# Innovation and productivity of European manufacturing

**Karl Aiginger, Gernot Hutschenreiter, Heinz Hollenstein, Norbert Knoll, Hannes Leo, Robert Wieser**

**Project management: Dagmar Guttmann**

**Research assistance: Dagmar Guttmann, Elisabeth Neppl, Traude Novak, Sonja Patsios, Eva Sokoll**

## Austrian Institute of Economic Research WIFO

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# INNOVATION AND PRODUCTIVITY OF EUROPEAN MANUFACTURING

# Chapter 1: Introduction

**KARL AIGINGER**

Innovation and technological change are engines of economic growth, particularly in countries with high levels of income and open borders. The competitiveness of a high-income region is based on the productivity of firms and their ability to supply new or improved products. Both high productivity and superior quality depend on the continuous upgrading of inputs, labour and capital, the restructuring of firms, and the re-focusing of institutions. New methods of production, improved and differentiated products, changes in management, organisation and working conditions are at the core of this process and are summarised under the term "innovation" (see Box 1.1 for definitions).

This study investigates the impact of innovation on productivity and production growth in the European Union. The question gained considerably in importance, since growth differences became larger in the nineties, and the USA are again forging ahead in productivity growth after decades of narrowing the gap between Europe an the USA. The question arises whether and to which extent innovation can explain the growth differences in general, and differences between Europe and the USA. For a number of reasons, the impact of innovation on growth will not always be easily recognisable:

- First of all, however important the term innovation is, it is equally difficult to measure. Easier to measure is research and development proper, harder to measure is the output of the innovation process and its qualitative components, such as qualifications, knowledge, and capabilities.

- Secondly, the period under investigation was by no means a period of calm or steady-state growth (defined as a period during which core variables grow smoothly at their equilibrium rates). The nineties witnessed currency crises, shocks from Asia and South America, the consequences of German unification, the opening of borders with Central and Eastern Europe, and the Balkan wars. Each of these events had an impact on at least a few countries.

- Thirdly, high rates of unemployment forced governments to focus on this problem. New policies responded in part by spreading employment among more workers, partly by making labour more flexible, partly by introducing early retirement plans and shorter working hours, and partly through programmes for retraining and the acceleration of new technologies and technology programmes. High budget deficits and the objective of building a common currency later shifted attention towards short run stabilisation rather than long run growth.

The growth performance of countries became more different in the nineties. This was the case for the total economy, for manufacturing. The United States succeeded to increase output, productivity and employment at the same time. Growth differences increased also within Europe. The crucial questions to be answered against this background are:

- Is innovation a major driver of growth in output and productivity, and did the link between innovation and growth become closer in the nineties?
- Is innovation related to the country differences in growth within the EU and to the acceleration of productivity specifically evident in the USA?
- Do the drivers of growth converge, first between the European countries and secondly between Europe and the USA?

The objective of this study is to provide a sound analytical background for policy conclusions. Economic policy plays a major role with respect to the drivers of growth, such as human capital, innovation, research, and capabilities. Many of these "drivers of growth" give rise to externalities, spillovers, economies of scale and feedback mechanism. The policy relevance of innovation and structural change make complementary indicators necessary, which characterise the factors shaping the business environment, such as financial systems, regulation, and openness.

Many studies exist which focus on specific aspects or a specific data set to investigate innovation. The novelty of this study is, that it takes a rather comprehensive approach. We combine theories with empirical literature. The study refers stylised mathematical growth models, evolutionary models, and the firm based approach of capabilities. It uses concepts and data at the macro level, at the sector or industry levels and at the firm level. Broad concepts of innovation are discussed and illustrated, including knowledge and information technology, as well as very narrow ones, if the data at the sector or firm levels are confined to research and development input.

Chapter 2 surveys the literature explaining economic growth. In equilibrium, growth in output and productivity occur parallel to one another. Growth theory stresses the roles of technological progress and human capital; it emphasises the relationship between spillovers and externalities and continued growth. Evolutionary theories underline the importance of learning and of absorptive capacity. The capabilities of firms, together with the role of institutions, define the national innovation system. Chapter 3 describes the notion of a knowledge-based economy, it presents indicators of the rising importance of knowledge, and policy channels which have evolved in reaction to this development. Chapter 4 focuses on the impact of information and communication technology (ICT) on growth. ICT is a crucial and - to some extent - the easier to measure component in the expanded base of knowledge. The quantitative impact of this cutting edge technology on growth and productivity has been measured for the USA, the EU, and its member countries. Europe's lower level of investment and expenditures in this sector - with the notable and important exception of mobile phones - does effect growth, and results in a "foregone growth premium". Chapter 5 investigates the differences in the growth performances of countries. Differences in growth, together with external shocks and policy priorities, imply that productivity accelerated in some, but not all European countries. We relate the growth and productivity differences in manufacturing to the factors which the theory suggests to be determinants of growth ("growth drivers") in developed countries: research, knowledge, information and communication technology, and capabilities. We examine the link between productivity and innovation at the sectoral level, investigating which industries are impacted more strongly, and determine whether or not the same sectors are enjoying higher productivity in the USA and in Europe.

Country profiles are drawn with respect to the drivers of growth and a broader set of policy variables. Convergence within Europe and the convergence of Europe towards the USA is examined with respect to the determinants of current and future growth. We show which European countries compare best according to the "drivers of growth" and how their performance relates to that of the USA.

Chapter 6 investigates the link between research and performance at the firm level. It presents the relevant literature and takes a closer look at the factors which determine the results. We then use a data set consisting of figures on large, quoted, non-merging firms, to more clearly specify the impact of research, thereby calculating the rate of return on investment in research and development.

Finally, we present the entire body of evidence on which we can base our answers to the most important questions and we suggest in which direction a policy aimed at increasing the innovative capacity and the growth of Europe might go.

## Box 1.1: Innovation, knowledge, and related concepts

***Innovation*** is the renewal and enlargement of the range of products and services, and the associated market; the establishment of new methods of production, supply and distribution; the introduction of changes in management, work organisation, and the working conditions and skills of workers.[1]

***Innovation*** can be considered an intermediate stage in the process of technological change, which covers the transformation of new ideas into marketable products or new production techniques. It follows invention (the generation of ideas) and precedes diffusion (the adoption of new products or processes throughout the economy and across countries). This definition, which reflects the famous Schumpeterian trilogy of "invention, innovation, diffusion" has been labelled the "*linear* model of innovation", provided the three stages are taken literally, one following the other, with clear borders in-between, and there is no feedback[2] . The three stages, though a helpful description of the core elements in the innovation process, inadequately conveys the complexity of the innovation process. Today, the innovation literature is based on a *systemic* view, which stresses the feedbacks[3] between the different stages of innovation, as well as interactions between firms and other institutions (universities, government bodies, etc).

The distinction between process and product innovation is important, since the first often reduces costs (by increasing producer value or decreasing costs), while the other increases consumer value or prices. Besides product and process innovation, Schumpeter also stressed that access to new markets, new sources of raw materials or a new combination of inputs and new organisational structures are important types of innovation.

Innovations, the result of the innovation process, are often classified as either subjective ("new to a firm"), objective ("a world novelty"), or as incremental or radical innovations. Whereas the generation of radical innovations (world novelties) requires substantial R&D inputs, the other two categories are based on various types of activities (purchasing machinery, engineering/design, organisational change, etc.). Innovation without R&D is a prominent characteristic of many novelties in the service sector.

Innovation describes the product or practice made available for implementation (an object), as well as the process of creating something new (an activity).

***Knowledge*** is an important input to production in general and specifically plays a vital role in the generation of innovation. It increases the quality of labour, the quality of management, and indirectly the quality of capital. In defining the competitive edge of high income countries, the significance of knowledge surpasses even that of labour and physical capital. Knowledge is a stock variable fed by years of formal education, recurrent training, and very importantly, by learning from experience and the use of new technologies. Confining a complicated concept within a nutshell, we could say that a "knowledge-based economy" is an economy, in which the accumulation of knowledge and the capability to use it defines the competitive edge. Still, this definition does not grasp the interactive nature of knowledge: Knowledge is, on the one hand, an input in the production function, while on the other hand, knowledge is created by and increases with production. Another way of capturing the term "knowledge based economy" is to enumerate constituent developments, such as

- the increasing codification of knowledge
- the expanding role of software as a source of innovation
- the fact that information has become a commodity
- the expansion of services
- the internationalisation of R&D
- the spread of technology-based firms.

It is typical that a great portion of knowledge can be held privately. In many instances, it is difficult to transfer knowledge because of its embodied and tacit nature. Codified knowledge is easier to transmit than knowledge embodied in persons.

[1] The Green Paper on Innovation, Bulletin of the EU, Supplement 5, 1995; see also "Innovation in a knowledge-driven economy", *European Commission* 567, 2000.
[2] This unilateral causality later implied by the sequence of invention, innovation, and imitation was not Schumpeter's own intention.
[3] A model stressing the feedbacks is the chain-link model of innovation by *Kline - Rosenberg*, 1986. It conceptualises innovation in terms of interaction between market opportunities and the knowledge bases of firms.

***Human capital*** is that knowledge which is embodied in persons. This term is used to emphasise the parallels to physical capital. It is necessary to invest in human capital (years of learning; hours of on-the-job training) in order to increase the stock of intangible knowledge, and to understand that it can, in turn, depreciate. In contrast to physical capital, the spillovers from existing knowledge are considerable. Property rights are more difficult to define, people can move more easily than machines, and knowledge can be transferred without the physical process of transportation (via immaterial processes).

On the one hand, in business literature, the definition of ***capabilities*** has stressed that firms need to have specific qualities, if they are to survive at a level of non marginal performance; capabilities are also called firm specific assets or strategic advantages. This concept emphasises the ability to implement new processes, a specific organisation, or a combination of capabilities to achieve non marginal returns. A capability is a routine or ability, usually team-based, in some specific activity. Capabilities are both a source of knowledge (one learns as one undertakes the activities), as well as a way of retaining knowledge (one remembers as one does). Knowledge is embodied in certain capabilities. At the macro level, a parallel concept to capabilities is the "innovative capacity" of an economy, or as it is called when the importance of institutions is addressed, the "national innovative capacity" or the "national innovation system". National innovative capacity is defined as "the ability of a country to produce or commercialise a flow of innovative technology in the long run". Following Stern, Porter, *Furman* (2000) the "national innovative capacity" depends on the innovation infrastructure, on innovation in leading clusters and the strength on linkages between infrastructure and clusters.[4]

***Absorptive capacity*** is the ability of a firm or an economy to integrate (new) knowledge into its own knowledge stock. The absorptive capacity of a firm is strongly enhanced by in-house innovative activities which, in addition to their (direct) contribution to innovation improve the learning capabilities of a firm (the search for, processing, and assessment of information related to innovation).

***Research & development*** is a specific activity aimed at creating innovations to solve specific, pre-defined problems. In the CIS, research and experimental development (R&D) is defined as "creative work undertaken in a systematic basis in order to increase the stock of knowledge, and to use this stock of knowledge to devise new applications, such as technologically new or improved products and processes". R&D is defined as the "most privileged method, by which the companies generate and acquire technological information". R&D is often divided into basic and applied R&D, though the two categories cannot be easily separated from one another.

## The definition of innovation in EU documents and in the CIS

The definition of innovation in the Green Paper has already been mentioned above. The innovation surveys (CIS) furthermore define innovative activity as "those steps necessary to develop and implement technologically new or improved products or processes".

Furthermore, the CIS manual suggests that innovation activities should include the acquisition of machinery and equipment, including integrated software linked to product and process innovations; the acquisition of patents, non patented inventions, licences, know how, trademarks, drawing plans, technical specifications and operational features; industrial design and production preparations, training directly linked to technological innovations; and the introduction of technological innovation to the market.

The Oslo Manual is a guideline for collecting "technological innovation data"[5]. It defines as a "technological product and process" (TTP) innovation implemented in technologically new products and processes and significant technological improvements in products and processes. TPP innovation must be distinguished from organisational innovation and "other changes in products and processes". A complete reorganisation of a firm is an organisational innovation (*Oslo Manual*, p. 55), while the introduction of just-in-time systems should be treated as process innovation. Other changes in products and processes might include "creative improvement ... in aesthetic or other subjective qualities".

[4] *Stern – Porter - Furman* (2000) explain in their empirical part patents per head (an output or productivity indicator) by variables motivated by the ideas driven growth model and by cluster based theory of national competitive advantages. The main empirical result is that education, infrastructure and institutions are contributing to country productivity. For an exposition on the National Innovative System, see also *Patel - Pavitt* (1994).

[5] The Oslo Manual: proposed guidelines for collecting and interpreting technological innovation data, OECD/EUROSTAT, 1997.

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# Chapter 2: Innovation, productivity and economic growth – A survey

**HEINZ HOLLENSTEIN – GERNOT HUTSCHENREITER**

## 2.1 Introduction

### Background

From a long-term perspective, the growth of per-capita income and productivity has been driven to a great extent by technical change. However, it has not been denied that other factors such as market-oriented reforms of the international trade regime, the financial system, and the provision of infrastructural services, etc. are also highly important factors in determining macroeconomic performance.[6] In view of the increasing importance of science and technology as sources of sustained economic growth, the "knowledge-based economy" has become a pervasively used metaphor for the characteristics of a highly-developed economy (see Chapter 3).

The productivity and income levels of the European economy are still significantly lower than those in the US, and the gap even widened during the 1990s. It is presumed that a weaker performance in innovation, for whatever reasons, is one of the core factors explaining the less favourable development of Europe. However, one should keep in mind, as set out in detail in Chapter 5, that there are significant differences among EU countries in terms of income levels, as well as growth rates.

### Outline

From such a vantage point, this report investigates empirically the relationship between innovation, productivity and economic growth at different levels of aggregation. The present chapter provides an overview and an assessment of the most important theoretical explanations of growth at the macro-level. Sections 2.2 and 2.3 are devoted to the formal growth models of mainstream economics – neo-classical growth models and endogenous growth models, respectively – whereas the evolutionary approach to economic growth is discussed in Section

[6] There may also be common factors – such as demand, capabilities and competition – driving both innovation and productivity growth.

2.4. Finally, the main analytical and policy implications of the various approaches are summarised and evaluated in Section 2.5.

### Characteristics of mainstream and evolutionary growth theories

Formal growth models in mainstream economics treat the role of "technical progress" in a highly stylised fashion. This is true for neo-classical, as well as for endogenous growth models. Neo-classical models emphasise the accumulation of physical and human capital, which are subject to diminishing returns. Over the long run, however, growth is entirely due to (exogenous) technical progress, which remains unexplained. The hallmarks of endogenous growth models are non-decreasing returns and the endogenous character of technological change. One reason for the continued appeal of neo-classical growth models lies in the fact that they form the basis of a straightforward methodology for the measurement of technical change ("growth accounting"; see Chapter 4).

Macroeconomic growth models are useful when discussing the roles of technology and innovation in the growth process, because they provide an analytical framework. They lead at least to broad policy conclusions and offer a rigorous outline for policy evaluation. Neo-classical and endogenous growth models differ in both their positive and their normative implications. While, e.g., the first tends to emphasise tax rates, the second leads to policy conclusions regarding incentives to innovate, such as public support for R&D and intellectual property rights, openness to trade, foreign direct investment and knowledge flows. However, both neo-classical and endogenous growth models and their treatment of technology and innovation are necessarily too stylised to guide technology and innovation policies in any detail.

The evolutionary approach provides more detailed insights into the innovation and growth process. However, this gain is not without cost, since much of the literature lacks the general equilibrium features of neo-classical and endogenous growth models. This is not perceived as a cost by many advocates of these approaches, since they view innovation and growth as fundamentally inconsistent with an equilibrium perspective.

## 2.2 Neo-classical growth models –technical progress unexplained

Neo-classical growth models can be characterised as capital-based models emphasising the accumulation of capital. In more recent neo-classical models, capital tends to be broadly defined. The broad concept of capital includes not only physical, but also human capital and sometimes other intangible assets. Whatever the number of inputs taken into account, what is characteristic to the neo-classical view is the assumption that capital accumulation drives productivity growth in the short run, but capital is eventually subject to diminishing returns. Long-run (steady-state) growth is entirely due to exogenous technical change. Without that famous "manna from heaven", growth would grind to a halt. Thus, neo-classical growth models emphasise the role of technology in a rather particular way. Despite its vital importance to the growth process over the long term, technological progress (just as differences in technology across countries) is left unexplained.[7]

### The Solow – Swan model

The canonical model of neo-classical growth theory is named after the seminal contributions by *Solow* (1956) and *Swan* (1956)[8]). In the Solow – Swan model, capital services and labour inputs are linked to output by an aggregate production function. The dynamics is provided by a capital accumulation equation, which specifies the relationship between investment in tangible assets and the capital stock. In the simplest case, introduced in Solow's original paper, investment is a fixed proportion of output.

In the Solow – Swan model, steady growth is compatible with a particular form of technological change, viz. labour-augmenting technical progress, which acts as if it were increasing the available amount of labour (see, e.g., *Barro – Sala-i-Martin*, 1995). What is more relevant is that technical progress is entirely exogenous – i.e. it remains unexplained. However, this does not mean that technology plays no role in that framework. Rather, the opposite holds true: In the steady state, output per capita and, since labour is fully utilised, labour productivity grows at the exogenously given rate of technical progress which is thus the only reason why there is long-term growth. This feature is widely seen as a major weakness because it "means that the rate of growth is determined outside the model and is independent of the preferences, most aspects of the production function, and policy behaviour" (*McCallum*, 1996, p. 50). For example, it is well-known that if the savings/investment rate increases, the long-run *level* of productivity increases, but the long-run *growth rate* remains unaffected.

As *Mankiw* (1995, p. 280) remarks in this context: "It might seem that the model unravels the mystery of economic growth by assuming that there is economic growth." However, in defence of the neo-classical model, *Mankiw* takes the debatable view that its "goal is not to explain the

[7] For a recent justification of that approach see *Solow* (2000).
[8] For an exposition see, e.g., *Barro – Sala-i-Martin* (1995) or *Valdes* (1999).

existence of economic growth. That task is too easy: it is obvious that living standards rise over time largely because knowledge expands and production functions improve."

This is a rather stark statement. As *Keely – Quah* (1998, p. 9) summarise their view on this matter "the problem is not just being able to explain the empirical facts or being able to generate growth in an explicit model". Rather, in the framework of the Solow – Swan model, it is impossible to discuss the incentives that form the state of technology, its evolution in time and its distribution across countries. But, as Keely and Quah remark: "Without knowledge on these, no policy recommendation can pretend to be well-informed".

