
Replacement Capital	481.014	733.017	1.078.675	1.186.228	930.092
	7,1 %	7,6 %	7,5 %	4,7 %	2,7 %
Buyout	3.150.195	4.834.879	7.409.785	13.257.380	14.405.952
	46,4 %	50,1 %	51,2 %	52,8 %	41,2 %
Total	**6.787.646**	**9.654.942**	**14.460.781**	**25.115.694**	**34.985.753**

Source: EVCA (2001).

The unique exception to this general trend within the EU appears to be Germany[103]. Germany's financial support has favoured biotechnology and start-up investments. France ranks second both in terms of total investment in biotechnology and of its share in early–stage financing, followed by the UK. French and German venture capitalists are playing an important role in supporting the rapid growth of their national systems of innovation in biotechnology. They are likely to start a phase of selection and buyouts among the vast population of new European biotechnology firms and to complement public start–up initiatives by providing financing to select growing biotechnology companies. However, the unbalanced distribution of venture

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[103] For greater detail on the correspondence analysis used in this section see the background study "Industrial Competitiveness in Biotechnology: a European Perspective", op. cit.

capital investments towards American early–stage biotechnology companies could represent a structural weakness in Europe for a considerable length of time.

5.4.4. *The regulation of intellectual property rights (IPR) in biotechnology*

One important factor contributing to the growth of biotechnology in the US has been the recognition and enforcement of strong intellectual property rights. The establishment of clearly-defined property rights has played an important role in the explosion of new firms since, by definition, few firms had complementary assets that enabled them to appropriate returns from the new science in the absence of strong patent rights. In the early years of biotechnology, considerable confusion surrounded the conditions under which patents could be obtained. Research in genetic engineering was on the borderline between basic and applied science, conducted primarily in universities or otherwise publicly funded, and the degree to which it was appropriate to patent results of such research became almost immediately the subject of controversy[104].

5.4.4.1. IPRs in biotechnology in Europe

By adopting Directive 98/44/EC of the European Parliament and Council on the Legal Protection of Biotechnology Inventions[105], after intensive and lengthy discussions, the EU equipped itself with a common set of principles regarding the granting of biotechnology patents. However, in spite of this political commitment, only four of the fifteen Member States have adopted the necessary legislation so far..

Most European national legislation did not explicitly address some of the most controversial problems in the regulation of IPRs in biotech. The dominant situation was one in which national legislation did not include, in general, legal principles that prohibit the granting of patents on living matter, but at the same time it did not offer definitions and general principles, much less specific guidelines, to manage the most controversial problems. At the same time, biotechnological inventions were de facto patented in most countries.

According to an OECD study on patenting practices in 22 Member States[106] all reporting countries allowed patentability without exceptions for a large variety of

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[104] Millstein and Kohler's groundbreaking discovery -- hybridoma technology -- was never patented, while Stanford University filed a patent for Boyer and Cohen's process in 1974. Boyer and Cohen renounced their own rights to the patent but were nevertheless strongly criticised for having being instrumental in patenting what was considered to be a basic technology. Similarly, growing tension emerged between publishing research results versus patenting them. Whilst the norms of the scientific community and the search for professional recognition had long stressed rapid publication, patent laws prohibited the granting of a patent to an already published discovery. In the second place, the law surrounding the possibility of patenting life-formats and procedures relating to the modification of life forms was not defined. This issue involved a variety of problems (see OTAF, 1984), but essentially boiled down, first, to whether living entities could be patented at all; and, second, to the scope of the claims that could be granted to such a patent (Merges and Nelson, 1994). The Bayh–Dole act of 1980 greatly facilitated university patenting and licensing, but the emergence of the industry–university connection depended very greatly on the revolutionary developments in micro–electronics and biotechnology in the second half of the 20th century.

[105] JO - L 213 of 30.7.98

[106] These include Germany, Australia, Austria, Belgium, Canada, Korea, Denmark, Spain, the United States, Finland, France, Hungary, Italy, Japan, Norway, New Zealand, the Netherlands, the Czech Republic, the United Kingdom, Sweden, Switzerland and Turkey.

objects. National differences concern the patentability of plants per se, parts of plants or vegetal varieties, and of animals per se, animal organs or animal varieties. All countries excluded the patentability of human beings, human organs or derived products of human origin, including cell lines, genes and sequences of nucleic acids or amino-acids. However, an isolated element of the human body, or one obtained through a technical process, including the sequence or partial sequence of a gene, might be patentable even though its structure may be identical to the naturally occurring one.

It is clear that national legislation does not include, in general, legal principles that prohibit the patentability of biotechnological inventions. At the same time, however, the implementation of patentability is subject to a number of specific norms that require explicit treatment by national legislators.

Directive 98/44 is based on the principle that biotechnological inventions can be patented, but there may be specific exclusions depending on the nature of the invention[107]. These exclusions clearly address the ethical concern expressed in the European Parliament and by the public about -the possibility of granting patents for processes that may modify human genetic identity or utilise human genetic materials in the organised form of embryos. However, the Directive is states clearly that an invention cannot be excluded for the sole reason that it concerns living matter.