What happens in the Solow – Swan model if the economy is not in its steady state, with output per worker growing at the rate of technical progress? First of all, if the economy is outside its balanced-growth equilibrium, output per worker follows a convergent trajectory to its steady-state growth path. This out-of-equilibrium behaviour is called transitional dynamics. Labour productivity (output per worker) is not exclusively determined by technical progress, but rather by a combination of the latter and physical capital accumulation. If the economy is sufficiently out of equilibrium, then capital accumulation explains most of the transitional dynamics of labour productivity (see *Keely – Quah*, 1998).

## Measuring technical progress – "growth accounting"

The continued appeal of the neo-classical growth model can at least partly be attributed to the fact that it provides the basis of a straightforward methodology for measuring the rate of technological progress. Such an explicit methodology was already provided by *Solow* (1957) under the usual neo-classical assumptions (perfect competition, input exhaustion, absence of spillovers in production, etc.), where technical progress is "Hicks-neutral". The aggregate production function is defined as a function of capital services and labour inputs multiplied by a shift parameter, which is often (incorrectly) interpreted as an index of technology. The rate of technical progress equals the well-known "Solow residual" or "multi factor productivity" (MFP) growth, i.e., the rate of change of the "index of technology". MFP growth is defined as the difference between output growth and the share-weighted growth rates of capital and labour inputs. Average labour productivity growth (measured as output per hour worked) can be decomposed into three factors (see *Stiroh*, 2001, p. 39): First, capital deepening (increase in capital services per hour); second, growth in labour quality, defined as the difference between the growth of labour input and the growth in hours worked; and third, MFP growth.

If the neo-classical assumptions fail to hold, the Solow residual can not be equated with technical progress. Rather, the Solow residual represents a "bundle of variables" (*Kendrick*, 1991, p. 150) or, as *Abramovitz* (1956, p. 11) put it succinctly, a "measure of our ignorance". Indeed many factors can cause a shift in the production function: "technical innovation, organisational and institutional change, shifts in societal attitudes, fluctuations in demand, changes in factor shares, omitted variables, and measurement errors" (*Hulten*, 2000, p. 61).

In Solow's pioneering study, growth in per-capita income was almost entirely (88%) attributed to MFP growth. *Kendrick* (1956) found that MFP growth accounted for 53% of the growth in real aggregate output in the US economy between 1899 and 1953. Thus, it appeared to be a reasonable research strategy to "squeeze down" the residual. This was accomplished by increasingly sophisticated exercises in "growth accounting", improving the measurement of inputs and expanding the definition of investment beyond tangible assets. By introducing a number of innovations in measurement, *Jorgenson – Griliches* (1967) managed to let the residual disappear – a result that predictably led to an intense debate. In any case, since the early studies, "growth accounting" has undergone considerable refinement and has reached a high level of sophistication (see, e.g., *Stiroh*, 2001). It still forms the basis of much current empirical work on economic growth. Recent applications concern the contributions of information and communication technology (ICT) to growth (see Chapter 4).

As emphasised in a critical review by one of its pioneers (*Abramovitz*, 1993), a fundamental problem associated with growth accounting lies in the fact that interactions between the "factors" of economic growth are not duly taken into account. In the context of innovation, it seems likely that some of the neo-classical assumptions (such as perfect competition, the absence of spillovers, decreasing returns) are violated. Against this background, *Grossman – Helpman* (1991, p. 14) launch a forceful criticism of growth accounting: "even with a comprehensive measure of the return to R&D, the accounting method attributing growth to various causes, including research, still would be subject to the (perhaps fatal) criticism that it cannot identify the primitive sources of output growth. In our view, the existing literature fails to provide an answer to the counterfactual question: What would the growth rate have been in the absence of any investment by firms in the creation of knowledge?"

The perceived neo-classical emphasis on (physical) capital accumulation may be seen as a result of the preoccupation with transitional dynamics (dealt with above) and "successful" growth accounting, diminishing or even eradicating the contribution of technological progress to economic growth (see *Keely – Quah*, 1998).

## The "neo-classical revival" – the broad concept of capital

International evidence, which has become increasingly available in recent years, appeared to be inconsistent with the Solow – Swan model. In particular, the model seemed inconsistent with observed differences in income, capital shares, and rates of return, as well as convergence properties. In the 1990s, empirical studies in the neo-classical spirit set out to reconcile the Solow – Swan model with the international empirical evidence. In their well-known empirical contribution, *Mankiw – Romer – Weil* (1992) augmented the aggregate production function with human capital. Specifically, they included the stock of human capital (proxied by educational attainment) in a (Cobb-Douglas) production function.

Mankiw, Romer and Weil find 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. They argue that their version of the Solow model (augmented by human capital, but retaining diminishing returns to capital and keeping productivity the same across countries) is able to explain nearly 80% of cross-country differences in income levels. They conclude that "the Solow model is consistent with the international evidence, if one acknowledges the importance of human, as well as physical capital" (*Mankiw – Romer – Weil*, 1992, p. 433).

However, the study by Mankiw, Romer and Weil was criticised on various grounds. *McCallum* (1996, p. 63) rejects the view that Mankiw, Romer and Weil have rescued the Solow model, arguing that in a sense they have restated the research agenda of neo-classical growth studies by shifting attention to international differences in income *levels*, whereas the original concern of neo-classical growth theory was with *growth*.

*Durlauf – Kourtellos – Minkin* (2001, p. 929) observe that current neo-classical research "imposes very strong homogeneity assumptions on the cross-country growth process as each country is assumed to have an identical (Cobb-Douglas) production function." Since Mankiw, Romer and Weil take the view that the level of productivity is essentially the same in all countries, so that differences in income levels are mainly due to differences in physical and human capital endowment, the observed dispersion in productivity across countries is a focus of debate (see, e.g., *Klenow – Rodriguez-Clare*, 1997B). In their analysis Mankiw, Romer and Weil assume that the rate of technical progress is the same in all countries. *Grossman – Helpman* (1994) have pointed out that the estimates of the coefficient of the investment variable will be biased, if technical progress actually varies by countries. The question of knowledge diffusion will be taken up at a later stage.

In summary, it remains a matter of debate whether Mankiw, Romer and Weil and the other studies constituting the "neo-classical revival" (*Klenow – Rodriguez-Clare*, 1997B) of the 1990s succeeded or failed to rescue the neo-classical growth model, in view of the empirical evidence. Conceptually, beyond the broad definition of capital, the models used in the "neo-classical revival" did not contribute anything important to the Solow – Swan model.

## 2.3 Endogenous growth models – explaining the sources of growth

A new avenue of inquiry was opened by the so-called "new" or "endogenous growth" models which made their first appearance in the 1980s. The basic difference compared to models in the neo-classical tradition is that endogenous growth models generate long-term growth without relying on exogenous technical progress. This feature can be achieved in two ways. First, by removing the diminishing-returns-to-capital property which is prominent in neo-classical models, and second, by rendering technological progress endogenous to the model in question (see *Stiroh*, 2001).

The first of these avenues is directly taken by the so-called "AK" models (for an exposition see *Barro – Sala-i-Martin*, 1995) which assume that output is a linear function of capital. In this simple setting, labour productivity growth can continue without exogenous technical progress.

The second route is taken by R&D-based endogenous growth or "idea" models. This can be illustrated by taking a broad view, based on the pioneering work of *Romer* (1986), which triggered off a wave of subsequent endogenous growth models. According to Romer, R&D activities are associated with externalities, which affect the stock of knowledge available to all firms (although, one might add, the assimilation of this knowledge may not be without cost). In this setting, the production function of the representative firm may include a function of firm specific variables such as capital services, labour and R&D inputs, and a shift term (index of technology), which is a function of the "stock of knowledge" (possibly proxied by accumulated past investment in R&D net of obsolescence) available to all firms. This formulation reflects the public goods characteristics of knowledge generating activities such as R&D.

In practice, there are a number of rather different interpretations of the shift term (level of technology), depending on the exact nature of the spillovers to be modelled. As pointed out, *Romer* (1986) had the stock of knowledge with its public goods characteristics in mind. In contrast, *Arrow* (1962A) was concerned with "learning by doing" which means that investment in physical capital is a source of spillovers as aggregate capital increases: The level of technology is determined by past gross investment. In his influential paper, *Lucas* (1998) focused on human capital, so that the level of technology is a function of the stock of human capital. To summarise, endogenous growth theory has the potential to take into account a variety of factors enabling innovation. In the terminology of the "AK" model referred to above, the difference in spirit between the neo-classical and new growth models may concern the relative importance of "A" or "K", i.e. technology or capital. This point will be taken up later.

### Growth in a new economy – the economics of "ideas"

Given the present context, the discussion is focused on "R&D-based" or "idea" models of endogenous growth (the terms are used interchangeably here) and their ingredients. "R&D-based" endogenous growth models inspired by the Austrian economist Schumpeter 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. These models treat R&D as an intentional entrepreneurial activity performed by profit-maximising firms.[9] "Ideas" generated by R&D lead to new processes and products which 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. The most prominent examples of "idea" model are *Romer* (1990), the family of models presented in *Grossman – Helpman* (1991) and *Aghion – Howitt* (1992).

Following Jones (1998, p. 73), the relationship between the "economics of ideas" and economic growth can be represented in the following way:

Ideas – Non-rivalry – Increasing Returns – Imperfect Competition

"Ideas" are intrinsically non-rivalrous. An organisational method, for example, used by one firm can simultaneously be used by many firms. The same applies to a particular computer program. On the other hand, the CD ROM on which the software is stored is rivalrous, and the skills necessary to use the computer programme or other "ideas" may be rivalrous, too.

[9] As a matter of fact, in advanced, research-intensive economies, the greater part of R&D is typically performed in the business enterprise sector; other elements of the innovation system, such as contract research institutes and universities are increasingly linked to the research agenda of the business enterprise sector by a variety of institutional arrangements and incentive mechanisms (see, e.g., *OECD*, 2000). For a criticism of this view see *Keely – Quah* (1998).

Just like other economic goods, "ideas" are, in general, at least partially excludable. However, they vary with respect to the degree of excludability (the latter is sometimes defined as the ability to charge a fee for its use). Non-rivalrous goods which are unexcludable are called public goods. An illustrative classification of various economic goods along these two dimensions is presented in Figure 2.1, borrowed (non-rivalrously) from *Romer* (1993A).

Producers of economic goods which are excludable are able to fully capture the benefits of their product. Economic goods which are unexcludable give rise to externalities, i.e. their entire benefit is not captured by their producer. Although innovation, which today is largely based on organised R&D efforts, is widely seen as a major determinant of the competitiveness of firms, it is at the same time well-understood that R&D does not exclusively affect the economic performance of those agents actually performing these activities. Rather, R&D gives rise to (mostly positive) externalities ("R&D spillovers").

*Griliches* (1979, 1992) distinguishes two major sources of R&D spillovers: First, innovative input goods are often traded at prices which do not fully reflect their marginal benefits. This gives rise to "rent spillovers". Griliches makes the point that the estimation of rent spillovers is entangled with problems of measurement of (real) output, which carry over to the measurement of productivity. In recent times, e.g., the rapid quality change in the computer industry has posed a considerable challenge. However, this type of spillover will not be dealt with in the present context. What is of concern here is the second type of externality, which Griliches termed "knowledge spillovers". Such spillovers 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 acknowledgement of externalities in the production of knowledge can be traced back to the seminal contributions by *Arrow* (1962B) and *Nelson* (1959). Arrow argued that the production of knowledge is afflicted by all three basic causes of imperfections in competitive markets – indivisibilities, uncertainty and externalities. "Markets for technology" are inherently imperfect (*Geroski*, 1995, *Metcalfe*, 1995). This is also the basis of the neo-classical market-failure[10]) approach to the economic analysis of technology policy (see, e.g., the survey by *Stoneman*, 1987).

[10] Probably the most fundamental form of "market failure" is the absence of a complete set of markets. *Stiglitz* (1994, p. 148) notes that there are fundamental differences between the production of knowledge and other goods, in particular: "There cannot exist a complete set of markets, and in particular there cannot exist competitive markets for commodities that have not yet been conceived, let alone invented."

The characterisation of technology as a public good, however, is misleading: In contrast to textbook examples of public goods, technological knowledge which is publicly available is often not appropriable without cost. Potential innovators have to be equipped with certain capabilities, called "learning" or "absorptive capacities" by *Cohen – Levinthal* (1989), in order to adopt and make efficient use of existing technological knowledge. In this sense, the appropriation of knowledge itself is a knowledge-intensive process.

In theory it is possible that negative externalities of R&D dominate, i.e. that market economies tend to over-invest in R&D. Such tendencies can be inferred from patent-race models of the winner-takes-all variety or when innovative products cannibalise others (*Stiglitz*, 1994). The empirical evidence, however, points in the opposite direction (i.e. to positive externalities). There is a huge body of empirical literature attempting to quantify R&D spillovers, using a variety of approaches (see Chapter 6).[11] More recently, there has been a surge in studies dealing with international R&D spillovers. They conclude that cross-border knowledge or technology flows have a significant, positive impact on productivity growth.[12]

While rivalrous goods are produced each time they are sold, non-rivalrous goods, such as ideas, are produced only once. Therefore they are characterised by the presence of sometimes very large fixed costs and zero marginal costs. It can be very costly to produce the first copy of a computer programme, whereas copying it to attain additional units takes place at virtually zero cost. This has the implication that the economics of ideas is associated with increasing returns and imperfect competition. Since with increasing returns to scale, average cost is always greater than marginal cost, producing new ideas at a profit requires "a move away from perfect competition" (*Jones*, 1998, p. 79).

As an illustrative example of an "R&D-based" or "idea" model, a sketch of the model with horizontal product differentiation by *Grossman – Helpman* (1991) is provided (see Box 2.1). It should be noted that there is a dual interpretation of the formal structure of the model (in terms of an expanding variety of consumer goods) which will not be referred to here.

[11] These studies typically point at social returns on R&D which exceed the corresponding private returns. *Jones – Williams* (1998) estimate that for the United States, the optimal R&D investment is at least two to four times the size of the actual investment. See also *Griliches* (1992, 1998), *Mohnen* (1996), *Klette – Moen – Griliches* (2000).
[12] See, e.g., *Coe – Helpman* (1995), *Coe – Helpman – Hoffmaister* (1997), *Bernstein – Mohnen* (1998), *Lichtenberg – van Pottelsberghe* (1998), *Keller* (1997), *Eaton – Kortum* (1996), *Eaton – Gutierrez – Kortum* (1998), *Eaton – Kortum* (1999).

**Figure 2.1: Economic attributes of various goods**

| | Rival goods *(objects)* | Non-rival goods *(bit strings)* |
|---|---|---|
| 100 | Private Goods: for example, a piece of unimproved land | An encoded satellite television Broadcast |
| | | A digital music recording<br>The design for a microprocessor |
| | A car | A computer code<br>The operations manual for Wal-Mart stores |
| Degree of excludability | A worker's labour effort | General principles of chemical engineering<br>Principles behind window-based graphical user interfaces<br>The do-loop in computer programming |
| | Fish in the sea<br>Clean air | |
| 0 | Sterile insects used for pest control | Public goods: for example, basic research in physics |

*Source*: Romer (1993A).

Finally, an alternative way of classifying endogenous growth models discriminates according to the policy implications of the models. Following *Klenow* (1998), endogenous growth models may be grouped in two broad classes: idea models (and, one might add, other models exhibiting externalities) and rival human capital models. The first type of models was dealt with above. The second class of models includes rival human capital models such as *Jones – Manuelli* (1990) and *Rebelo* (1991). In this context, "rival" means that skills accrue exclusively to the person investing in those skills. The two classes of endogenous growth models can be radically different with respect to their policy implications. While the market solution of the ideas models is characteristically inefficient and thus calls for policy intervention, e.g. in the form of R&D subsidies, the market solution (decentralised equilibrium) of the second type of models can be efficient.

**Box 2.1: An "idea" model: The Grossman – Helpman model with horizontal product differentiation**

For illustrative purposes, a brief sketch of the structure of one "idea model" - the basic endogenous growth model with horizontal product differentiation – by *Grossman – Helpman* (1991), is provided. This model contains a constant-elasticity-of-substitution production function for the homogenous final output good due to *Dixit – Stiglitz* (1977), which is assembled from the set of intermediate goods existing at that time. A consequence of this specification is that, at any point in time, multi factor productivity (MFP) is a strictly increasing function of the number of available intermediate goods used in the process. This property reflects gains from increasing specialisation in production. As the number of intermediate goods increases, manufacturing involves an ever larger number of finer production processes. Each intermediate good is produced by a monopolist by means of a constant-returns-to-scale technology.

An essential ingredient of the model is an "ideas" production function in the vein of *Romer* (1990)[13]. The number of intermediate goods is increasing over time, whereby the increase per unit of time is proportional to the resources (R&D labour) used in R&D, multiplied by the stock of knowledge accumulated in the country. In the simple case, where the accumulated stock of knowledge is set equal to the number of intermediate goods developed so far, the rate of innovation (the growth rate of the number of intermediate goods) increases proportionally with the R&D resources employed. The value of a representative firm, which is manufacturing intermediate goods, equals the costs incurred by product development. In addition, the model contains equilibrium conditions for the capital market (no arbitrage) and for the labour market (full employment).

The (steady-state) solution of the model has the following properties: Along an equilibrium growth path, a country's rate of innovation is, ceteris paribus, higher, the larger the resource base of the country and the productivity of its R&D sector, and the lower the elasticity of substitution and the subjective discount rate (the more patient the inhabitants of the country are). In this model, the growth rates of final output and of MFP turn out to be proportional to the rate of innovation.

## A globalised world – the role of international knowledge diffusion

Modern economies are interconnected by a variety of linkages: international trade, foreign direct investment, migration and knowledge flows. It is obvious that cross-border knowledge diffusion is potentially very important for small countries and, as emphasised by the literature on catching-up, for countries lagging behind the technological frontier[14]). However, even for large, technologically advanced countries or economic areas such as the United States or the European Union as an entity, the diffusion of knowledge is crucial for their growth performance. The importance of international knowledge diffusion is illustrated by *Eaton – Kortum* (1996), who found that more than 50% of the productivity growth in each of the 19 OECD countries included in their sample can be attributed to innovations from just three countries (the USA, Germany and Japan). These three countries alone, together with France and the United Kingdom, reap more than 10% of their growth from domestic research. See also *Eaton – Kortum* (1999).

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[13] Recent empirical work on the "ideas" production function includes *Porter – Stern* (2000).
[14] See *Gerschenkron* (1962), *Abramovitz* (1986) and the survey by *Fagerberg* (1994).

*Endogenous growth in open economies*[15]*)*

The Solow –Swan model has nothing to say about international knowledge diffusion. In the absence of barriers or costs of information, it appears natural to assert that neo-classical growth models "postulate one world-wide rate of technical progress" (*Streissler*, 1979, p. 254). In a similar vein, *McCallum* (1996, p. 50) points out that the exogeneity of technical progress in the Solow model implies that "the model itself suggests either the same growth rate for all economies or, depending on one's interpretation, different values about which it has nothing to say". In fact, this very assumption underlies important recent work in the neo-classical tradition.

More promising are those R&D-based endogenous growth models which evolved from a marriage of the theories of growth and international trade. Such models have been applied to examine the factors of long-term growth in the context of open economies (*Rivera-Batiz – Romer*, 1991, *Grossman – Helpman*, 1991).

Traditional international trade theory had been concerned with "gains from trade" attributable to specialisation. The latter is based on comparative advantages, which, in turn, arise from differences in factor endowments and technology across nations. More recently, economies of scale were recognised as an additional source of welfare gains (*Helpman – Krugman*, 1985). Finally, endogenous growth theory also deals with dynamic increasing returns and learning mechanisms (see the survey by *Grossman – Helpman*, 1995). This led to new insights regarding the role of international linkages (including knowledge flows), as additional "productivity transmission channels" (*Helpman*, 1997).

Endogenous growth theory provides a suitable analytical framework, according to which one can evaluate the economic impact of international knowledge flows. In their seminal work, *Grossman – Helpman* (1991) analyse two borderline cases: The first case, which is used as a benchmark, may be termed perfect "informational autarky" since no international diffusion of basic knowledge takes place. The second case is characterised by perfect (complete and costless) international diffusion of knowledge. This case is akin to the frictionless transferability of technology in applications of the Solow – Swan model. In the first case, knowledge capital therefore acts as a "national", in the second case as a "global" public good. The Grossman – Helpman model leads, among others, to the prediction that the international (global) diffusion of knowledge increases the growth rates of output and productivity. Introducing international trade

[15] This section partly draws on *Hutschenreiter* (1998) and *Hutschenreiter – Kaniovski* (1999).

in intermediate goods into the model with perfect international diffusion of knowledge impacts on the attainable *levels* of output and productivity, without affecting their growth *rates*.

However, it appears more realistic to assume that while basic technological knowledge is diffused across national borders, the rate of diffusion depends on the height of the communication barriers between the countries involved and on their respective "absorptive capacities". An endogenous growth model by *Hutschenreiter – Kaniovski – Kryazhimskii* (1995) examines the (asymmetric) case where a relatively small technological follower has the "absorptive capacity" to adopt part of the knowledge stock of a larger technological leader, thereby raising the productivity of its own R&D activities. The absorptive capacity of the follower is modelled as an increasing function of the knowledge accumulated in that country. It is shown that along an equilibrium growth path, the follower asymptotically approaches the rate of innovation and the rate of MFP growth of the leader, to which it is linked informationally. While the *growth rates* of MFP are asymptotically equalised, the *levels* of MFP do not necessarily converge.

These results are consistent with the view of *Klenow – Rodriguez-Clare* (1997A, p. 607) "that all countries grow at the same rate in the long run, with countries being at different points in the distribution at any point of time due to policies and institutions that affect how fully a country benefits from world frontier technology ... Faster-than-average growth could be explained as the result of adoption of better policies and an improvement of institutions that permit those countries to benefit more from frontier technology."

A generalised (symmetric) model of *Borisov – Hutschenreiter – Kryazhimskii* (1999) – which contains, as special cases, both the leader – follower model outlined above and the extreme cases analysed by *Grossman – Helpman* (1991) – allows for a mutual exchange of knowledge based on the absorptive capacities of both countries involved. One major implication of this model is that in the long run, no country can gain from impeding the flow of basic knowledge to a partner country (rest of the world). The induced reduction of available knowledge in the rest of the world has repercussions (negative feedback) on the country which restricts the flow of information. The long-run equilibrium growth rate of output and MFP common to both countries will decline.

Several hypotheses with respect to the impact of international technology diffusion on productivity growth can be derived from the R&D-based endogenous growth or idea models referred to above:

First, access to a larger pool of knowledge increases the productivity of R&D activities in the countries involved[16], thereby enhancing future productivity growth. Thus, in addition to the traditionally recognised channels of technology diffusion (international trade, foreign direct investment, etc.), a country's productivity growth is positively correlated to 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. Secondly, international trade provides opportunities to use the input goods developed abroad that qualitatively differ from domestic input goods, and thus to increase productivity. Third, both international trade and foreign direct investment are vehicles for cross-border learning about products, production processes, market conditions, etc. and may lead to a reduction in the costs of innovating and contribute to future increases in MFP.

### *Policy implications*

It was stated above that when using the terminology of the "AK" model, the difference between the spirit of neo-classical and new growth models can be seen as one which concerns the relative importance attributed to "A" or "K", i.e. technology or (extended) capital. As *Klenow – Rodriguez-Clare* (1997A, p. 611) emphasise, the "A" and the "K" views have different positive and normative implications: "Suppose productivity differences reflect differences in technology used. Unlike the neo-classical growth model, technology-based models generically have scale effects because of the non-rival nature of innovation, imitation, adoption and adaptation. Technology-based models also suggest a prominent role for openness (access to higher quality or more specialised goods through imports or access to better technology through joint ventures or technology licensing). And whereas the normative implications of the neo-classical model centre on tax rates, those of technology-based models extend to trade policy, foreign investment policy, and intellectual property protection." Of course, one has to add the R&D subsidies curiously omitted by Klenow and Rodriguez-Clare or, more generally, incentives to innovate, as key instruments of growth-oriented policies. This spirit implied by the endogenous growth view has been illustrated by the models discussed.

[16] Closely related to the analysis of innovation is the analysis of imitation (*Grossman – Helpman*, 1991, *Helpman*, 1993, *Barro – Sala-i-Martin*, 1997). In practice, the borderline between imitation and innovation is fuzzy.

## 2.4 The evolutionary approach to economic growth

### The evolutionary approach – an alternative to mainstream growth models

*Basic features of the evolutionary approach*

The ideas models of endogenous growth dealt with above highlight the role of increasing returns in the macroeconomic growth process. Although, with respect to a knowledge-based economy, these models are clearly more appropriate than models in the neo-classical tradition, they are fundamentally criticised by theorists of evolutionary economics.

*Nelson* (1998), to mention one of the most prominent scholars of this line of thought, draws attention to three aspects neglected in both neo-classical and endogenous growth models which, in his view, are indispensable when theorising on economic development. First, technological advancement has to be conceptualised as a disequilibrium process involving a high degree of ex-ante uncertainty, path dependency and long-lasting adjustment processes. Secondly, growth theory should be based on a more realistic theory of the firm, which 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 which presumably contributes strongly to an explanation of cross-country differences in economic growth. Seen from this perspective, modelling growth within a general equilibrium framework is inappropriate; it impedes the analysis of key drivers of economic development.

*High policy relevance of evolutionary thinking*

The critique of evolutionary economics is highly relevant for policy design. In the evolutionary setting, measures to enhance firm capabilities (in a broad sense), as well as the development and strengthening of institutions conducive to growth, become core areas of policy, which are hardly addressed in the policy-oriented work inspired by neo-classical thinking.[17] The evolutionary critique of mainstream growth models is clearly reflected in policy discussion and design in many countries, as well as in the European Union and international organisations such as the OECD.[18]

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[17] For a discussion of the rationale and the orientation of (technology) policy from a neo-classical and a evolutionary point of view see, for example, *Metcalfe* (1995) or *Lipsey – Carlaw* (1998).
[18] The EU, as well as the OECD, stress the systems approach to innovation, which reflects evolutionary thinking on economic development. See the "Green Paper on Innovation" (*European Commission*, 1996) and the documents produced in the framework of the OECD National Innovation Systems (NIS) Project (see

In the following, we shortly discuss two core aspects of the evolutionary view of economic growth, that is the (dynamic) capabilities approach at the micro-level and the systemic view of technical change at the macro-level ("National Innovation Systems"). Finally, we briefly assess the strengths and weaknesses of this approach.

## Creation of dynamic firm capabilities

### *The capability view of the firm – a more realistic concept*

The standard approach to explaining productivity (growth) at the firm level is a production function which, in addition to labour and physical capital, contains "R&D capital", i.e. the depreciated stock of past R&D investments, augmented by R&D spillovers, as additional factors of production (*Griliches*, 1979). In Chapter 6, this approach is discussed in some detail, and the main findings of the empirical research to date, as well as our own estimates are presented.

This concept of the firm, as argued, for example, by *Foss* (1997) or *Teece – Pisano* (1998) is too 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. Of mention are marketing skills, 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 is conceptualised as a firm's capabilities. They are dynamic in nature, being the result of strategic decisions in the past, and representing 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[19] and gives rise to qualitative differences among firms.

The capability view of the firm is clearly more appropriate than the classical concept[20] and yields straightforward implications for policy. From this perspective, supporting (dynamic) firm

www.oecd.org/dsti/sti/s_t/inte/index.htm), as well as the OECD Growth Project (see www.oecd.org/subject/growth/products/index.htm).

[19] Path-dependency may also produce negative effects resulting from "capability rigidities" (*Leonard – Barton*, 1992).

[20] The appropriateness of the (broader) capability view of the firm is confirmed –in reference to just one of the traditionally neglected aspects of a firm's capabilities – by studies looking at the productivity effect of specific organisational configurations and their change. These show that (the change of) organisational characteristics and in-house training are positively related to productivity (growth). In particular, it is shown that the productivity effects of the adoption of ICT is strongly increased if it is combined with organisational innovations and investment in training activities. For an overview of such studies see *Arnal – Ok – Torres* (2001); a typical example of such a study is *Breshnahan – Brynjolfsson – Hitt* (1999).

capabilities is a more promising way of promoting innovation and productivity growth than a policy focussing primarily on R&D.

### *Difficulties of measuring capabilities at the macro-level*

However, to explain economic growth at the macro level, the capability approach is useful only if capabilities can be measured at an aggregate level. An attempt in this direction has been undertaken by *Peneder* (2001A), who uses the share of 3-digit industries characterised in terms of specific capabilities ("marketing-driven", "technology-driven", "intensive use of knowledge-based services", "skill-intensive") as proxies for the stock of capabilities available in a country's manufacturing sector. Empirical analysis (*Peneder*, 2001A, 2001B) yielded a strongly positive cross-country correlation between these aggregate capability indicators and performance measures such as productivity, unit values (a proxy for quality; see *Aiginger*, 1997) and wages. The (aggregate) capability approach thus seems to be a useful way of comparing and explaining economic performance among countries.[21] It is therefore adopted in the empirical analysis of aggregate growth in Chapter 5.

*Peneder's* (2001A) approach to measuring capability does not cover all the elements of a firm's capability which we mentioned above, although he argues that some of the neglected aspects (e.g. organisational skills or learning capacity) are captured indirectly by their presumed correlation with the variables included, such as labour qualifications. At the empirical level, there might therefore be only a gradual difference to the production function approach; in this case, measures of human and R&D capital input could also be interpreted as proxies for the broader notion of capabilities.

## National Innovation Systems – the role of interconnected institutions

### *The institutional framework determines innovativeness and growth*

From an evolutionary perspective, institutions are a crucial factor in explaining the performances of firms and the economy as a whole. The institutional framework is shaped to a large extent at the national level, giving rise to important differences across countries.[22] This

[21] The taxonomies of industries underlying the measurement of capabilities at the aggregate level have also been presented and used for empirical analysis in the previous Competitiveness Report (*European Commission*, 2000).
[22] In view of the rapidly growing internationalisation of R&D, of trade in knowledge-intensive goods, licensing, etc., the ability to realise potential gains from international knowledge flows is contributing increasingly to the performance of NIS. The importance of this source of innovation and growth is also stressed by endogenous growth theorists such as *Grossman – Helpman* (1991), *Romer* (1993B) and others (see above).

aspect of growth theory is treated in the literature under the heading "National Innovation Systems" (NIS).

NIS are defined by various authors (*Freeman*, 1987, *Lundvall*, 1992, *Nelson*, 1993) in quite similar ways. NIS are 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. 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 performance might also reflect varying degrees of the "knowledge distribution power" (*David – Foray*, 1994, 1995) or, in more general terms, the efficiency of NIS, and not only different endowments with innovation-related factors of production. The NIS approach can be seen as the macroeconomic counterpart of the capability view of the firm.

### *Specification problems at the empirical level*

However, at the empirical level it is rather difficult to define explanatory variables capturing institutional factors and the mentioned systemic properties.[23] Measures of type and the intensity of interactions are probably the most useful (and tractable) proxies: frequency and intensity of R&D co-operation among firms, character and intensity of the use of external knowledge sources, measures of joint research of universities and private firms, as well human capital flows between the public and the business sectors, etc.[24] However, important properties like the "quality of public policy", incentive mechanisms in firms and in "non-market" institutions, etc. are difficult to capture.

In view of such measurement problems and the basic difficulty in determining the relative importance of the various elements of NIS, it is not surprising that there is no overall measure of the efficiency of a NIS, which could be used as an explanatory variable in the empirical analysis of economic growth. At present, we dispose only of pieces of evidence showing the importance of several types of interaction to innovation performance; for a summary of this evidence see, for example, *OECD* (1999).

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[23] A closer look at the conceptual and measurement concept for comparing NIS, developed in *David – Foray* (1994), strongly supports this assessment.

[24] The "Community Innovation Survey" (CIS) yields valuable information on these aspects. See also the work undertaken within the framework of the OECD NIS Project: www.oecd.org/dsti/sti/s_t/inte/index.htm.

*Evidence of the importance of institutional factors from the OECD Growth Project*

Though not directly related to the NIS concept, results from a broadly-based empirical work recently undertaken within the framework of the "OECD Growth Project" significantly improved our knowledge regarding the links between on the one hand policy and institutions and, on the other hand, economic performance. Among the many studies, one may mention, for example, *Bassanini – Scarpetta – Hemmings* (2001) who investigated the growth effects of macroeconomic stabilisation policy, the size of the public sector, the openness of the economy and some characteristics of financial markets, or *Leahy – Schich – Wehinger – Pelgrin – Thorgeirsson* (2001), who analysed in more detail the role financial market regulation and development play in economic growth; other studies were devoted to the impact of entrepreneurship (*Audretsch – Thurik*, 2001) and "social capital" (*Temple*, 2000; survey by *Temple*, 1999), respectively. The main findings of the OECD Growth Project are summarised in *OECD* (2001)[25]).

## Strengths and weaknesses of the evolutionary approach to growth

The evolutionary approach yields valuable insights with respect to the dynamics of growth processes at the conceptual and, more importantly, the empirical level. The basic ideas yield a framework which is very useful for the design and analysis of policy. Correspondingly, it is by now the dominant paradigm for innovation policy and a core element in policy-oriented growth analysis. It plays a crucial role in exercises defining the best policy practices in these fields, as can be seen, for example, in *OECD* (1998) or *Andersson* (1998).

However, this approach also has fundamental weaknesses. Firstly, it is rather difficult to find appropriate measures of basic concepts such as capabilities or NIS, which could be used as explanatory variables in empirical analyses of growth, in particular at the macro-level. Secondly, it seems hard to construct relatively simple (and thus tractable) formal models of growth, based on the main ingredients of evolutionary thinking, which would allow the derivation of generalised hypotheses to be tested empirically by the use of econometric methods.

Notwithstanding these problems, several aspects of the capability view of the firm, as well as some elements of the NIS approach, are covered by the indicators used in Chapter 4 to characterise the progress of firms towards a knowledge-based economy. Moreover, a set of such

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[25] The full report will be available in September 2001.

variables is used to explain empirically the differences between countries with respect to economic growth (see Chapter 5).

## 2.5 Summary and policy conclusions

### Summary

*Up to the 1980s: dominance of neo-classical growth models*

The neo-classical growth model dominated the literature until the early eighties, although it rests on very restrictive assumptions: markets are perfectly competitive, capital is subject to diminishing returns and technical progress is exogenous, i.e. it is determined outside the model. The implications of this model are inconsistent with empirical evidence; in particular, they are at variance with the differences between countries in terms of income levels, capital shares and rates of return, and the phenomenon of income convergence cannot be explained.

*Three approaches to correct for the weaknesses of the neo-classical model*

In the 1980s, growth theory basically developed in three directions, as it sought to overcome the weaknesses of the neo-classical model. A first approach tried to rescue the neo-classical model by broadening the concept of capital. The basic feature of a second set of models is the endogenisation of technical change. Thirdly, the eighties witnessed the unfolding of evolutionary thinking on economic growth in the tradition of Schumpeter. In contrast to the other models, which adhere to the equilibrium perspective of mainstream economics, the evolutionary analysis of the growth process is based on disequilibrium dynamics.

*The extended neo-classical model*

The extended neo-classical model augmented the aggregate production function with human capital. Although at a glance, these models appear more realistic, they remain unsatisfactory. They imply that productivity levels vary among countries solely due to differences in physical and human capital endowments, whereas the productivity of these factors of production is the same everywhere. The unrealistic, restrictive assumptions of the basic neo-classical model, such as diminishing returns, exogenous technical change, etc. remain unchanged.

### *Endogenous growth models*

Endogenous growth models drop the assumption of decreasing returns on physical and human capital. In this way, they are able to generate permanent economic growth. The most sophisticated, as well as theoretically and empirically most convincing models of this class are the "R&D-based" or "idea based" growth models. Their main features are the endogeneity of R&D-based knowledge ("ideas") production and the non-rivalry of knowledge, i.e. its usefulness to everybody, as soon as it is produced, an assumption giving rise to increasing returns to scale (large fixed costs, zero marginal costs) which, in turn, imply imperfect competition. Knowledge is excludable only partially, i.e. it is partially a public good; a certain extent of knowledge spills over to users who did not contribute to its generation (positive externalities). However, the use of externally produced knowledge requires certain capabilities which, in turn, require investments (building-up absorptive capacity). Knowledge spillovers across borders are an important channel of technology diffusion, with a high potential for productivity convergence across countries. The realisation of this potential depends on the openness of a country to cross-border information flows and its absorptive capacity determined by own R&D investments. International knowledge flows complement knowledge distribution through trade and foreign direct investment. Even for large technologically advanced countries international diffusion is an important source of innovation and growth.