The debate about IPRs in biotechnology is still highly controversial and problematic. The emergence of a regime where property rights can be precisely defined and appropriated has been favourable to the development of the biotechnology industry in the US, especially as an incentive for the creation of DBFs. At the same time, however, there is growing concern that permissive attitudes have gone too far and that the current US system might not be sustainable in the long run. In Europe, the IPR situation is much less extreme, and there is opposition to the Directive as well as problems of harmonisation across national legislation. The issues raised clearly go far beyond biotechnology and will continue to be controversial over the next decade(s). Within this environment, the key concerns raised at the frontier of science and technology can only be resolved through informed discussion, careful economic analysis, sound policy debate, and finally and most importantly, democratic consensus.

5.4.5. *European biotechnology policies: France and Germany*

It was suggested earlier that the slow pace of development of biotechnology in Europe has been due to lack of the basic preconditions for innovative activities in this field. These concern the scientific and industrial base, the organisational structures linking science to industry, venture capital and intellectual property rights.

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[107] The following inventions are excluded from patenting:
- the human body and its elements in their natural form;
- new plant varieties and animal races and the essentially biological processes for the production of plants and animals;
- inventions that are contrary to public order and morality;
- processes for reproductive human cloning and for the utilisation of human embryos for industrial and commercial purposes;
- processes for the modification of the genetic identity of animals without evident utility for human health.

However, in recent years European biotechnology appears to have found new dynamism. One possible reason for this might be that policies have begun to exert some impact. Many European countries began to initiate policies supporting biotechnology in the 1980s. These included measures to introduce some typical US institutional features that have been crucial to the development of new biotechnology start–ups (such as fostering venture capital, developing financial markets tailored for new high-risk companies, promoting the commercialisation of academic research and mobility between academia and commercial activities), but primarily aimed at strengthening technology transfer and the founding of new firms. Efforts were also directed towards supporting basic research in universities and national research laboratories and, in some countries, firms (France). Furthermore, in the UK and France, the government has been instrumental in the foundation of some of the oldest European biotechnology firms, namely Celltech in Britain and Transgene in France.

The effects of policies seem to have been widely different between countries and regions. The experience of France and of Germany, discussed below, suggests such different patterns[108].

5.4.5.1. France

Starting in the early 1980s with the “mobilisation (later “expansion”) programme”, public support in France has been directed towards stimulating both private and public sector research in biotechnology. A large part of basic research was actually conducted by public structures such as the Centre National de la Recherche Scientifique (CNRS) and the Institut National de la Recherche Médicale (INSERM). These institutes have also transferred funds to private institutions like the Institut Pasteur. Beyond supporting start–ups through venture capital and stimulating the creation of science and technology transfer centres within the major universities and research institutes, public funding was used to revitalise large established groups operating in the life sciences. In the 1990s, with the launch of the BioAvenir programme, this latter form of intervention became more pronounced, as suggested by the joint support to Rhône Poulenc and several public research centres, aimed at creating public–private partnerships.

The improvement of some indicators of biotechnology activity in France, and subsequently the creation of a more solid scientific and technological base, became evident during the implementation of a “latent” national champion policy, in which a large part of the public research system was made available to one private group. Such an approach has been thought to have retarded the birth of new firms in the early 1990s. However, this period was also one of little investor interest in biotechnology in general. In recent years, French policy has been characterised by new initiatives aimed at promoting knowledge transfer, the mobility of scientists, and more generally, increasing co–ordination between different agents and at improving the control of funded projects. Moreover, the opening of the “Nouveau Marché” is showing itself to be a relevant channel for collecting financial resources.

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[108] The experience of the United Kingdom has been well documented in several reports, such as the “Genome Valley” report of the Department of Trade and Industry and “Entrepreneurship in UK biotechnology: the role of public policy”, by G. Owen with J. Lemme; Diebold Institute Entrepreneurship and Public Policy Project. Consequently, it is not covered in a specific section in this report.

5.4.5.2. Germany

Publicly-funded research has been the primary source of biotechnology knowledge in Germany as well. The “Applied Biology and Biotechnology Programme”, launched in 1986 by the Federal Ministry of Research and Technology, was intended to stimulate biotechnology research in universities (by the creation, for example, of “Gene Centres” at the universities of Munich, Cologne, Heidelberg and Berlin) and knowledge transfer to firms. Established chemical and pharmaceutical corporations were, in this phase, the main subjects of such interventions.