### *The evolutionary approach to economic growth*

Although endogenous growth models which depart from the (neo)"classical world" of perfect competition, decreasing returns, etc. are considered to be more realistic, they are fundamentally criticised by the evolutionary approach to economic growth. The basic ingredients of the latter are, firstly, the conceptualisation of growth as fundamentally a process of disequilibrium, involving high ex ante uncertainty and long-lasting adjustment processes, etc.; secondly, a broader view of the firm which stresses firm capabilities at large, which result from the strategic, cumulative creation of mostly intangible assets (marketing skills, organisational learning, networking, trust, etc.); and thirdly, the role of interconnected institutions giving rise to "National Innovation Systems". Differences with respect to the second and third elements are the prime cause of variations between countries with respect to innovation and growth performance.

*Assessment: Endogenous growth models vs. the evolutionary approach*

The evolutionary approach is clearly more realistic. It is intuitively convincing, provides valuable insights on the process of economic growth in a historical perspective and yields detailed policy implications. However, it is rather difficult to find appropriate measures of basic concepts such as capabilities or National Innovation Systems, which could be used to empirically explain growth differences between countries, in particular at the macro-level. In addition, because of its reliance on inductive methods, it is hard to construct parsimonious formal models of growth which could be used for stringent econometric tests of generalised hypotheses. The construction of formal models, which can be used as tools in the understanding of general characteristics of economic growth, is a major strength of mainstream theories. Among these, endogenous growth models are the most convincing, because they rely on quite realistic assumptions: increasing returns to scale, imperfect competition, and the partially public good character of knowledge. However, mainstream models only enable the stylised capture of innovation and growth processes; as a consequence, they provide nothing more than general policy guidelines.

Given the strengths and weaknesses of both approaches, it would be unwise to abandon either formal modelling in the vein of endogenous growth models or the richer, but informal view of the growth process which characterises evolutionary thinking. We would rather follow *Romer* (1993B), who advocates the parallel, but not isolated, use of both approaches within a (co-ordinated) research programme, in search of a better understanding of the relationship between knowledge, innovation and economic growth.

## Policy conclusions

A first important policy implication is common to all models of economic growth developed since the early eighties. Investment in human capital, that is in basic education, training and learning, is of crucial importance to the fostering of growth. With this exception the main policy conclusions differ among the three approaches mentioned above.

*Policy implications of the extended neo-classical model*

In view of its adherence to the basic assumptions of classical economics (perfect markets, etc.), the extended neo-classical model does not have much to say about policy. According to this view, policy should be restricted to guaranteeing free markets and securing good infrastructures, with special emphasis on education and basic research. To this end, there is, in addition to the direct provision of infrastructural services, scope for indirect policy measures (tax policy).

*Policy implications of endogenous growth models*

In the framework of endogenous growth models, there is more scope and need for policy intervention. The partially public-good character of knowledge reduces the incentive for firms to undertake R&D; as a consequence, R&D investments are below the social optimum. Private R&D should therefore be supported by tax policy. In addition, intellectual property rights are a means of increasing the incentive for firms to invest in R&D. At the same time, the patent system must not be too restrictive; otherwise the diffusion of knowledge is unduly hampered. Competition policy is another area which can be used to counteract suboptimal R&D investment levels. Because the co-operation of firms in R&D is a way of internalising knowledge externalities (and of increasing the benefits of R&D investment through the use of complementary knowledge) such agreements should not be impeded, although there is a danger that co-operation favours restrictive business practices in the goods market. The international diffusion of knowledge is facilitated by the free flow of physical and human capital, as well as knowledge, across national borders. Therefore, liberal policies towards international trade, foreign direct investment and cross-border joint ventures are an important instrument in securing benefits from frontier technology. The benefits of such policies are higher, the better developed a country's capacity to absorb knowledge produced abroad. Supporting investments in R&D and human capital is an efficient way of improving absorptive capacities; the same holds true for measures facilitating technology diffusion within a country.

*Policy implications of the evolutionary approach to economic growth*

The policy conclusions derived from endogenous growth models are also maintained by the evolutionary point of view. However, according to evolutionary thinking, some additional measures are required. The ex-ante uncertainty of technical change stressed in this view calls for a mechanism to guarantee technological variety in an early stage of technological development, 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, the provision of venture capital, etc.). The selection of superior technology is then left to the free market process. The capability view of the firm implies that measures facilitating investment in intangibles are important. In principle, such investments are up to private business; nevertheless, there might be scope for policy, e.g. making sure that the incentives for training are put right (measures against poaching, tax incentives, etc.). Further scope for policy is derived from the concept of the National Innovation System. In this context, specific measures to improve the interaction between the various elements of the system are called for: strengthening science/industry relationships to guarantee full and rapid use of basic knowledge created at universities (joint research, facilitating university spin-offs, recurrent education for practitioners, exchange of highly qualified staff, etc.), facilitating R&D co-operation in the private sector. Finally, policy makers should take the context-specificity of policies into account. For example, international policy benchmarking is, in many instances, important for improving policy, but the best policies have to be adapted to the specific properties of the National Innovation System.

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# Chapter 3: Progress towards the Knowledge-Based Economy

**NORBERT KNOLL**

## 3.1 Introduction

During the last decade, policy makers have increasingly devoted attention to the factors that influence the rate and direction of innovation. In particular, developments in the ICT sector have been discussed as a currently dominant source of both technological change and overall economic growth. The visible limitations of this approach and an improved understanding of the innovation process have widened the perspective. Essentially, industrial innovation is a process of knowledge creation and the outcome depends on the learning that takes place at the level of individuals, firms, sectors and nations. Consequently, analytical concepts, which focus on capabilities and competencies, as well as other factors, which constitute a specific learning environment, have attracted attention[26].

In this chapter, we start by discussing the essential assumptions and implications of concepts such as the Knowledge-Based Economy; by comparing current ideas with earlier approaches, which focused on the role of information and ICTs, some distinct features will be drawn to attention. The subsequent section is devoted to the two main dimensions of knowledge generation: skill base and interactivity. Both aspects are conducive to the examination of empirical evidence at the country level. Finally, policy options from the perspective of knowledge will be discussed. As several examples of the policies, which support innovation, reveal, European countries have developed new strategies, which address the challenge of improving the framework for knowledge generation in the economy.

## 3.2 The Knowledge-Based Economy as an analytical concept

Since the early 1990s, a number of socio-economic concepts have based their explanations of structural change in industrialised economies on the growing importance of information and knowledge. The Information Society (IS), for example, has become a visionary metaphor of current developments, which have been brought about by the availability of an ever-increasing variety of low cost ICT. The widespread use of ICT in the creation, processing and distribution

[26] See also the preceding chapter in this report.

of information has provoked drastic changes at all levels of economic activity (intra-firm, inter-firm, and international). More recently, the notion of the Digital Economy – sometimes the Internet Economy – has been used to emphasise, inter alia, that electronic networks alter the way economic transactions are carried out, as well as the positions of market participants[27].

Similar to information and the use of ICT, the creation and exploitation of knowledge has become the focal point of competing theories of structural change in the economy. Knowledge, as opposed to information, has a much broader scope, including practical skills and competencies. Furthermore, technology can be regarded as another specific body of knowledge, which is used in the production of goods and services[28]. Conversely, information is confined to explicit, well-structured and codified knowledge[29]. Concepts, such as the Knowledge-Based Economy (KBE) or the Learning Economy, point out that the accumulation of knowledge (learning) and the capability to use it are the driving forces behind an emerging stage of economic development[30].

Irrespective of what side one takes, ICT does play a crucial role in the explanation of structural change. More or less by definition, the developments within the ICT sector and the diffusion of ICTs require thorough treatment, if the IS framework is chosen. Even if knowledge is at the heart of the explanatory framework, there are at least two reasons for including ICT in our investigations:

- First, the ICT sector ranks amongst the most knowledge-intensive, if investments in intangibles, such as R&D, training and software are considered characteristic of knowledge-based industries and services. For example, in most countries, the R&D intensity of ICT industries as a whole is significantly higher than the manufacturing average[31]. Similarly, when compared to other industries, both IT services and ICT manufacturing show an outstanding share of investment in software.

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[27] The literature on the Information Society and related concepts saw tremendous growth during the 1990s. See, for example, *Brynjolfsson – Kahin* (2000), DOC (1999), *Durmont – Dryden* (1997), *European Commission* (1994A, 1994B), *Eliasson* et al. (1990).

[28] See e.g. *Freeman* (1982). *Johnson* (1992, p. 28) defines technology as knowledge used in the production process: "Knowledge used in the production process is called technology, and new (or recombined or rediscovered) knowledge, introduced into the economy, is called innovation."

[29] See e.g. *Lundvall* (1997).

[30] See e.g. *Cowan – Paal* (2000), *Lundvall – Borrás* (1997) and *OECD* (1996A). Knowledge-based or learning-based concepts are rooted in the understanding of industrial innovation, which was developed in the late 1980s and early 1990s. The literature on National Innovation Systems – see e.g. Chapter 2 in this report, *Lundvall* (1992) and Nelson (1993) – has been particularly important.

[31] See e.g. *OECD* (2000D). It is also remarkable that ICT sectors account for a major share of all business R&D in some countries - for example, in 1997, for more than one-third of all business R&D in Ireland and Finland, and more than one-fifth in countries such as Canada, France, Italy, Japan, Sweden and the USA.

- Second, after an accelerated diffusion during the 1990s, ICTs have become commonly used tools when it comes to supporting access to relevant and timely information. Applications, such as World Wide Web and Internet, enable faster diffusion of codified knowledge and networking[32]. To a certain extent, applications of ICT are key technologies and share common characteristics with general-purpose technologies[33].

Despite the importance of information (codified knowledge) and ICT as specific bodies of knowledge, the Knowledge-Based Economy also encompasses such concepts as the Information Society or Information Economy for at least two reasons[34]:

- A major difference between the two concepts is the complex nature of learning processes enabling the creation of new knowledge. During the cumulative process of enlarging the stock of knowledge, different forms of learning (e.g. learning-by-doing, learning-by using) take place and different kinds of useful knowledge must be absorbed[35]. Furthermore, the division of labour in each stage of the innovation process – ranging from the basic research end of the spectrum to the incremental improvements of already marketed products – requires frequent interaction and communication both within as well as between (specialised) organisations (in-house functions, suppliers, customers, collaborators, etc.). As a result, co-operation is a common feature of innovating firms[36].

- Although the widespread use of ICT raises important questions, such as those of re-organisation, improvement of user skills, infrastructure requirements, etc., the transmission of information can be considered a rather 'trivial' process, as opposed to the transfer of knowledge in general. Even when information is distributed or accessed via fairly complex communication systems with sophisticated functions, the repair of malfunctions is a purely technical matter. Lundvall (1997) has argued that the limitations of the transferability of tacit knowledge persist, even though it can, to a certain extent, be embodied in products,

[32] See e.g. *OECD* (2000B).
[33] A general purpose technology (GPT) is "[...] a technology that initially has much scope for improvement and eventually comes to be widely used, to have many uses, to have many Hicksian and technological complementarities" (*Lipsey* et al., 1998, p. 43).
[34] See e.g. *OECD* (1996, p.13): "Although the knowledge-based economy is affected by the increasing use of information technologies, it is not synonymous with the information society. The knowledge-based economy is characterised by the need for continuous learning, regarding both codified information and the competency to use this information."
[35] See e.g. *Rosenberg* (1982, 120ff.) and *Johnson* (1992).
[36] For a brief discussion of innovation models, see for example *Rothwell* (1994) or *Dodgson – Bessant* (1996). In the context of industrial innovation, *Patel – Pavitt* (1998) distinguish between 'specialisation by discipline within science and technology' and 'specialisation by corporate function inside the business firm'. Data from the recent Community Innovation Survey (CIS-II) reveal that during the innovation process, more than a quarter of innovating firms in Europe participate in collaborative ventures.

process equipment and software systems, such as business information systems and expert systems. Human skills, which are required to absorb, allow for and promote change, cannot be fully automated. If tacit, non-codified knowledge is involved, parties transferring knowledge face new forms of problems. For example, the transfer of knowledge between organisations or countries might require (i) substantial institutional learning[37], (ii) a transfer of individuals – moving knowledge by moving people – or (iii) an indefinite period of learning-by-using at the receiving side.

It becomes rather clear that the capability to participate in learning processes is essential for 'knowledge-based' organisations and economies. Innovation as an interactive learning process is based on the individual and institutional competencies to extend the already accumulated stock of knowledge[38] via the combination with knowledge from external sources. Access to distinct bodies of knowledge is essential and makes interactions indispensable. The acquisition of external knowledge might be as simple as the singular purchase of embodied knowledge (e.g. skilled human capital, machinery, etc.); however, it might also require the formation of specialised teams, which frequently interact either on the basis of projects which can be terminated or in permanent collaborative ventures.

What follows for a student of the Knowledge-Based Economy? First, the variety of forms of knowledge represented by individuals, information and technology matters, when innovation is understood as a cumulative process in which new knowledge is created by combining knowledge which already exists. It is also important to remember that both the sources (where has the knowledge been produced?) as well as the learning processes (how has it been produced?) may differ. Due to complementarities among the bits and pieces, the outcome of the innovation process depends on the availability of linkages enabling both interactions among all actors involved, as well as a smooth flow of knowledge. It follows that, for example, a lack of skills hinders innovation even when the most sophisticated technologies are available, and vice versa. Similarly, a country with an outstanding stock of scientific knowledge might show a poor innovative performance due to missing links to domestic industry. Furthermore, each stage[39] of the innovation process has specific knowledge needs (e.g. knowledge about the laws of nature in basic research, knowledge about user needs during the design of a product, etc.).

[37] Using a fairly broad definition of institutions as "sets of habits, routines, rules, norms and laws, which regulate the relations between people and shape human interactions" (*Johnson*, 1982, p. 26), allows us to transfer the concept of learning from individuals to organisations and even countries.
[38] The available stock of knowledge includes, inter alia, costless by-products of routine activities (learning-by-doing, learning-by-using) and formerly targeted efforts in R&D.
[39] This does not imply any plead for linear models of innovation, because even interactive and iterative processes can be regarded a sequence of (virtual) stages.

Second, in the Knowledge-Based Economy, innovation and diffusion are two sides of one coin. Once fed into the system, knowledge becomes part of the accumulated stock of knowledge within an economy and can be used in further (future) innovative activities. For example, as soon as an innovating firm comes up with a new product (e.g. machinery, software, etc.), new knowledge will be available for further innovative activities: within the producing firm, knowledge has been accumulated (during the innovation process), which will be available for the development of future products (e.g. a new version) or for collaboration with others. Simultaneously, on the user-side, the product will increase the stock of embodied knowledge and, for example, the machinery (or software) will make contributions to process innovation or product innovation within the user-firm (inter-firm knowledge spillovers)[40].

Third, from a knowledge perspective, human capital and ICTs play key roles. Ultimately, people carry out innovative activities; individual learning, interaction and communication are far from becoming fully automated processes. The tacit dimension of individual skills and capabilities can hamper the availability and flow of knowledge. Consequently, a lack of human capital will limit the speed of innovation, as well as the diffusion processes. ICTs seem to be another driving force in the Knowledge-Based Economy. ICTs (as a set of technologies) represent an ever-increasing body of knowledge, which has an impact on learning processes in all parts of the economy. As an infrastructure for the distribution of, as well as access to codified knowledge, some rather simple ICT applications such as PCs have already become indispensable tools.

Finally, the characteristics of learning processes during the creation and use of knowledge have important implications for the design and implementation of policies, which support innovation. To put it simply, policy plays an important role because it provides a general framework for learning, which shapes the extent and structure of innovative activities in an economy. Governments can shape the way into the KBE by addressing (i) the creation and (ii) the use of new knowledge. Single bodies of knowledge, such as science, skills and technology (for example ICT) can also be addressed. However, since innovation is an interactive learning process, based on the combination of different forms of knowledge stemming from a plenitude of sources, the provision of a framework which stimulates interactions between the parties involved in innovative activities has become ever more important.

[40] The example of an innovating firm should also make clear that innovative activities (learning processes) cause spillover effects; learning performed in order to solve a problem in a specific context will – at least for some time – make knowledge available which can be used for other purposes.

In summary, the Knowledge-Based Economy as an analytical concept addresses the role of knowledge and learning processes in the economy. It is an extended version of the Information Society, which has focussed on information and ICTs. Knowledge – as opposed to information (codified knowledge) – is at the heart of the explanatory framework and the creation of new knowledge (innovation) is that which must be investigated. Innovative activities, understood as learning processes, are by nature (i) cumulative, (ii) interactive and (iii) require different forms of knowledge (regarding information, skill bases, and technology).

## 3.3 Dimensions of knowledge generation

In principle, the notion of the Knowledge-Based Economy is derived from the fact that economic activities are mirrored in the sphere of knowledge. Rather general claims about the growing importance of the generation, distribution and use of knowledge as a 'new' and distinctive feature of economic development have provoked critique because all economic activity has always rested on knowledge, not only in our society but in all forms of human society.[41] As a result, the growth of knowledge itself is rather a sign of the cumulative nature of knowledge, than a proof of structural change.

Nevertheless, some developments, which took place during the last decade within the sphere of knowledge generation, seem to justify the notion of the KBE. Some emerging trends appear to be important, because they – in one way or another – either reflect structural change in the economy, or impact on the direction, as well as on the mode of knowledge generation. Attempts to capture the KBE have pointed at developments such as the increasing codification of knowledge, the role of software as a source of innovation, the role of information as a commodity, the expansion of services, the internationalisation of industrial R&D, the rapid diffusion of electronic commerce, the spread of New Technology-Based Firms (NTBFs), etc. To a certain extent, all these trends offer useful insights into economic developments within firms and specific sectors. However, their scope is limited, when it comes to evaluating their relevance to innovative activities in the overall economy.

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[41] *Cowan – Paal* (2000, p. 10) note that "[...] palaeolithic society was by any standards knowledge-based , and palaeontologists have demonstrated the existence of well-formed bodies of knowledge with respect to animal behaviour, pyrotechnology, materials, mining, symbolic communication and even medicine [...]". For a critical discussion of concepts of the KBE see also *Smith* (2000A, 2000B). Referring to Machlup, Chris Freeman formulated a critique of another strand of KBE-concepts as early as 1982: "[...] if a very wide definition of 'knowledge industries' is adopted, then Machlup has demonstrated that they already employed a quarter of the United States labour force in 1959. [...Machlup] estimated that over 30 per cent of the US labour force were engaged in occupations essentially concerned with producing and handling information rather than goods." (*Freeman*, 1982, p. 5).

In what follows, we will investigate the rather general question of structural change in the generation of knowledge, by looking at its dynamics along two main dimensions: individuals and interactions. Skills will be addressed first. Based on the discussion in the preceding chapter, innovation is a learning process and the overall skill base of an economy – in other words, the capability of its individuals to participate in innovative activities – is one of the determinants of success[42]. As argued earlier, all learning processes rest on interactions between specialised individuals and organisational units; consequently, not only the level of resources devoted to industrial innovation, but also the pattern of interaction and collaboration are important.

## The skill base: Steady growth of higher education

Innovation rests on human skills and competencies, which are required to absorb knowledge from different sources and to generate novel combinations. Conversely, a lack of skills or a limited transferability of knowledge (tacit, non-codified knowledge) can hamper flows of knowledge. It is, for example, rather obvious that the absorbent capacity of individuals matters and electronic access to more and better information alone is not sufficient for the generation of new knowledge.

During the innovation process, the necessary cognitive skills can be of rather general nature or highly specialised. Research and development for example, has a distinct need for individuals with an education in Science & Engineering (S&E) in one or several disciplines. Despite the importance of R&D in the innovation process, the education and training of the general labour force has an impact on innovative performance. As a result, an innovating economy needs a labour force, which has a significant proportion of members in both the high-skilled and medium-skilled segments.

[42] In this chapter, we use three indicators of human resources (attainment of education, human resources in science and technology, and R&D personnel). From the point of view of investment in knowledge generation, one additional measure, intangible investments (R&D, software, public spending on education) deserves to be mentioned. *OECD* (1999A) shows that since the mid-1980s, "investment in knowledge has grown slightly more rapidly than GDP in the OECD area". The indicator is problematic because a major proportion stems from public spending on education. Consequently, differences in efficiency and the institutional setting of educational systems limits cross-country comparisons. See also *Smith* (2000A, p.5) who questions other claims commonly derived from this indicator.

**Table 3.1: Percentage of the population that has attained at least upper secondary education or tertiary education; ranked according to age group 25-64 (Secondary education; 1998)**

| | At least upper secondary education | | | | | At least tertiary-type B | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 55-64 | 45-54 | 25-64 | 35-44 | 25-34 | 55-64 | 45-54 | 25-64 | 35-44 | 25-34 |
| Portugal | 12 | 14 | 20 | 20 | 29 | 7 | 8 | 9 | 9 | 11 |
| Spain | 12 | 23 | 33 | 38 | 53 | 8 | 14 | 20 | 21 | 32 |
| Italy | 19 | 35 | 41 | 50 | 55 | 7 | 8 | 9 | 9 | 11 |
| Greece | 22 | 36 | 44 | 52 | 66 | 8 | 13 | 16 | 19 | 22 |
| Ireland | 31 | 41 | 51 | 56 | 67 | 11 | 16 | 21 | 22 | 29 |
| Belgium | 34 | 51 | 57 | 61 | 73 | 14 | 22 | 25 | 28 | 34 |
| United Kingdom | 53 | 58 | 60 | 62 | 63 | 17 | 23 | 24 | 25 | 26 |
| France | 41 | 56 | 61 | 63 | 75 | 11 | 18 | 21 | 20 | 30 |
| The Netherlands | 50 | 56 | 64 | 68 | 74 | 17 | 23 | 24 | 26 | 27 |
| Finland (1997) | 41 | 62 | 68 | 78 | 84 | 18 | 27 | 29 | 33 | 36 |
| Austria (1997) | 56 | 68 | 73 | 78 | 84 | 6 | 10 | 11 | 13 | 12 |
| Sweden | 60 | 73 | 76 | 80 | 87 | 20 | 29 | 28 | 31 | 31 |
| Denmark | 67 | 78 | 78 | 80 | 85 | 19 | 27 | 25 | 27 | 27 |
| Germany | 76 | 84 | 84 | 87 | 88 | 19 | 25 | 23 | 26 | 22 |
| EU[1] | 41 | 53 | 58 | 62 | 70 | 13 | 19 | 20 | 22 | 25 |
| Japan | 57 | 77 | 80 | 91 | 93 | 13 | 23 | 30 | 40 | 45 |
| USA | 80 | 87 | 86 | 88 | 88 | 27 | 37 | 35 | 36 | 36 |
| Standard deviation EU | 20.358 | 20.594 | 18.351 | 18.483 | 16.521 | 5.248 | 7.329 | 6.652 | 7.529 | 8.394 |
| Coefficient of variation | 0.497 | 0.389 | 0.316 | 0.298 | 0.236 | 0.404 | 0.386 | 0.333 | 0.342 | 0.336 |

[1] Unweighted average.

*Source*: WIFO calculations, *OECD* (2000C).

The level of educational attainment is a proxy of the skills available in the labour force ('stock of human capital'). Countries still differ widely in the distribution of educational attainment across their populations (Table 3.1). However, differences between the education attained by younger and older persons have been shrinking. For example, a comparison of the education attained by persons aged 25-34 with those aged 55-64 shows tremendous growth in the number of persons completing an upper secondary education; a similar trend is evident in tertiary education. Consequently, this indirect measure of human capital reveals steady growth in the skill base available to the economy in all European countries. Compared to the United States, the European Union is still in a position of catching up –for Japan, this situation is reversed.[43]

The progress made during the last decade can be measured by comparing the rates of graduates in the age groups 35-44 and 25-34. Table 3.1 shows that Europe has progressed both the share of population with at least upper secondary education (from 62% to 70%) and with tertiary education (from 22% to 25%). From the point of view of cohesion, it is of particular interest that Spain and Ireland made significant progress in both upper secondary education (Spain: from

[43] For a comprehensive discussion of the empirical evidence see *OECD* (2000C).

38% to 53%; Ireland: from 56% to 67%) and in tertiary education (Spain: from 21% to 32%; Ireland: from 22% to 29%). However, Europe is still well behind the United States, and improving the qualification structure of the overall labour force will require time. As a result, initiatives for adult training and education have been gaining importance.

**Table 3.2: Human resources in science and technology; R&D personnel as a % of the labour force**

| | HRSTC as a % of the labour force | | R&D personnel as a % of the labour force | |
|---|---|---|---|---|
| | 1994 | 1999 | 1985 | 1998 |
| Belgium | 17.5 | 19.5 | 1.2 | 1.2 [3] |
| Denmark | 17.1 | 18.5 | 1.3 | 2.0 |
| Germany | 12.3 | 14.4 | 1.8 | 1.5 |
| Greece | 10.8 | 12.7 [1] | 0.6 [5] | 1.0 [2] |
| Spain | 8.9 | 12.7 | 0.6 [6] | 1.0 |
| France | 14.6 | 15.0 | 1.4 [5] | 1.5 [2] |
| Ireland | 11.2 | 13.9 [2] | 0.6 | 1.2 [3] |
| Italy | 6.8 | 8.1 | 0.7 | 0.8 [2] |
| Luxembourg | 12.8 | 17.1 | .. | .. |
| The Netherlands | 15.1 | 16.8 | 1.2 | 1.9 [2] |
| Austria | 6.3 [3] | 6.6 | 1.2 [5] | 1.2 [4] |
| Portugal | 6.8 [1] | 7.2 | 0.3 [8] | 0.6 [2] |
| Finland | 17.4 [1] | 18.0 | 1.3 [7] | 2.4 |
| Sweden | 19.5 [2] | 20.9 | 1.5 [7] | 2.4 |
| United Kingdom | 13.0 | 14.8 | 1.4 | 1.3 [4] |
| EU | .. | 13.5 | 1.2 | 1.3 |
| EU unweighted average | 12.7 | 14.4 | 1.1 | 1.4 |
| Standard deviation | 4.2 | 4.4 | 0.5 | 0.5 |
| Coefficient of variation | 0.3 | 0.3 | 0.4 | 0.4 |

[1] 1998; [2] 1997; [3] 1995; [4] 1993; [5] 1989; [6] 1988; [7] 1987; [8] 1986.
HRSTC = Number of persons with a tertiary education, who are also working in a S&T profession.

*Source*: WIFO calculations, SST EUROSTAT; European Commission (2001, p. 130 and p. 61).

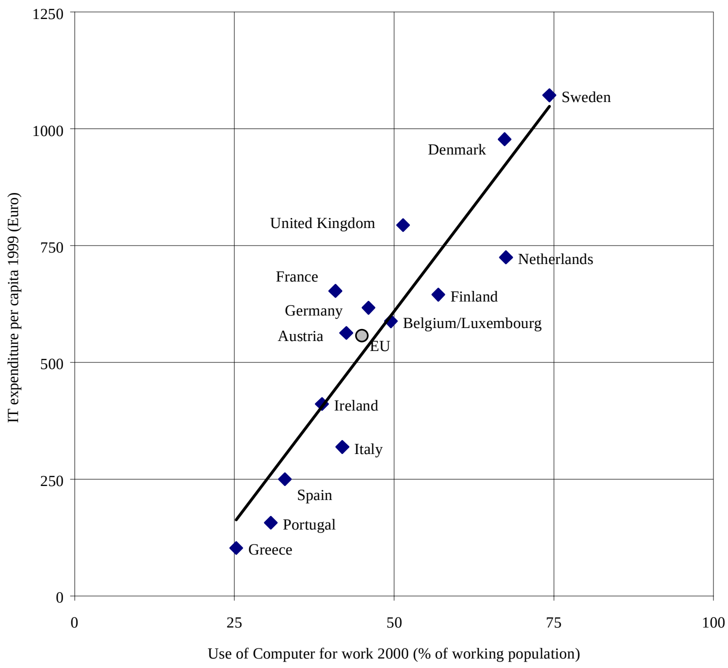
While the level of education attained is a proxy of the potential of available human resources, employment data reveal the actual use of human resources in a country. Two indicators are of particular interest: (i) the proportion of persons who have tertiary education and work in an S&T occupation (HRSTC) and (ii) R&D personnel as a percentage of the labour force (Table 3.2). According to the Community Labour Force Survey (CLFS), nearly 23.5 million people in the EU have a tertiary education and work in an S&T occupation. In 1999, Sweden had the highest overall level (20.9%) followed by Belgium (19.5%), Denmark (18.5%) and Finland (18%). Similar to educational attainment, HRSTC reveals significant improvement in the human resources dimension throughout the 1990s in the vast majority of European countries; some of them, most notably Spain, Ireland and Luxembourg, even grew more quickly.

For most innovative activities, R&D is particularly important, and human resources are the keys to success. Over the longer term (during the period 1985 to 1998), R&D personnel as a percentage of the total labour force grew – with the Nordic countries Finland, Sweden, and Denmark leading the field (Table 3.2). Despite marked increases in a number of countries, growth in the European Union was moderate (an increase from 1.18% to 1.27%), reflecting significant decreases in the proportion of R&D personnel in Germany and the United Kingdom; the latter was the only member of the EU with a slight decrease in R&D personnel, as estimated in terms of volume. Again, from the point of view of cohesion, it is of particular interest that Greece, Ireland, Portugal and Spain doubled their stock of research personnel. As a consequence, in these countries the increase of R&D personnel as a percentage of the economically active population was particularly high.

From the point of view of skills, one additional aspect deserves to be mentioned: technical change and the danger of an eroding skill base. During the 1990s, ICTs became a common form of infrastructure for social and economic life and thereby challenged the educational system[44]. For example, in the European Union, PC-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) in the EU saw an even more dramatic increase (from 31 to about 1,600). In many countries, computers are common as well, as increasingly indispensable tools for the majority of the working population (Figure 3.1). As a result, not only the infrastructure, but also the skills required for the creation, processing and distribution of codified knowledge have changed dramatically.

[44] For a discussion of information and communication technologies in the EU during the 1990s, see also the European Competitiveness Report 2000 (*European Commission*, 2000, pp. 35-42). The relationship between ICT investment and growth of output, as well as productivity, will be discussed in detail in Chapter 4 of this year's Competitiveness Report, which also includes an annex on skill shortages in ICT and policy responses.

**Figure 3.1: IT-intensity and use of computer for work**




*y = 18.065x – 293.77;* $R^2$ *= 0.839*

*Source*: WIFO calculations using EITO (2001), Eurobarometer, November 2000.

In conclusion, the education attained by workers and general skill levels has risen across the European Union. In most countries, both R&D personnel, as well as the number of persons with third level education, who are working in science & technology professions has grown. During the innovation process, high quality labour is particularly important. As a result of the uneven pattern of development, further efforts to improve the qualification structure in the overall labour force will be necessary in most Member States. Furthermore, technical change – in particular the growing importance of ICTs as common tools at work – demands a comprehensive response from education and training policies.

## Shifting the frontier of knowledge: Innovation as an interactive process

Innovation is a complex learning process and firms draw knowledge from a 'distributed knowledge-base'[45]; from the perspective of the innovating firm, relevant knowledge used during this process is not only internal, but distributed according to source and type of knowledge. The

[45] The term "distributed knowledge base" has been used in *Smith* (2000B) for mapping knowledge-flows across particular industries.

specialisation of "knowledge-generators" makes external links, such as inter-firm-linkages indispensable. The Community Innovation Survey (CIS2) [46] produced new evidence on the role of external sources and knowledge-flows:

- The structure of innovation expenditures reveals that both internal problem-solving activities and embodied knowledge – 'technology' in the form of machinery, equipment and software – play important roles in the innovation process. On average, about 75% of total innovation expenditures are spent on intramural R&D and machinery & equipment. While in large firms, the share of R&D tends to be higher (on average about 58%; machinery & equipment about 16%), small firms show a reverse pattern (R&D about 21%; machinery & equipment 56%).

- During the innovation process, the innovating firm interacts – or even collaborates – with other institutions. In manufacturing, about 45% of process innovators and 67% of product innovators developed the innovation on their own. In both fields, the percentage of firms, which collaborated, with other firms is significant: 29% of process innovators and 25% of product innovators. The partners of collaborating firms vary widely: On average, the most common partners are customers (21%), followed by suppliers of equipment, materials, components & software (20%) and universities and other institutes of higher education (15%).

Close linkages, in particular collaboration, have become a common pattern of innovation, on both local (regional), as well as global scales. There is wide evidence that localised interaction – the formation of industrial districts and clusters – offers advantages for collective learning[47]. Innovating firms might benefit not only from proximity in a geographical, cultural and social sense, but also from the localised capabilities of a region (e.g., a region’s infrastructure and institutional endowment)[48]. Consequently, innovation policies address the needs of localised knowledge creation by improving the region’s distinct institutional endowment (for example, the provision of specific human resources, science parks, assistance through formal and informal networking).

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[46] Selected results of the Community Innovation Survey (CIS2), which was organised by the European Commission and conducted during 1997/98 in 17 EEA countries, are presented in *European Commission* (2001, pp. 93-110).
[47] For example, *Amin – Wilkinson* (1999), *Cooke – Morgan* (1994) and *Marceau* (1994). Collective learning may be defined as "the creation and further development of a base of common or shared knowledge among individuals within a productive system." (*Lawson*, 1999, p. 159).
[48] See *Maskell – Malmberg* (1999). *Lundvall – Borrás* (1997) discuss policy instruments and programmes aimed at sustaining existing networks or creating new linkages.

In an increasingly globalised world economy, the distributed knowledge base of innovating firms is not confined to a (spatially) narrow environment. MERIT's CATI-Database on international strategic technology alliances reveals that industrial firms increasingly form strategic technology alliances for transferring technology or joint research between domestic and international partners. For example, the number of new partnerships set up annually increased from about 30-40 in the early 1970s to around 600 or more in the 1980s and 1990s. Inter-firm-co-operation has become increasingly concentrated in a small number of high-technology industries. During the 1990s, the growth of inter-firm technology collaboration was particularly high in biotechnology (Table 3.3) [49].

**Table 3.3: International strategic technology alliances: 1980-1998, by technology (counts, share in %)**

| | 1980-1984 | 1985-1989 | 1990-1994 | 1995-1998 | 1981-1998 | 1991-1998 |
|---|---|---|---|---|---|---|
| | Counts (Share in %) | | | | Growth p.a. | |
| Information Technology | 469 | 927 | 1132 | 1135 | 9.99 | 2.75 |
| | (36.5) | (36.5) | (45.7) | (42.7) | | |
| Biotechnology | 230 | 499 | 490 | 633 | 7.81 | 11.56 |
| | (17.9) | (19.6) | (19.8) | (23.8) | | |
| New Materials | 122 | 317 | 186 | 146 | 8.17 | 0.70 |
| | (9.5) | (12.5) | (7.5) | (5.5) | | |
| Aerospace & Defence | 82 | 137 | 225 | 139 | -0.81 | -12.24 |
| | (6.4) | (5.4) | (9.1) | (5.2) | | |
| Automotive | 51 | 169 | 60 | 130 | -0.62 | 4.45 |
| | (4.0) | (6.7) | (2.4) | (4.9) | | |
| Chemicals (non-biotech) | 150 | 231 | 246 | 183 | 1.58 | 1.51 |
| | (11.7) | (9.1) | (9.9) | (6.9) | | |
| Other | 182 | 260 | 138 | 289 | 0.92 | 13.25 |
| | (14.2) | (10.2) | (5.6) | (10.9) | | |
| Total | 1286 | 2540 | 2477 | 2655 | 5.67 | 3.33 |
| | (100) | (100) | (100) | (100) | | |

*Source*: WIFO calculations using CATI (MERIT).

The interactive nature of the innovation processes is not confined to inter-firm linkages. As mentioned above, universities and institutes of higher education do play an important role in the collaborations of innovating firms. The interplay between science and industry is multifaceted, as the inter-sectoral co-authorship of scientific publications[50] and the bibliometrics of patent documents[51] reveal. For example, in a number of fields of technology, the citation linkage between patents and scientific papers is rapidly growing. Since scientific findings provide, at the very least, important background information, the absorption of tacit knowledge in science-

[49] For a detailed discussion of research partnerships see *Hagedoorn – Link – Vonortas* (2000).
[50] See e.g. *Godin – Gingras* (2000).
[51] See e.g. *Meyer* (2000).

related fields requires a certain degree of scientific education. Furthermore, basic science can, inter alia, offer access to research methods, as well as enable participation in international knowledge-networks.[52]

During the last decades, changes have evolved in both the modes of knowledge generation and its content. Some fields of economically relevant knowledge have seen tremendous growth. Patenting data from the USPTO[53] reveal that Biotech and ICT are among the fastest growing fields of inventive activity. For example, during the first half of the 1980s, certain patent classes such as *Active Solid-State Devices (includes e.g. transistors)*, *Semiconductor Device Manufacturing, Data Processing, Electrical computers, Drugs, Bio-Affecting and Body Treating Compositions, Molecular Biology and Microbiology* accounted for a significantly lower proportion of patents granted than in the second half of the 1990s. Due to the extraordinary growth in the ICT-sector, patents classified as electrical have now outnumbered chemical patents and challenge the lead of mechanical inventions (Table 3.4).