Characteristics of recent public policies in Germany have been the support for an environment encouraging new start–ups, and the “regional” focus in the development of some high–tech industries. Local labour markets, specialised inputs and knowledge spillovers are suggested as the main factors contributing to such phenomena. The Ministry of Research launched the BioRegio programme in 1996 to create a competition between 18 German regions, each of which was expected to define research projects based on biotechnology networks. Three of them (Munich, Rhineland and Rhine-Neckar) “won” the competition and received extra-funding, and one, Jena, received a special vote by the jury. This type of intervention is seen as one of the crucial factors contributing to growth in the number of new biotechnology firms, after a decade during which Germany had been losing its leading European position in life sciences.

It should be stressed, however, that such intervention has worked differently in different regions. In most of them, firm and job creation has been limited, both in terms of the number and size of new firms, and then of new jobs. A review of the leading regions shows that the new start–ups have been able to rely on a pre–existing, and quite diffused, knowledge base, as represented by universities, research institutes, and even the chemical and pharmaceutical industry. The case of Rhine-Neckar is characteristic. The majority of life science firms are located in the Heidelberg Technology Park (i.e., very close to university clinics and the German Cancer Research Centre), and, furthermore, chemical and pharmaceutical companies have long been present in the area. One can only speculate how the future will unfold once public support is over.

Clearly, it is difficult to evaluate the effectiveness of different policy approaches and arrive at one that might be preferable to others[109]. What emerges clearly, however, is that forward-oriented policies can have an impact, but that the presence of other factors-principally an established and developed knowledge and competence base – is necessary to attain a “critical mass” for the growth of the sector. Even if policies have played an important role in the recent dynamism of European biotechnology, it is not easy to isolate the contribution of any particular intervention. As already noted, the simultaneous presence of various factors appears to have played a determinant role. In many countries, indeed, policies have often been criticised for the lack of co–ordination between different measures and for the lack of a “strategic” vision.

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[109] Another interesting case is Denmark, where the development of biotechnology firms is in different ways linked, according to many observers, to their relationship with large and established companies like Novo Nordisk and Heineken. On the other hand, creating a favorable framework for foreign investment by providing fiscal incentives has been central to Ireland’s biotechnology policy. The birth of new firms is mainly concentrated in areas such as Dublin where, again, a solid knowledge base and a scientific community were already present.

5.4.6. *Other institutional factors: public perceptions and overall regulatory stance*

Public perceptions and attitudes can affect the economic and regulatory conditions under which an industry operates. Their impact can be felt through supply channels (attraction to young graduates and scientists, perceived social utility of related research, perceived risk factors with respect to financial conditions), the economics of production or the demand for the products and techniques that the industry puts on the market.

Regulation tends to be specific to the field of application and the technology. Generally, there cannot be any unequivocal judgement over its role as its short-term effects may differ from its longer term ones. However, there is little doubt that the regulatory framework can have a major impact on the competitiveness of biotechnology in Europe.

Available research (Gaskell et al., 2000) seems to suggest that the European public discriminates quite clearly among the fields of application of biotechnology. Europeans are neutral about agricultural biotechnology and opposed to both genetically modified food and the cloning of animals. By contrast, perceptions of medical and environmental biotechnology are very positive.

In the EU, no genetically modified organisms (GMOs) have been placed on the market for the past 3 years (since October 1998). Though the EU has one of the strictest pre-market risk assessment systems in the form of Directive 90/220/EEC, revised this year (see Directive 2001/18/EC), Member States have refused to authorise GMOs. As a consequence, genetically modified food products have not been authorised under the sector-based legislation and the entry of new genetically modified plant varieties onto the Common Catalogues was not possible, despite positive assessments from the EU's scientific bodies.

The above situation and the uncertainty as to when authorisation of GMOs and derived products may restart, has led the biotechnology industry to focus most of its investments – especially concerning R&D and the basis for new start-ups and SMEs, – in non-plant related areas, where mechanisms for product approval are in place and functioning.

This situation is in stark contrast with the one in the US where markets for all areas of biotechnology are in place.

5.5. Adoption of biotechnology among large European firms

An important aspect of the development of European biotechnology is the considerable lag, compared to American (and to some extent British) companies, in the adoption of new techniques, notably molecular biology, by many large established companies. The relevance of this factor is crucial. Given the low rate of creation of new firms, the development of biotechnology in Europe has rested on the activities of large companies. Moreover, in the absence of a vibrant research activity by large firms, prospective start-ups lacked an essential source of survival and growth through the establishment of collaborative agreements. As mentioned previously, in the absence of such skills, large companies would turn to the American scientific and technological base to tap and absorb the new requisite skills during their catching-up process. Thus, in Europe, a vicious circle between the relative backwardness of large firms and the low rate of formation of new start-ups has been created.

The rate of adoption of biotechnology by established companies varied widely across the world and between firms. Within Europe, some large British and Swiss firms were able to adopt the technology rather quickly. Other firms, with smaller research functions, more local in scope or more orientated towards the exploitation of established research, found the transition more difficult. Thus, almost all of the established French, Italian, German and Japanese companies appear to have been slow to adopt the new technologies. To be sure, some German companies (e.g. Hoechst) were among the first to establish connections with the American research base in biotechnology (as early as 1982 Hoechst signed a multimillion, ten-year agreement with Massachusetts General Hospital). Nevertheless, the actual absorption of the new technologies progresses on average more slowly in Europe than in the US.