**Table 3.4: Utility patents granted by the USPTO in technological classes**

| | Period 1 (1990-1994) | | Period 2 (1995-1999) | | Share by classes (%) | | | Increase between periods |
|---|---|---|---|---|---|---|---|---|
| | Patents granted | Average | Patents granted | Average | Period 1 | Period 2 | 2000 | Increase of patents granted (%) |
| Chemical Classes | 142782 | 28556 | 177506 | 35501 | 29.5 | 28.4 | 26.9 | 24.3 |
| Mechanical Classes | 216823 | 43364 | 246701 | 49340 | 44.8 | 39.5 | 39.4 | 13.8 |
| Electrical Classes | 124726 | 24945 | 199750 | 39950 | 25.8 | 32.0 | 33.7 | 60.2 |
| All Classes | 484331 | 96866 | 623957 | 124791 | 100.0 | 100.0 | 100.0 | 28.8 |

*Source*: WIFO calculations using U.S. Patent and Trademark Office.

In conclusion, policies aimed at improving the general conditions and particular circumstances affecting the capabilities of firms to innovate must take the interactive nature of innovation processes into account. Innovation is a complexly networked activity and innovating firms depend on inputs from a knowledge base that is distributed according to spatial considerations, as well as specialisation. Not only the localised capabilities of a region, but also the international knowledge-flows matter. Especially for science-related fields (e.g. biotech and ICT), which have shown particularly strong growth in terms of inventive activity, both the

[52] For a comprehensive discussion of linkages between science and technology, see, e.g. *Rosenberg* (1982) and *Pavitt* (1993).
[53] U.S. Patent and Trademark Office.

locally provided research infrastructure – in particular universities – and knowledge from international sources are vital.

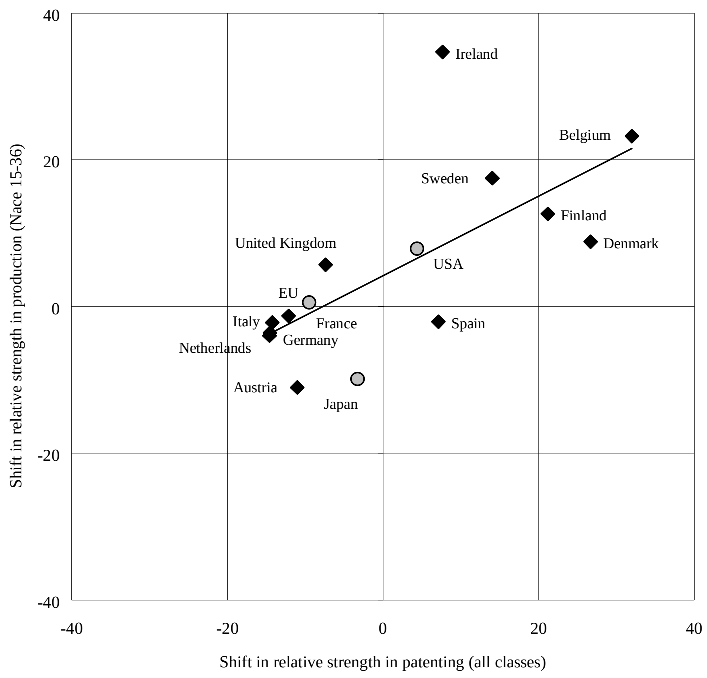
## 3.4 Policy options from a knowledge perspective

Traditional measures of technological activity suggest that the creation of new knowledge have important economic implications. For example, Figure 3.2 shows the dynamics of inventive activity and the dynamics of manufacturing production during the 1990s. Countries with an increasing share of patents relative to the Triad tend to increase their share of economic output in manufacturing. Similarly, in addition to spillover effects, firm-level evidence reveals a positive impact of R&D on the growth of firms.[54] Consequently, investments in knowledge creation are clearly vital to growth, and innovation policy is therefore a central concern of governments.

Within the analytical framework of the Knowledge-Based Economy, the main policy goals are the improvement of innovative capabilities and the expansion of innovative activities within an economy. The major difference to traditional approaches is the underlying systemic view of strategies and measures. Innovation is understood as an interactive learning process based on different modes of learning, different types and sources of knowledge, and specific capabilities at the individual and institutional levels. Policies supportive of the KBE intend to foster both the creation of new knowledge (improving the stock of knowledge), as well as the establishment of a framework for the better exchange and utilisation of knowledge (Box 3.1); the ideal policy mix addresses both innovative activities and the diffusion of technologies and applications because the use of technologies might well add to the existing stock of knowledge. This becomes quite clear in the case of ICT, and as a consequence, several initiatives by Member States are formulated under headings such as Information Society and Network Economy.

[54] See Chapter 6 in this report.

**Figure 3.1: Dynamics of inventive activity and production in the 1990s**[55]




$y = 0.5424x + 4.1775; R^2 = 0.4599$

*Source*: WIFO calculations using information from the U.S. Patent and Trademark Office and EUROSTAT (New Cronos).

[55] The shift in the relative strength in patenting is calculated via the average number of patents granted to one country relative to the number of patents granted to all countries in the Triad during the periods 1990-1994 and 1995-1998; the shift between these two periods (in %) is interpreted as a measure of the dynamics during the 1990s. Due to the limited availability of data, the indicator has been calculated for Austria, Belgium, Denmark, Finland, France, Germany, Ireland, Italy, Japan, the Netherlands, Spain, Sweden, the United Kingdom and the USA; by the same token, for calculations, this sample represents the Triad. The dynamics of production were calculated analogous to the dynamics of inventive activity. However remind that patents are referring to all sectors, while production is measured for manufacturing. We believe that most of the patents are applied in manufacturing, this must however not be the case for all patents.

**Box 3.1: The "new" diversity of innovation support policies**

During the 1990s, innovation policy was gaining importance in all EU Member States. Depending on their particular needs, and with varying degrees of emphasis, countries were developing new strategies and increasingly addressing the challenge of providing a framework which stimulates both the extent and direction of innovative activities, as well as interactions between the parties involved. Increasingly, policies were going beyond the traditional demarcation line of science and technology policy. The effectiveness of these policies was improving due to the provision of links with other policies and the stimulation of interactions between them.

The measures are not necessarily novel. Establishing additional publicly-funded programmes, implementing initiatives intended to shape the scientific research agenda and stimulating the interaction between science and industry is not new at all. However, the design and implementation of the measures reflects changes in perspective. An improved understanding of innovation as an interactive learning process based on the innovative capabilities of individuals, firms, and regions has prompted diversity in practice. Science has proven to be an increasingly important body of knowledge and, in a dynamic view, technology-based firms in new growth areas attract the attention they deserve.

**Innovation rests on human skills**

Recent reforms in Member States have increasingly addressed the supply of human resources and in particular, the need for trained scientists and engineers. For example, in order to consolidate its position as a leading research nation, the Swedish Government has decided to invest in 16 graduate schools, specialising in fields, which reflect priority research areas. Similarly, Austria has made major efforts to reform its university system. Since 1994, the government has developed 43 'Fachhochschule' study programmes (polytechnics), in close co-operation with industry; a primary goal has been to alleviate the problem that research students often lack the skills required by employers. Furthermore, a 1999 amendment of the University Studies Act allows for shorter university courses of study (bachelor’s degree). Over the longer term, the Austrian system of higher education will resemble the German and Finnish systems, which comprise two parallel sectors (universities and polytechnics). Several countries, including Finland, have already reacted to the increasing demand for lifelong learning and offer a wide range of short-term courses for graduates of higher education, as well as continuing education for professionals.

**Enhancing innovative capabilities of firms**

In most member countries, public support for industrial R&D has a long tradition and, during the 1990s, some governments decided to increase R&D funding significantly. For example, in Portugal, the budgetary share allocated to science & technology doubled from 1.08% in 1988 to 2.08% in 1999, and interalia since the Finnish government increased public R&D funding. A number of countries have introduced new R&D tax schemes or have modified existing provisions. In many cases, the design of tax incentives supports policy objectives beyond a mere extension of business R&D expenditures and contributes, for example, to an increase in human capital or supports the special needs of start-ups and SMEs. A tax reduction scheme in the Netherlands allows employers to reduce income tax and social security payments for R&D-employees. Belgium operates a system of R&D tax credits and tax benefits for firms, which hire R&D personnel. The British Government introduced tax incentives in order to stimulate R&D in SMEs.

**Strengthen the innovative competencies of regions**

From a regional point of view, the formation of networks and clusters enhances the competitiveness of local firms and improves the region’s attractiveness as a business location. In some Member States, networking and cluster initiatives date back to the early 1990s; others have designed initiatives only recently. In Spain, for instance, the National Plan for R&D 2000-2003 designates 12 strategic, sectoral high-growth areas for which programmes will be co-ordinated with regional policies – implemented by Spanish autonomous communities – and linked to existing clusters. The British Government announced in its budget for the year 2000 a £50m Innovative Clusters Fund, designed to allow

| | |
|---|---|
| | Regional Development Agencies (RDAs) to co-finance business incubation and small scale infrastructure; £15m was allocated to RDAs for 2000-01. Additional funds have since been allocated to boost the funding for 2001-02 to £54m. This new Regional Innovation Fund will be used by RDAs to support clusters and networks of businesses. Similar initiatives in Austria, Denmark, Germany, Ireland, the Netherlands and Sweden will encourage knowledge sharing between (specialised) firms and establish regional partnerships (involving municipalities, local business associations, universities and regional authorities). |
| **Securing world-class research in science** | Publicly funded research infrastructure and universities constitute an important element in national systems of innovation. During the 1990s, several countries developed programmes aimed at the creation of specialised Centres of Excellence (CoE) in scientific research. As a result, a leading position in well-defined priority areas, the absorption of knowledge developed abroad and participation in international knowledge-networks will be improved. During the last decade, several countries have chosen this approach. For example, the Danish National Research Foundation supports 25 Centres of Excellence; the Dutch Government has introduced BROCHURE (Bonus incentive scheme for research schools); and Finland extended its CoE Programme to the funding of umbrella organisations which produce core facilities and infrastructure, which can be shared by several research groups. |
| **Industrial rejuvenation: Technology-based firms in new growth areas** | New technology-based firms (NTBFs), which – at least over the longer term – will fulfil an important role in the economy, face severe difficulties in accessing key resources, including finance, human resources, managerial skills, etc. Start-up policies are increasingly adopting a systemic approach of going beyond the mobilisation of risk capital. The French Innovation Law of 1999 is quite typical: The law encourages the transfer of technologies from public research into the economy and the founding of innovative enterprises. Furthermore, it places significant emphasis on the creation of NTBFs through incubators within universities and public research infrastructures, as well as the establishment of national and regional priming funds. Incubators – e.g. the Danish Technology Incubators, the Dutch Twinning Programme, and the Irish 'Campus Companies', - are in close association with the existing innovation infrastructure (science and technology parks, universities, venture capital industries, etc.). The focus of the NTBF's entrepreneurial activities is mostly in science-based areas such as biotech and ICT. Consequently, initiatives include measures to enhance networking, as well as to improve the climate for spin-off creations from universities. The German EXIST programme, for example, supports several regional networks of universities, research institutes, venture capitalists, private companies and consultants, chambers of trade and commerce, science parks and business centres. |

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# Chapter 4: ICT investment and growth of output and productivity

**HANNES LEO**

## 4.1. Introduction

Information and communication technology (ICT) may well be the most important modern technology and certainly a core element of the Knowledge-based Society. Expenditure on, production shares of and investment in ICT are rising, albeit at different rates of growth across member countries and between the EU and the USA. ICT has a significant impact on growth of GDP and productivity, although the scope of this impact are still subject to scientific controversy.

The consensus is growing that the "new" economy does have an economic impact. This is mirrored by Robert Solow who recently declared as obsolete his famous paradox that "we can see the computer age everywhere but in the productivity statistics"[56]. His change of mind was obviously based on the remarkable performance of the US economy, and on research on the growth and productivity impact of information and communication technology (ICT).[57]

In the 1990s, several causes combined to accelerate ICT diffusion and growth: technological change was coupled with massive price cuts, which made for a surge in digital technologies, that appears to be limited in its spread solely by the bottleneck created by the ability of individuals, enterprises and society to integrate these technologies in daily routine tasks. The Internet has spread much faster than other key inventions (thus it took electric light, electric motors and the internal combustion engine some decades to diffuse). An already existing predisposition of firms to exploit the opportunities of ICT, liberalisation of telecommunications and growth features of the Internet economy (economies of scale and network effects) together brought new vigour and eagerness to invest in new technologies. In the USA, business investment in computers and peripheral equipment, measured in real terms, jumped more than fourfold between 1995 and 1999 (see e.g. *Oliner – Sichel*, 2000). A rapid increase is also detectable in Europe, though not at the same pace as in the USA.

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[56] Cited in *Gordon* (2000)
[57] See for example *BLS*, 2000, *EU*, 2000, *Daveri*, 2000, 2001, *Gordon*, 2000, *Jorgenson – Stiroh*, 2000, *Kiley*, 2000, *OECD*, 2000, 2001, *Oliner – Sichel*, 2000, *Whelan*, 2000: studies which account for the positive impact of ICT on aggregate output and productivity growth.

Nevertheless, there are still divergent opinions of the overall importance of ICT for the economy, most notably on the productivity impact of ICT investment. The debate on the significance of the "new" economy primarily discusses the magnitude of the impact of ICT investment on economic development in non ICT producing sectors. Sceptics confine the impact of these developments to the ICT-producing industries. Recent research rather supports the view that the impact of ICT is felt in wider parts of the economy and thus has a positive effect on output and productivity growth, which in turn further raises the importance of this topic for economic policy.

The following chapters first report trends for ICT expenditure, production and investment and analyse country differences (Section 2). Then we discuss the methodological issues related to measurement of the output and productivity growth impact of information technology (Section 3), ICT expenditure and investment trends in Europe and the USA (Chapter 3). We present studies which quantify the impact of ICT on aggregate growth-cyclical effects and spillovers on labour. Chapter 5 provides a summary of findings thus obtained.

## 4.2. International trends in ICT spending and investment

### 4.2.1. ICT expenditure

The importance of ICT can be measured in terms of expenditure, production and investment. All are increasing, though at different rates in different countries. Expenditure in Europe seems to be more cyclical and, on average, lower than in the USA, although there are some noteworthy exceptions: Sweden and the UK spend as much on ICT as the USA.

ICT expenditure measures the diffusion of ICT goods and thus the absorption of ICT by businesses, private households and the government sector. Consequently, the readiness of firms to invest in these technologies and the willingness of private households and the government to use them impacts on the overall ranking of countries.

*Country differences and overall gap*

The available indicators on ICT spending reveal distinct differences in the level of expenditure between OECD countries. Sweden, and the UK in Europe, and Australia and the USA take the lead, spending about 8% per GDP for 1999, followed by the Netherlands and Denmark with expenditures close to 7%. France, Germany, Italy and Spain (the other large European countries) are grouped around or below the European average (1999: 5.6%). This European pattern is thus very heterogeneous: Small countries like Sweden, the Netherlands, Denmark and the UK exhibit ICT expenditure levels which are above or close to the United States. Germany, Italy and Spain – the large countries which significantly impact on average spending in Europe – are lagging behind. The overall result is that the expenditure share is 2.5 percentage points or nearly one third lower per GDP spending than in the USA.

**Table 4.1: International comparison of ICT investment and production**

| | Share of ICT in business sector employment, 1998 | Share of ICT in business sector value added, 1998 | ICT expenditure as a % of GDP, 1998 | ICT expenditure as a % 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 1) | 4.0 | 6.4 | 6.0 | 5.6 |
| Japan | 3.4 | 5.8 | 6.2 | 6.0 |
| USA | 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 |

1) Weighted average (with GDP 1990), WIFO-calculations.

*Source*: *OECD*, 2001A, *WITSA*, 2000, WIFO calculations.

The European spending gap correlates with the smaller ICT-producing sector (see *McMorrow – Roeger*, 2000) but also comes from 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: the ICT producing sector encompasses only 2.6% of overall business sector employment, even though Australia is among the big ICT spenders.

### *Expenditure follows business cycle in Europe*

Throughout the 1990s, overall ICT spending increased both in Europe (+6.5% p.a.) and the USA (+7.8% p.a.), substantially accelerating in the second half of the decade (EU +3.7% p.a., USA 6.2% p.a., see Table 4.2). ICT expenditure increased far more steadily in the USA than in Europe (see Figure 4.1). The annual growth rates in Europe seem 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 low GDP growth. In the USA the overall growth performance and the growth of ICT expenditure are smoother but seem to be similarly coupled.

**Box 4.1: Data availability and definitions of ICT expenditure**

ICT expenditure measures the diffusion of computer hardware and peripherals, communications equipment and software. For Europe no official data are available, but figures are derived from surveys by private sources. The predominantly used data source is collected by IDC (*WITSA*, 2000). EITO also uses IDC data as a source and publishes its ICT expenditure data based on some adaptations of IDC data. Less frequently used sources are data from REED and Credit Suisse First Boston. It should be noted that ICT expenditure encompasses spending by businesses, private households and the government sector. To analyse its impact on output, growth and productivity investment figures are needed.

The data collected by ICD is gathered both at country level and from corporate headquarters[58]. ICD is the only available source for European countries which allows systematic cross-sectional comparisons for the 1992–1999 period. As ICD 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.