<u>What factors have possibly contributed to this?</u>

- The relative strength of the local science base appears again to be relevant. American and UK science is arguably more advanced, leading to a slower diffusion of the new techniques to continental European pharmaceutical firms. However, many Swiss firms established strong connections with the US scientific system, suggesting that geographic proximity as such played a much less important role in the diffusion of molecular biology.

- Second, it is possible that the size and structure of the various national pharmaceutical industries determine diffusion. The existence of a strong national pharmaceutical industry, with some large internationalised companies, may have been a fundamental factor in the rapid adoption of biotechnology. In many European countries, the industry was highly fragmented into small companies engaged essentially in the marketing of licensed products and the development of minor products for the domestic markets. However, while size or global reach may have been a necessary condition, the delay of the largest German firms in adopting these techniques suggests that it was not sufficient. The largest German firms were undoubtedly among the most internationalised and largest companies in the world.

- Another important factor may be the degree of diversification. Most European firms have been large chemical firms, largely diversified into different technologies and markets, ranging from chemicals and pharmaceuticals to agricultural applications. US firms have been more specialised into narrowly defined areas. In other words, even if chemistry was the fundamental technological base for all firms, the European corporations have been essentially defined by their chemical culture, whereas US firms have been focused on more specific products and markets and, as a consequence, perhaps, more ready to explore new and alternative research. Moreover, in the early stage of development, biotechnology was often perceived as an opportunity for synergies. Over time, however, pharmaceutical, agri-food and chemical applications tended gradually to diverge and to progress along distinct paths.

- An additional factor is the stringency of the regulatory environment, especially as concerns pharmaceuticals. There is now widespread recognition that the introduction of the 1962 Kefauver - Harris Amendments had a significant impact in inducing a deep transformation of the US pharmaceutical industry. Similarly, it has been suggested that the European country whose leading firms did move more rapidly to adopt the new techniques - Britain – also appears to have actively encouraged a "harsher" competitive environment. This induced British firms to pursue strategies aimed less at fragmentation of innovative efforts into numerous minor products than at concentrating on a few important products that could be diffused widely into the global market. By the 1970s, the ensuing transformation of British firms had led to their increasing expansion in world markets.

The diffusion of the new technologies has varied also between firms. Most of the firms that rapidly adopted the new techniques have been large multinational or global companies, with a strong research presence in the US and in international markets. These firms had developed early a "taste" for science and were able to integrate the new knowledge into the firms. This, in turn, was accomplished through organisational changes directed towards building and sustaining close links with the public research community through the successful adoption of academic-like forms of organisation of research. Other institutional factors have also been necessary, albeit not sufficient.

- First, it is possible that the Anglo-Saxon forms of corporate governance made it easier for firms to “hire and fire” personnel or cut non-performing assets; continental companies seem to have hesitated to give long–term employment to biologists before biology was proven to be successful over the long run.

- Second, it is possible that the American advantage in the use of biotechnology within large corporations, as well as in new biotechnology companies, relates to the proximity and availability of first-rate scientific research in universities and in the closer integration between industry and the academic community. One might also speculate that this has been the result of the strong scientific base of the American medical culture and of the adoption of strict scientific procedures in clinical trials. Through this mechanism, American companies might have to develop earlier and stronger relationships with the biomedical community, and with molecular biologists in particular.

5.6. Concluding comments

European biotechnology is still lagging significantly behind the US. Despite encouraging signals of dynamism – especially in the small Northern European countries – and a wave of entries of new DBFs – especially in Germany – innovative activities remain far below the American levels. European companies rely partially on American research while, more worryingly, US firms do not seem to consider European research equally attractive. The new European DBFs, furthermore, are much smaller than their American counterparts, much less active in the global network of collaborative relations and in the markets for technology, and are mainly present in platform technologies.

To some extent, the European performance deficit in biotechnology is the result of its late entry. Even in such a strongly science–based industry, innovative activities are characterised by various forms of increasing returns, and early entrants acquire long-lasting leadership. This is a crucial point, since it implies that catching–up is inherently difficult. Yet, catching–up is possible, but it requires determined efforts to generate the appropriate skills, market signals and incentives.

Europe has had policies promoting biotechnology in place for several years, and some important results have already been achieved. Recent developments suggest that the policies might have begun to produce effects. Thus, it could be that European biotechnology might take-off suddenly and sooner than expected.

However, the results of this chapter suggest that late entry is only part of the problem and that the take–off of European biotechnology is still hindered by a variety of structural factors. This leads to some general implications.

5.6.1. A systemic approach seems necessary

First, it is important to recognise that the lagging behind of European biotechnology also has systemic causes, rather than being simply the result of specific market or institutional failures. Successful innovative and commercial activities in this industry depend on a delicate blend of skills and incentives and require the integration and co-ordination of several differentiated agents, capabilities and functions. Focusing on some specific aspects of the puzzle is not likely to yield the desired outcomes and a co–ordinated strategy appears to be necessary.

Biotechnology involves the exploration of an enormous, imprecisely defined and rapidly changing space of unknown opportunities. This requires both decentralisation of efforts and a variety of approaches, as well as an ability to integrate and co-ordinate them. Clearly, this is a challenge to which no unique, optimal solution may exist but alternative strategies may in fact be appropriate. For example, in the de-coding of the human genome the Human Genome Project was achieved by extreme decentralisation of tasks and approaches among a large number of institutions, while Celera Genomics approached it through strong centralisation of resources and efforts. Both approaches have been partially successful and each benefited from the existence of the other.

US leadership in biotechnology derives from a unique blend of capabilities and institutional arrangements. These include a strong scientific, technological and industrial base; mechanisms that favour communication and transfer of knowledge between academia and industry; a financial system that promotes the start–up of new, risky ventures; strong intellectual property protection; and a favourable climate in terms of public perception and regulation that does not restrict genetic experimentation. European biotechnology need - and probably should not - necessarily take the US model as the one to follow. Some aspects of the development of biotechnology in the US cause concern, especially as regards IPRs. Moreover, Europe has different institutional set-ups, histories, traditions and skills. On them, it might be possible to develop a different, but equally successful, road to competitiveness. However, some basic lessons can be learned from the US case and serve as a source of inspiration for European policy.

5.6.2. Strengthening basic scientific research and building a European research system

Second, it is clear that the availability of leading–edge scientific capabilities is the fundamental precondition for successful development of biotechnology. Without a strong and integrated scientific research base, no technological take–off is possible. Nor can European industry simply tap the American scientific knowledge. At the very least, acquiring knowledge implies the ability to produce knowledge. Access to the scientific community requires direct and active participation in the networks of scientists. The dynamics (and the economics and sociology) of scientific research is characterised by strong path–dependence and first–mover advantages.

Europe is lagging behind in this respect too. While centres of excellence exist, Europe does not attract foreign resources, and European biotechnology in the large companies relies significantly on American research. Increased funding is certainly necessary, but it is only a part of the solution. An important finding is that the European research system is weak in terms of organisational diversity, it is specialised in rather narrow areas and is insufficiently interconnected across different research areas, types of organisations and stages of the research process. Thus, higher degrees of pluralism in funding sources, lower dependence on closed national systems, higher integration of research with teaching, clinical research and medical practice should become priorities of a European research policy in this area, allowing more efficient exploitation of available resources.

Finally, the European research systems may still be too rigid and bureaucratic and segregated. While important advances have been made in recent years, further progress needs to be made in this respect

5.6.3. *Integration of research and industry*

The European research system may still be insufficiently integrated with industrial research. This is most likely a reflection of several factors, possibly that that European industry does not fully exploit the potential offered by European science, as well as institutional and organisational obstacles, which could be more directly relevant here, such as low mobility of researchers and bureaucratic obstacles to collaboration .

Policies in this area have focused on introducing incentives for academic researchers to become involved in industrial research and in building bridges between university and industry, as well as developing financial and infrastructure facilities like venture capital, science parks, etc. In practice, these measures, important as they are, appear to reflect an understanding of the innovation process based on the transfer of knowledge. However, because innovation is primarily an interactive process, more emphasis is necessary instead on how to integrate more directly different agents and fragments of knowledge. To a considerable extent, these difficulties derive from some long–standing characteristics of the European academic systems, particularly the integration of research and teaching and the structure of career paths in universities. In fact, universities often lack the necessary organisational capabilities to sustain intense interchange with industry. Again, considerable progress has been achieved in this area in recent years, but science and industry continue to encounter difficulties in their interactions. Thus, measures are necessary to favour the development of more direct linkages between universities and industry, through the integration of research and teaching and the development of markets for technology. These observations apply both to the creation of university spin–offs and to the relationships between universities and large corporations.

5.6.4. *Sustaining the creation and development of dedicated biotechnology firms*

The creation and development of a strong DBF sector is a crucial priority. DBFs constitute an important organisational device allowing exploration of the new opportunities. In Europe, this sector remains underdeveloped and too concentrated in a few areas. Moreover, the European DBFs are hardly comparable with the American biotechnology firms. They are far too small and too specialised in specific niches. Their ability to grow appears severely constrained.

Once again, interventions aiming at promoting the birth of DBFs have been at the centre of European biotechnology policies for more than a decade. The emphasis is still on strengthening industry–university relations, the creation of the "entrepreneurial university", the development of venture capital and, to a lesser extent, on intellectual property rights. Although these are important, the main problem is an inadequate supply of cutting–edge scientific research and the difficulties that afflict the European research system. While venture capital remains an essential instrument for supporting the process of formation and the early growth of the new firms, it ought to be understood as one instrument within a wider array of sources of funding (including public research funding) and managerial capabilities.