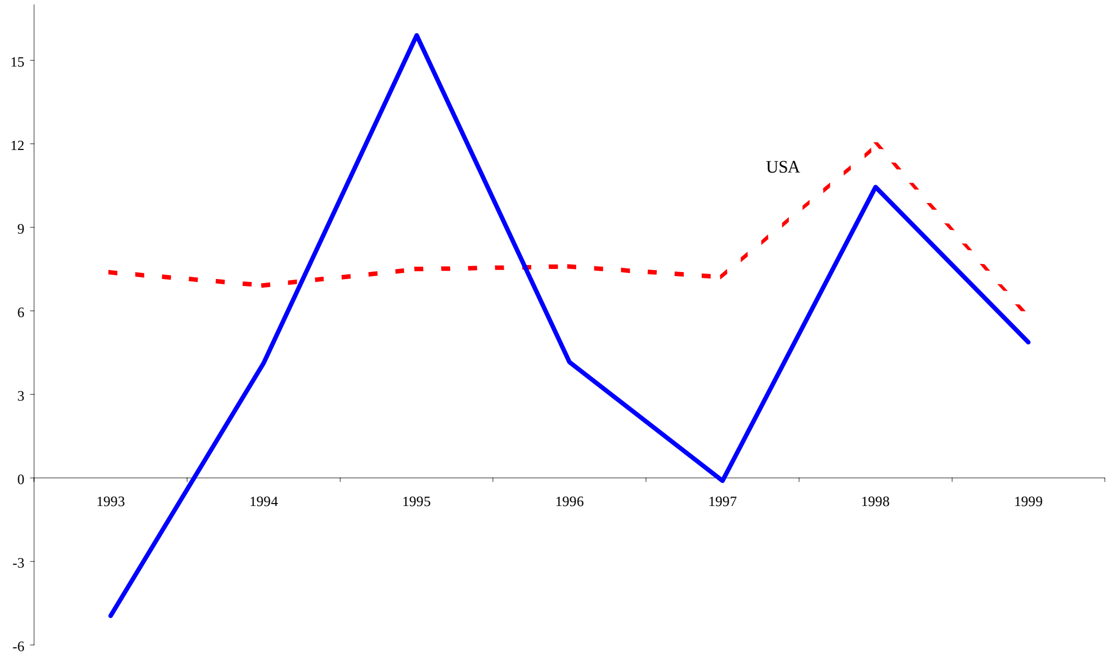
As these data sets are somewhat difficult to assess in their quality, OECD was motivated to extract ICT investment figures from the System of National Accounts 1993 (SNA 1993). This approach renders information for a limited number of countries as the SNA 1993 guidelines are not systematically implemented by all countries (see *OECD*, 2001B).

The situation in the USA 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, *EU*, 2000, *WITSA*, 2000, *Oliner – Sichel*, 2000, *Landefeld – Grimm*, 2000.

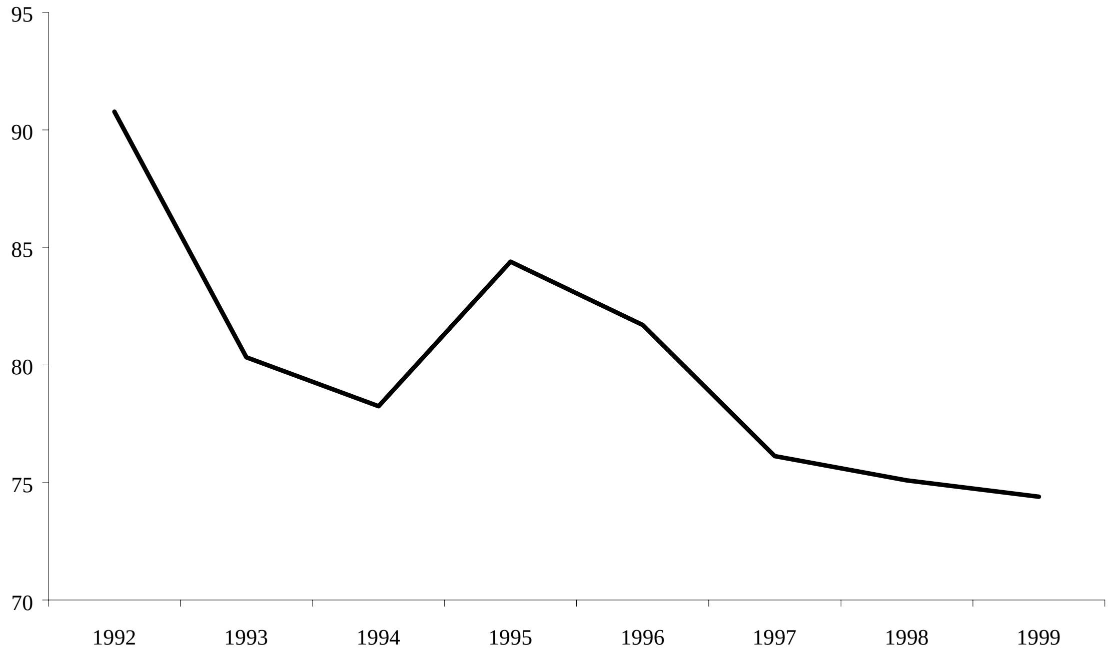
[58] IDC data collection takes place at country and corporate headquarters levels. Each local IDC office conducts interviews with local computer vendors and distributors. These data are compared with information from multinational vendors, collected and updated at IDC headquarters and regional research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

**Figure 4.1: Annual growth rate of nominal ICT expenditure in the USA and Europe**




*Source*: *WITSA*, 2000, WIFO calculations.

**Figure 4.2: European ICT expenditure in % of US expenditure**




*Source*: *WITSA*, 2000, WIFO calculations.

*The gap widens for EU total*

The gap between ICT shares in Europe and the USA has widened since 1992 (exactly 2.3% in 1992 and 2.7% in 1999). Since, however, GDP in the USA is growing faster, the growth of ICT expenditure is more dynamic. Measured relative to US expenditure, European expenditure in ICT declined from 90% in 1992 to 75% in 1999 (see Figure 4.2).

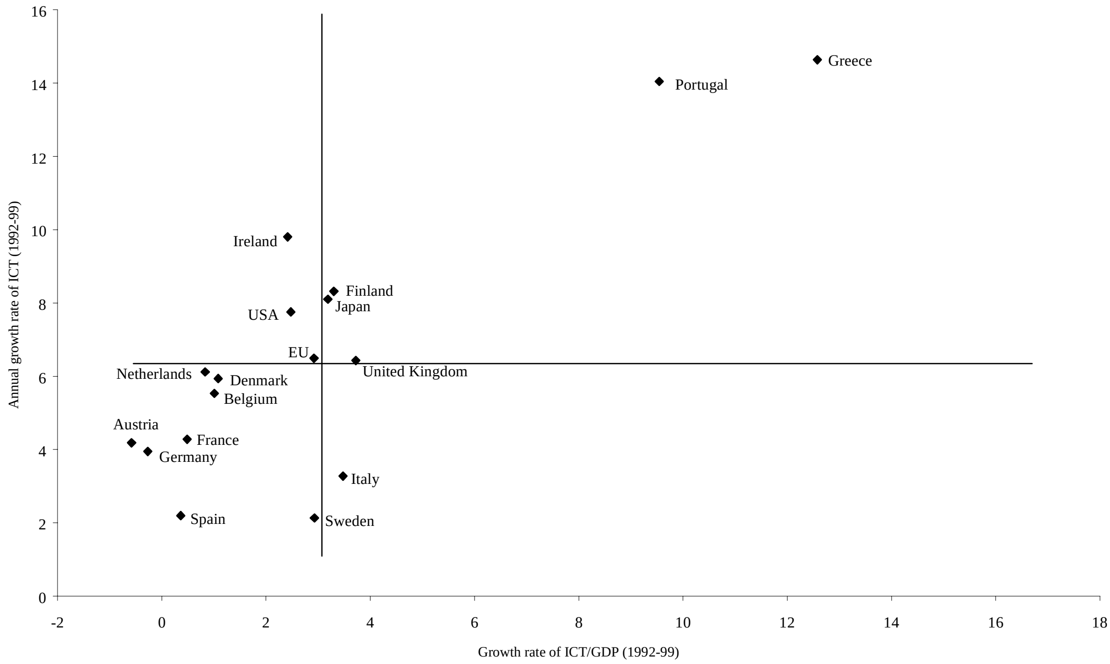
### Table 4.2: Annual growth rates of ICT expenditure (1992–1999)

| | Annual growth rate | | | Acceleration |
|---|---|---|---|---|
| Country | 1992-95 | 1996-1999 | 1992-1999 | second half - first half |
| Belgium | 6.8 | 4.7 | 5.5 | -2.1 |
| Denmark | 7.6 | 4.6 | 5.9 | -3.0 |
| Germany | 5.8 | 3.8 | 3.9 | -2.0 |
| Greece | 23.7 | 7.7 | 14.6 | -16.0 |
| Spain | -1.7 | 3.5 | 2.2 | 5.2 |
| France | 5.7 | 3.5 | 4.3 | -2.2 |
| Ireland | 9.4 | 9.7 | 9.8 | 0.3 |
| Italy | 0.3 | 3.8 | 3.3 | 3.5 |
| Netherlands | 7.0 | 6.2 | 6.1 | -0.7 |
| Austria | 5.1 | 4.4 | 4.2 | -0.7 |
| Portugal | 24.9 | 6.2 | 14.0 | -18.7 |
| Finland | 12.6 | 5.6 | 8.3 | -7.0 |
| Sweden | -1.7 | 4.0 | 2.1 | 5.7 |
| United Kingdom | 4.2 | 8.5 | 6.4 | 4.3 |
| EU | 4.7 | 5.0 | 4.7 | 0.3 |
| USA | 7.3 | 8.3 | 7.8 | 1.0 |

*Source*: *WITSA*, 2000, WIFO calculations

The most dynamic European countries with respect to ICT expenditure growth are Greece, Portugal Ireland and Finland (see Figure 4.3, Table 4.2 and 4.3). All of them increased their share of ICT expenditure per GDP in the 1990s and are now above or close to the European average (see Figure 4.2). The same applies – although at a lower level – to the Netherlands, Denmark, Belgium and the UK. In contrast, countries like Spain, Italy, Austria, France and Belgium on average showed below-EU-average growth of their ICT expenditures in the 1990s, and consequently a more or less stagnating share of GDP devoted to ICT. Germany and Austria even experienced a reduction of ICT expenditure per GDP.

**Figure 4.3: Growth rate of ICT expenditures and ICT expenditures in % of GDP**




*Source*: *WITSA* 2000, WIFO calculations

There are four countries which deserve special attention as they somewhat disturb rather systematic pattern: Greece, Portugal, Italy and Sweden. Sweden maintained its high level of ICT expenditure over the 1990s even if the growth rate of ICT expenditures was below European average. It should be noted that the USA, which spend about as much on ICT as Sweden, had to increase its ICT spending level significantly to achieve this level of ICT per GDP. Italy slightly increased its ICT spending per GDP, however this reflected more sluggish growth of GDP than high growth of ICT expenditures. In Greece and Portugal, the high growth rates were driven by heavy investment in the telecommunications infrastructures – an investment which the majority of European countries had already made in the first half of the 1990s.

Overall, the acceleration of ICT spending between the first and second half of the 1990s is in Europe not as pronounced as in the USA. This is clearly visible at the country level (see Table 4.2): In the second half ICT expenditures grew faster only in UK, Sweden , France, Italy, Ireland and Spain thus contributing to the overall acceleration in Europe.

### Table 4.3: ICT in % of GDP and growth rates for ICT in % of GDP

| Country | 1992 | 1995 | 1999 | Difference 1999 - 1992 | Annual growth rate of shares 1992-99 |
|---|---|---|---|---|---|
| Belgium | 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 |
| USA | 7.5 | 7.9 | 8.9 | 1.4 | 2.5 |

*Source*: *WITSA*, 2000, WIFO calculations.

### Table 4.4: Nominal investment in ICT in % of GDP

| | ICT investment/GDP | | | Total fixed investment/GDP | | |
|---|---|---|---|---|---|---|
| | 1992 | 1999 | Difference 1999-1992 | 1992 | 1999 | Difference 1999-1992 |
| Belgium | 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 | 2.37 | 0.56 | 20.72 | 21.26 | 0.54 |
| USA | 2.60 | 4.54 | 1.94 | 17.01 | 20.33 | 3.32 |

*Source*: *Daveri*, 2001, WIFO calculations for EU average.

### 4.2.2. ICT investment

ICT expenditure includes expenditure by private households and the government sector. Nevertheless it is the business sector which provides the relevant figures for estimating the ICT impact on output and productivity investment.[59]

Based on the calculations of Daveri (2001) nominal ICT investment in 1999 is about a third of nominal ICT expenditure. The main trends for investment are identical to those outlined above for ICT expenditure. US investment level is higher, Europe's investment is growing cyclically and declining relative to the USA. However, none of the European countries – and this is contrast with ICT expenditure – reaches the US level for ICT investment. The latter may be due to the different weighting of the components (hardware, software, communications equipment) in the calculation of ICT investment for Europe.

The rapid diffusion of information technology is mirrored in the rising share of ICT investment goods in non-residential gross capital formation in the business sector. In 1999, about one third of all investments in Finland and the US business sector were devoted to ICT goods (see Table 4.5, *OECD*, 2001A). In Australia, this share encompassed about one fifth of business sector investment. In France, Germany, Italy and Japan – the other countries in the sample – the level of investment in ICT was about half as large as in the USA and in Finland. The rapid increase of ICT investment – which is discernible in all countries – accounted for about 50% of the rise in investment in the US business sector.

This eagerness to invest in the new technology was somewhat surprising given the long-lasting discussion of the "productivity paradox" which "complains" about the missing productivity impact of investment in computing equipment. Managers obviously had a different perception of the impact of digital technologies on output and productivity growth. The dramatic drop of prices (see Box 4.3) for these assets supported the trend and favoured substitution between different types of capital goods.

[59] *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, respectively. These coefficients are then multiplied by the corresponding WITSA spending items for EU countries to obtain nominal IT investment spending data for the 1992–99 period.

**Table 4.5: Nominal share of investment in ICT in % of total investment of the business sector**

| | | Germany | France | Italy | Finland | Unweighted average 4 EU countries | Japan | USA | Australia | Canada |
|---|---|---|---|---|---|---|---|---|---|---|
| IT equipment | 1980 | 4.1 | 2.5 | 4.0 | 2.6 | 3.3 | 3.3 | 5.1 | 2.2 | 4.5 |
| | 1990 | 5.3 | 3.3 | 4.2 | 4.5 | 4.3 | 3.8 | 7.0 | 5.4 | 5.8 |
| | 1995 | 4.6 | 3.5 | 3.5 | 5.5 | 4.3 | 4.6 | 8.7 | 8.0 | 7.9 |
| | 1999 | 6.1 | 4.0 | 4.2 | 3.8 | 4.5 | 5.2 | 8.5 | 6.5 | 7.6 |
| Communications equipment | 1980 | 4.9 | 3.3 | 3.9 | 4.0 | 4.0 | 3.4 | 7.1 | 4.4 | 3.2 |
| | 1990 | 5.0 | 3.7 | 5.7 | 4.8 | 4.8 | 4.0 | 7.5 | 3.9 | 4.0 |
| | 1995 | 4.2 | 4.4 | 6.7 | 13.0 | 7.1 | 5.3 | 7.3 | 5.2 | 4.4 |
| | 1999 | 4.3 | 5.8 | 7.2 | 20.3 | 9.4 | 6.9 | 8.2 | 5.6 | 5.3 |
| Software | 1980 | 2.8 | 2.4 | 1.7 | 2.9 | 2.5 | 0.6 | 3.0 | 1.0 | - |
| | 1990 | 3.7 | 2.8 | 3.8 | 5.5 | 4.0 | 4.7 | 8.0 | 4.4 | - |
| | 1995 | 4.5 | 3.6 | 4.3 | 11.6 | 6.0 | 6.0 | 10.1 | 6.1 | - |
| | 1999 | 5.7 | 6.2 | 4.9 | 11.9 | 7.2 | 5.7 | 15.0 | 8.7 | - |
| ICT equipment and software | 1980 | 11.8 | 8.2 | 9.6 | 9.5 | 9.8 | 7.2 | 15.2 | 7.6 | - |
| | 1990 | 14.0 | 9.8 | 13.7 | 14.9 | 13.1 | 12.4 | 22.5 | 13.7 | - |
| | 1995 | 13.3 | 11.5 | 14.4 | 30.0 | 17.3 | 15.9 | 26.1 | 19.3 | - |
| | 1999 | 16.2 | 16.0 | 16.3 | 36.0 | 21.1 | 17.9 | 31.7 | 20.8 | - |

*Source*: *OECD*, 2001B.

There are considerable differences between countries in investment and uptake of ICT, partly due to policy differences. Competition is particularly important. Sufficient competition helps to lower 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, significant effects of liberalisation in 1998 should be felt in the years not included in the data.

### *Capital stocks and investment contain ever higher shares of ICT*

Two more indicators underline the increasing importance of ICT. Firstly, the capital stocks of all ICT components have risen much faster than those of capital goods in general. The capital stock of communications equipment and software increased by about 10% annually in Europe, that of hardware by about 30% (unweighted averages). Compared to the USA, growth rates for capital stock of communications equipment were higher in Europe, about the same for hardware and lower for software. Secondly, the share of ICT investment in total investment increased substantially, most notably that for hardware. Today, 32% of total business investment is in ICT in the USA, after 15% in 1980. In Europe it rose for large countries from 10% to 16%, and skyrocketed in Finland to 36%.

**Table 4.6: Growth of ICT and aggregate capital stocks, 1991–99**

| | 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 |
| USA | 4.9 | 31.2 | 17.4 | 2.6 |

*Source*: *Daveri*, 2001, WIFO calculations.

## 4.3. Measuring the impact of ICT investment

Investment in information technology impacts on economic output and productivity growth through three separable channels (see *Stiroh*, 2001, *EU*, 2000, *McMorrow – Roeger*, 2001):

1. **Growth of labour productivity:** The primary effect of ICT use should be an increase in labour productivity through additional capital formation (ICT capital) which raises the productivity of labour (i.e. capital deepening).

2. **Increase in multi factor productivity:** Technological progress allows production of improved capital goods at lower prices, thus raising multi factor productivity growth in the sector producing IT goods. The magnitude of this effect depends on both the speed of technical progress and the share of the ICT sector in overall production.

3. **Spillovers:** ICT investment induces embodied technological change, thus increasing multi factor productivity growth outside the IT sector, generating production spillovers or externalities.[60]

[60] *OECD* (2001) finds evidence that there is also 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 pick-up in MFP growth

## Box 4.2: The neoclassical growth-accounting methodology

The neoclassical growth-accounting methodology uses a production function to relate inputs and outputs. Variations in output are accounted for by changes in production inputs, i.e. capital and labour. The proportion of output that cannot be attributed to inputs is called multi factor productivity (MFP) and catches all output increases which are due to technological and organisational changes that are not explained by changes in inputs. Starting from the results of this growth-accounting exercise, the calculation of labour productivity is straightforward: output and input variables in the production function are divided by the labour input.