Finally, it is important to recognise that DBFs exist in a relationship of strong complementarity with the large corporations. The latter are fundamental sources of demand for products and services of DBFs and provide crucial integration capabilities for transforming different fragments of knowledge into products. Large firms constitute reservoirs of technological and managerial competence. Especially in Europe, DBFs have been – and may increasingly become –spin–offs of large incumbents rather than of universities. Supporting the creation of DBFs may raise the competitiveness of "downstream" industries, mainly pharmaceuticals.

5.6.5. Intellectual property rights

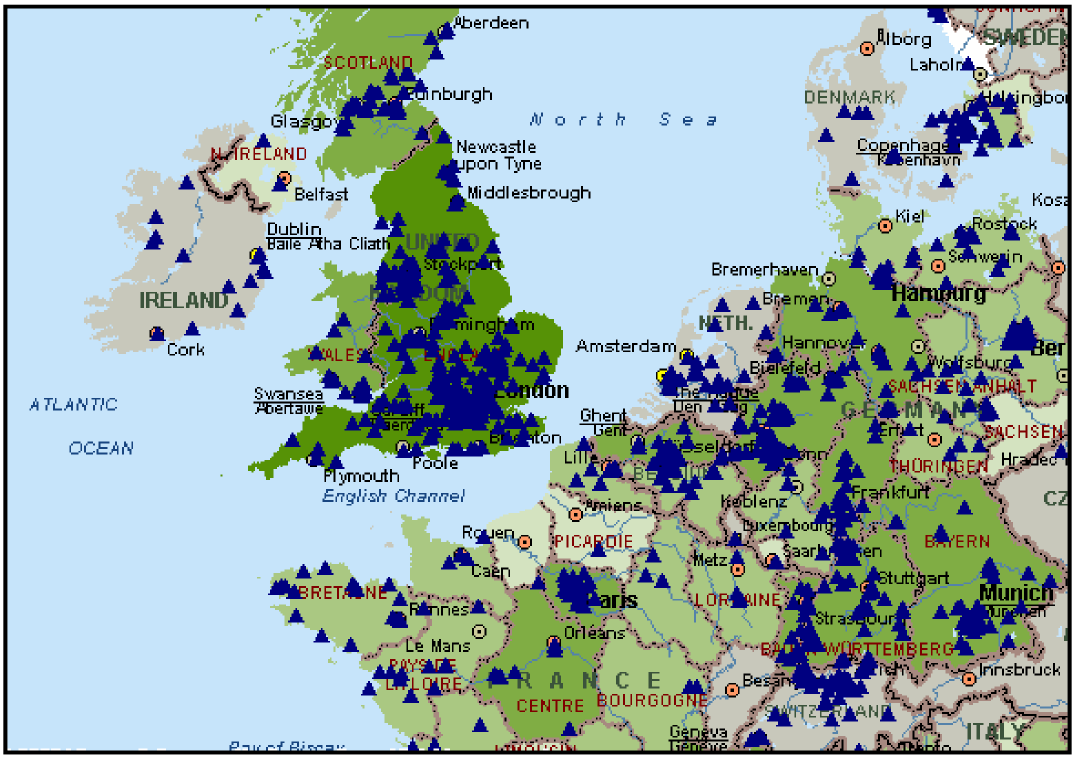
Intellectual property rights constitute one of the most delicate and important issues for biotechnology. While problems of clarification and harmonisation of the legislation on these matters remain, the emerging European approach is on the whole balanced and flexible enough to accommodate diverging requirements. The creation of the Community Patent and the implementation of the Biotechnology Patent Directive will provide a useful addition in this area, by making EU-wide protection easier.

The problem concerning IPRs is also closely linked to issues pertaining to regulation and public perception. This question goes beyond biotechnology into the wider issue of the social and political control of scientific progress. This is a difficult and important matter, where no clear solution can be proposed. In the end, the democratic process must decide what is morally acceptable. However, misinformation and emotional reaction might seriously hamper progress that provides enormous benefits to society.

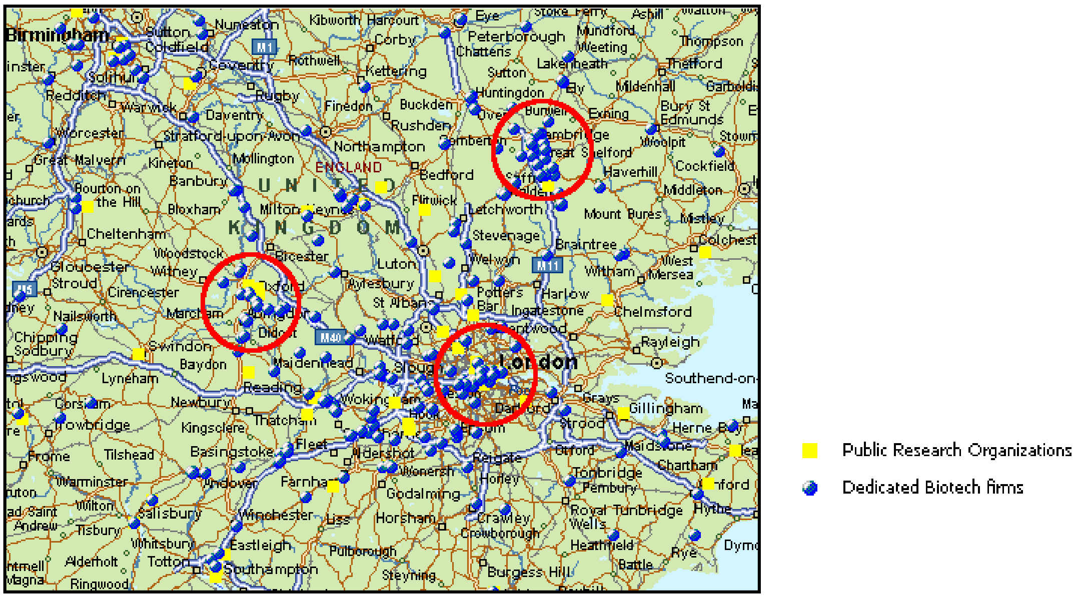
It is useful to recall that rigorous regulation is not always an impediment to scientific and technological progress. On the contrary, it can be beneficial, both by providing reassurance to society and by forcing industry to adopt higher quality standards which, if combined with more streamlined administrative procedures, can lead it to become more competitive and efficient. In this respect, the example of the regulatory reforms concerning product approval in the pharmaceutical industry might be instructive. However, onerous regulation can severely undermine competitiveness by placing unnecessary constraints on innovation, thus encouraging individuals and companies to relocate.

ANNEX V.1:
GRAPHS FOR CHAPTER V

Annex Graph V.1.: European Dedicated Biotechnology Firms: main geographical clusters



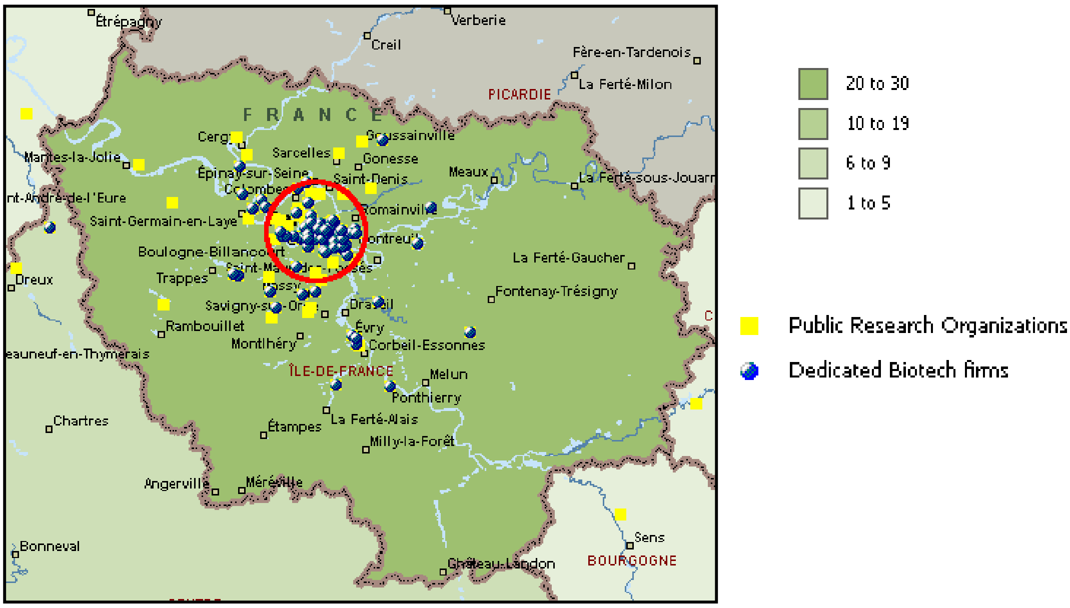
Annex Graph V.2: main UK biotechnology clusters



Annex Graph V.3: German biotechnology clusters: Bavaria and Baden-Württemberg

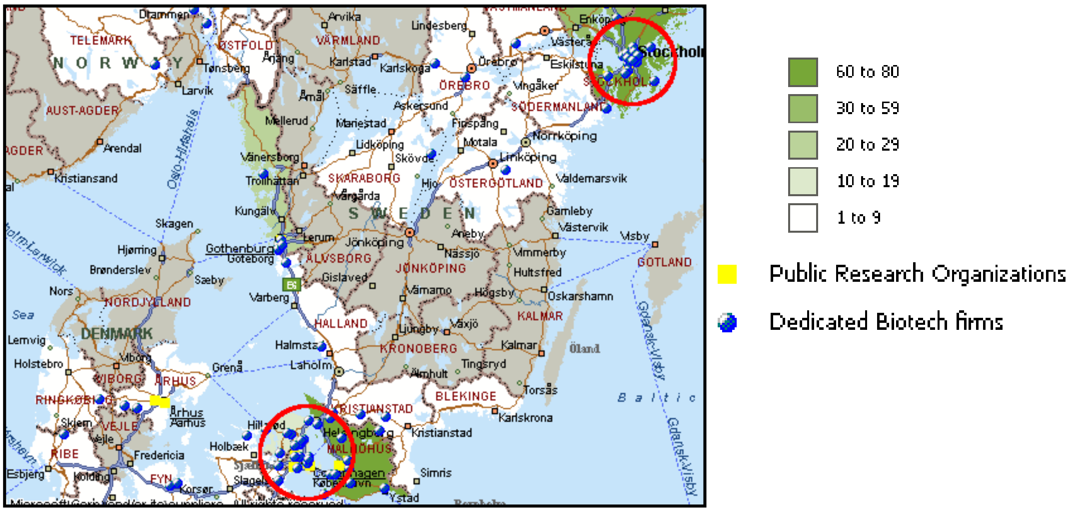
Source: BID, University of Siena.

<u>Annex Graph V.4</u>: French biotechnology companies: Île-de-France



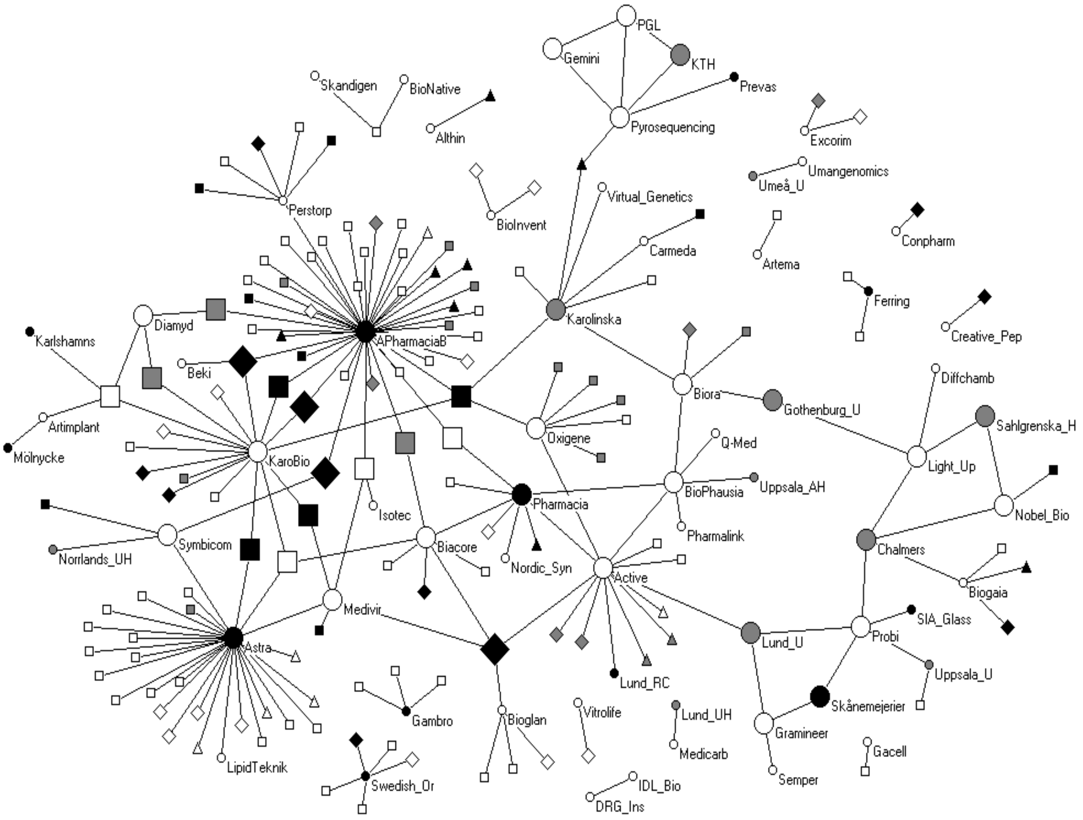
<u>Source</u>: BID, University of Siena.

Annex Graph V.5: Main Nordic biotechnology clusters



Source: BID, University of Siena.

Annex Graph V.6: The Swedish network of R&D collaborations in biopharmaceuticals



Shape: **Nationality**	**Colour: Organisation Type**	**Size: Critical points for network connectivity**
Circles: Swedish organisations	White: New Biotechnology Firms	Large nodes: Articulation points
Boxes: US partners	Gray: Public Research Organisations	Small nodes: Peripheral nodes
Diamonds: European partners	Black: Large Established Companies	
Triangles: Other partners		

Source: BID, University of Siena.

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