Measurement of the impact of information technology on economic development requires that the capital input is broken down in ICT and non-ICT capital. Many studies further disaggregate information technology into computer hardware, software and communications equipment. The overall growth contribution from the use of information technology capital equals the sum of the contributions from computer hardware, software, and communication equipment.

In the standard growth-accounting framework, the real growth rate of each input is weighted by that input's income share[61]. Both components of this simple multiplication deserve some attention:

1. First, the nominal capital stock of the input is measured to estimate income shares. This stock earns a gross rate of return that must cover the real net rate of return common to all capital, together with taxes and the loss of value which this input suffers over time (capital service). The product of the gross rate of return and the nominal productive stock equals the nominal income flow generated by this input. This is divided by the total nominal income for the economy to obtain the desired income share. This method is applied to measure the income share for each type of capital. The income share for labour inputs is then measured as one minus the sum of the income shares for the various types of capital (see for example *Oliner – Sichel*, 2000).
2. An important issue in every growth-accounting exercise is the correct measurement of real prices for ICT. There are few sectors in the economy where technological progress increases the performance of goods and services at such a pace as ICT. Taking ICT components at nominal prices would ignore these huge performance increase of ICT by itself and, of course, when these goods and services are applied in the economic process. In order to cope with this situation, hedonic price indices have been developed. These are statistical tools for developing standardised per-unit prices for goods, such as computers, whose quality and characteristics are changing rapidly. In designing hedonic price indices, a statistical model is used that makes a regressive estimate of the prices of a basket of goods based on a set of their qualities or characteristics. Using the statistical relationship between observed price changes and changes in the characteristics and qualities of goods, a hedonic price index is then developed that measures relative price changes while holding quality and characteristics constant (*Landefeld – Grimm*, 2000).

To sum up, the main forces determining the growth contribution of ICT and its components are the size of the capital stock, its growth rate, the usage costs of capital and the development of prices for ICT goods.

The growth-accounting approach thus rather "mechanically" attributes shares in output growth according to the size of the input factor, its growth rate and – in case of capital – the capital services generated by this input. Growth-accounting techniques assume the result when factor shares proxy for output elasticities and do not estimate econometrically the contribution of inputs to output or productivity growth. Growth-accounting therefore provides a valuable and well-tested means for understanding the proximate sources of growth, namely accumulation of capital and labour, plus multi factor productivity. In particular, this framework does not model the underlying technical improvements that have driven capital accumulation. In this sense, the neoclassical framework provides a superficial explanation of growth. Additional evidence produced by alternative methods is necessary to validate these results (see *Oliner – Sichel*, 2000, *Stiroh*, 2001).

in the second half of the 1990s. Countries that have experienced a substantial pick-up in MFP growth in this period typically have a higher diffusion of ICT technologies, as well as lower costs of ICT technologies.

[61] Using the log values of the variables.

## 4.4. The economic impact of investment in ICT

### 4.4.1 The mainstream results for the USA and Europe

Despite all the differences in the approach and all the problems with the data, there is unanimity that ICT really does significantly contribute to growth and productivity, that this impact is larger in the USA than in Europe, and also greater in the second half of the 1990s relative to the first.

The US economy grew rapidly in the 1990s, especially in the second half. The European economy also managed to accelerate growth rates but at a lower level. Most studies[62] underline 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 multi factor productivity (MFP). The European Union has experienced a more modest acceleration in labour productivity growth of ¼ of a percentage point over the same period to reach an annual average rate of 2% for the second half of the 1990s" (*Mc Morrow – Roeger*, 2001).

One obvious candidate for explaining the strong 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 mainstream result of the studies[63] is that ICT investment explains about 0.4 to 0.5 percentage points in the first half and 0.8 to 1 percentage point of output growth in the second half of the 1990s (see Table 4.7). Thus the importance of ICT for economic growth more than doubled compared to the first half of the past decade[64]. This increase ist due to to rapidly falling prices for information technology which push up the growth rate of real capital stocks (see Table 4.6), thus allocating a larger part of overall growth to information technology. As demonstrated by *Schreyer* (2001), hedonic price measurement may in some countries double the magnitude of growth effects for hardware investments.

For EU member countries there are basically two estimates available on the growth impact of ICT investment (*EU*, 2000, *Daveri*, 2001). *OECD* (2001B) and *Schreyer* (2000) present estimates for four European countries as part of a sample of eight countries. Estimates for

[62] *OECD*, 2000: Studies over the past years (*Schreyer*, 2000, *Scarpett, et a.l*, 2000, *OECD*, 2000a, *Federal Reserve Board*, 2000) have furnished evidence.

[63] *BLS*, 2000, *EU*, 2000, *Daveri*, 2000, 2001, *Gordon*, 2000, *Jorgenson – Stiroh*, 2000, *Kiley*, 2000, *OECD*, 2000, 2001, *Oliner – Sichel*, 2000, *Whelan*, 2000)

[64] The major exception is *Kiley* (2000): He estimates a negative growth impact of ICT which is due to adjustment costs associated with the implementation of ICT. In his framework the effect of ICT would turn positive once investment in ICT will be reduced or halted. Then adjustment costs would not cancel out the positive impact of ICT on output growth.

European countries generally calculate a lower contribution of ICT to output growth. On average, about 0.4 to 0.5 percentage points of output growth in Europe in the nineties are due to ICT. The estimates in the two available studies for the full sample exhibit some differences (see Table 4.8). *Daveri* (2001) finds a somewhat larger ICT growth contribution for Europe (relative to EU 2000), specifically in the first half of the 1990s. Consequently the acceleration between the two periods is not as distinct as in EU 2000. Daveri‘s estimate for the growth contribution of ICT in the USA is specifically high, he calculates a contribution of 0.94% for the whole nineties ( not only the second half).

The distinct difference in the contribution of information technology for Europe vs. the USA can be seen in Table 4.8. Both in the 1990s as a total and in subperiods none of the European countries had achieved a growth contribution of ICT investments that is comparable to the USA. In the USA, about 0.94% percentage points of output growth in the 1990s are attributed to ICT investments (see table 4.8, first column). The UK achieved 0.76 percentage points due to investment in ICT and is thus the European country with the highest contribution. Other big European ICT investors are the Netherlands, Sweden, Finland and Ireland, the relative position of the countries are partly different according to the two estimates in table 4.8. The low overall contribution of ICT to European growth is dominated by the low ICT growth contributions in large countries like Germany, France, Italy and Spain.[65]

**Table 4.7: ICT growth contribution**

| | Country/Region | Period | Software | Hardware | Communications Equipment | Total ICT |
|---|---|---|---|---|---|---|
| OECD, 2001 | USA | 1990-95 | 0.14 | 0.20 | 0.08 | 0.42 |
| | | 1995-99 | 0.27 | 0.49 | 0.13 | 0.89 |
| Jorgenson & Stiroh, 2000 | USA | 1990-95 | 0.15 | 0.19 | 0.06 | 0.40 |
| | | 1995-99 | 0.21 | 0.49 | 0.11 | 0.81 |
| Oliner and Sichel, 2000 | USA | 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 |
| EU, 2000 | EU | 1992-94 | - | - | - | 0.27 |
| | | 1995-99 | - | - | - | 0.49 |

Compared to the USA, Europe seems to lose 0.3 to 0.5 percentage points of economic growth. The major cause for the lower contribution of ICT to aggregate growth in Europe is lagging investment in ICT. Other factors to affect the outcome of these growth-accounting exercises

[65] The difference in the results between Europe and the USA is somewhat lower in the *OECD* (2001B) estimate. The OECD used official data from the System of National Accounts. France, Germany, Finland and Italy were however the only European countries in the sample.

(price measurement and usage costs of capital) were assumed to be similar to the USA and thus cannot account for growth differences (see *Daveri*, 2001, *EU*, 2000)[66].

## Table 4.8: ICT growth contribution in Europe

| | Daveri 2001 1991-99 | Daveri 2001 1991-95 | EU 2000 1992-94 | Daveri 2001 1996-99 | EU 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 |
| USA | 0.94 | 0.53 | - | 1.45 | - |

*Source*: *Daveri*, 2001, *EU*, 2000.

### Box 4.3: The growth contribution of hardware, software and communications equipment

Most 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 renders information on the relative growth impact of the different forms of information technology. In the USA, the largest contribution to output growth stems from hardware investments[67]. In the second half of the 1990s, hardware investment raised output by 0.5 to 0.6 percentage points (see Table 4.7). 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 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 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, Box 4.1). For example, quality-adjusted prices for computers and peripherals have been falling at about 24% annually (*Landefeld – Grimm*, 2000). This is much faster than for software and communications equipment. Research in Germany (*Moch*, 2001) more or less confirms the rate of price decline as applies in the USA for computer hardware.

[66] The major forces determining ICT growth contribution are the size of the capital stock, its growth rate, the usage costs of capital and the development of prices for ICT goods.
[67] Firm-level evidence supports this view: these studies suggest that computers did have am 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 – Hitt*, 2000).

*Is it productivity in ICT production or do spillovers exist?*

While the general impact is assessed in a rather similar manner, the relative importance of productivity growth within the ICT sector relative to spillovers from ICT to other industries is far from resolved.

Higher labour productivity in the USA is mainly due to capital deepening (0.1 to 0.33 percentage points) and multi factor productivity growth (0.3 to 0.9 percentage points)[68]. Both categories are substantially influenced by IT usage and production. The positive impact of ICT-related capital deepening is present in all studies cited in Table 4.9 and emphasises the direct, labour productivity increasing impact of ICT investment. The controversial issue is the effect of non-ICT-producing sectors on multi factor productivity growth. *Gordon* (2000) attributes almost all of the acceleration of multi factor productivity growth to the ICT-producing sectors (see also Box 4.3). Although *Jorgenson – Stiroh* (2000) and *Oliner – Sichel* (2000) calculate about the same effect for ICT-producing sectors, they still find a substantial contribution from non-ICT-related sectors (0.4 to 0.5 percentage points) to multi factor productivity growth. Thus they support the view that ICT use has had positive effects in non-ICT-producing industries.

Gordon (2000) argues that 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[69]. He therefore subtracts a term to account for this cyclical effect and makes some adjustments for price measurement. These adjustments eliminate the contribution of non-ICT-producing sectors to the acceleration of multi factor productivity growth (see Table 4.9). He repeats this exercise for subsamples of the economy by either excluding the ICT-producing industries or the manufacturing sector and thus arrives at a reduction of multi factor productivity in the remaining parts of the economy. His 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

[68] Other factors are changes in labour quality (shifts from unskilled to skilled workers), cyclical factors and – in some comparisons – changes in price measurement (see table 4.9).

[69] In a fast growing economy the 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 diminished 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).

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[70].

**Table 4.9: Sources and alternative explanations of the acceleration in labour productivity**

| | 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 | 0.91 | 1.33 | 0.95 | 1.16 |
| 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 |
| MFP | 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.

This controversy cannot be decided at the aggregate level but needs evidence either at sectoral or firm level. If there is a positive impact of ICT investment it should be visible in the largest users of ICT investment goods in the services sector: communications, wholesale and retail trade, finance, insurance and business services (see *OECD*, 2001A). Most of these service sectors have exhibited rather weak productivity growth which is partly related to well-known measurement problems of the output in service industries. It is – as *Brynjolfsson – Hitt* (2000) argue – most unlikely that the productivity of the US banking sector has decreased, given its high spending on ICT and the observable improvement in service diversity and quality.

Consequently, limited acceleration of productivity growth in non-ICT producing industries was found in a number of papers (see *Brynjolfsson – Hitt*, 2000, *Brynjolfsson – Yang*, 1996 for studies at firm level). These studies support the hypothesis that productivity growth is confined to ICT-producing industries but did not find a negative impact of ICT usage in other industries. Recent studies are more optimistic on the impact of ICT investment. *OECD* (2001A) found evidence for a positive productivity impact of ICT in the ICT-using sectors. Denmark, Finland, Germany, the Netherlands and the United States have experienced an increased contribution of

[70] There are more critical comments which will not be discussed in detail: *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 workweek expands faster than the data measure. *Kiley* (1999) assumes large adjustment

ICT-using services 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. To be successful, investment has to be coupled with organisational changes and upskilling of the labour force (see *Bresnahan – Brynjolfsson – Hitt*, 2000). Consequently, it is not surprising that recent studies more frequently find positive impacts of ICT usage than older ones.

Based on comprehensive research on the productivity impact of ICT on the sectoral level, *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 result again hints that investment in ICT takes time to unfold its impact on output and productivity and underlines that productivity growth due to ICT is not confined to the ICT-producing sectors (see also *Bailey and Lawrence*, 2001, *Nordhaus*, 2001).

*Stiroh* (2001) produces further support by decomposing aggregate productivity growth into the contribution of individual industries and inter-industry reallocation effects and thus demonstrates that ICT-related differences are large and important for understanding the US productivity revival. ICT-producing and ICT-using industries account for almost all of the productivity revival that is attributable to the direct contributions from specific industries. Industries which were not essentially impacted by the ICT revolution made no contribution to the US productivity revival. Thus, the US productivity revival seems to be fundamentally linked to ICT.

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costs that create frictions which cause investment in ICT capital to be negatively associated with productivity, at least in the short run.

**Box 4.4: The productivity impact of ICT-producing industries**

The argument that rapid productivity increase in the ICT-producing industry contributed substantially to overall productivity growth is not controversial but rather supported by most of the studies cited above. OECD studies demonstrate that ICT-producing industries have made significant contributions to labour productivity growth in several OECD countries (*Scarpetta et al.*, 2000). Some clue to the importance of ICT on productivity growth can be derived from analysing the sectoral productivity performance and the contribution of each sector to overall productivity growth.

Consequently, the contribution of the ICT sector to overall economic performance depends on the rate of productivity growth, on the size of the sector and the specific composition of goods produced. *OECD* (2001A) demonstrates that the machinery and equipment industry had considerably higher productivity growth than the manufacturing sector overall in most of the eleven countries analysed. Labour productivity growth was much higher in the two key ICT-producing sectors, i.e. the electrical and optical equipment industries. In general, the manufacturing part of the ICT sector has a considerably higher productivity growth than manufacturing overall, and the services part of the ICT sector tends to have more rapid productivity growth than the service sector as a whole. The large variation in performance across countries points, amongst other things, to varying specialisation within the ICT sector. Some countries are specialised in ICT production in which technological progress was not as fast as for semi-conductors or computers.

The *OECD* (2001A) study on Denmark, Finland and Germany – the only countries with sufficient data – gives some indications of this relationship. In Finland[71] and Germany the contribution of the ICT-producing sector increased dramatically in the second half compared to the first half of the 1990s. In contrast, the role of ICT-producing industries in Denmark declined over the same period.

Additionally, the importance of the ICT-producing sector for recent growth performance has been confirmed by several national studies. In Finland, mobile telephone producer Nokia accounted for 1.2 percentage points in the country's GDP growth of 4% in 1999, even though it produced only 4% of overall GDP (*Forsman*, 2000). Furthermore, labour productivity growth in the ICT services was substantially higher than in the total economy (*Flottum*, 1998). The Bank of Korea found 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). And a recent study in Canada attributes much of the Canada-US productivity gap in manufacturing to the performance of two sectors, machinery and electronic products, both of which are important producers of IT products (*GU and Ho*, 2000). The ICT-producing sector is thus an important driver of growth and productivity, although certain countries, such as Australia, have improved growth and productivity even though they are only very small producers of ICT-related goods and services.

Last but not least, the cyclical effect claimed by *Gordon* (2000) as the major factor behind the pickup in productivity should have happened at the beginning of the business cycle but not in the middle of it. The latter indicates that something structural in the economic process has changed. This productivity increase happens at exactly the same time that a significant increase in ICT spending was observable in the USA. Furthermore, if the productivity increase is a cyclical phenomenon it should be evenly distributed over industries and not be connected to ICT usage in the industry. According to *Stiroh* (2001), the opposite holds true: the most intensive users of ICT experienced the largest productivity gains, consistent with the idea that ICT has real economic benefits.

Overall – and as is demonstrated by a number of studies (*OECD*, 2000, Schreyer, 2000, *Scarpetta et al.*, 2000, *OECD*, 2000a, *Federal Reserve Board*, 2000) – it has to be emphasised

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

that there is no single factor that by itself explains the divergence in growth performance between countries. Countries that improved performance in the 1990s have generally been able to draw more people into employment, have increased investment, and have boosted multi factor productivity (MFP). ICT investment is playing a crucial and – likely – growing role in setting the foundation for future growth. Policies to stimulate ICT investment and use have to ensure that competition (and regulation) will further lower prices for ICT equipment and services, provide adequate skill upgrading which allows to draw more people into employment and support complementary organisational innovation at firm level.

## 4.5 Conclusions

The growing consensus that the positive growth and productivity performance in the USA is related to increased investment and diffusion of ICT goods and services has raised fears that the weaker economic performance of European Union member states is caused by a reluctance to adopt these new technologies.

### The gap does not close quickly

Seen overall, the ICT spending gap between Europe and the USA widened in the 1990s, even though both regions expanded their expenditures: In 1992, European ICT expenditure per GDP amounted to 5.2%, this was 2.3 percentage points below the US level. While the gap narrowed in the first half of the 1990s, it thereafter increased to 2.7 percentage points in the second half. Figures of ICT per GDP somewhat hide the more dynamic development in the USA: In 1992, European ICT expenditure still amounted to 90% of US expenditure, but by 1999 had dropped to about 75% of the US level. The gap is even larger for ICT investment in the business sector: In 1999, the US economy invested about 4.5% of GDP in information technologies. This is almost twice the European level of 2.4%.

### Leading European countries are close to or have surpassed the USA in ICT expenditure

The situation in the European Union is marked by heterogeneous spending levels in the member states: While the UK and Sweden have already surpassed, and the Netherlands, Denmark and Ireland have drawn close to the US level in overall ICT expenditure, some of the larger countries drag the European average downwards.

## Economic impact

Recent growth-accounting studies have demonstrated the increasing contribution of ICT to aggregate economic growth. In the USA, ICT investment explains 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 more than doubled compared to the first half of the past decade. Estimates for European countries generally calculate 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 USA, Europe seems to lose 0.3 to 0.5 percentage points of economic growth due to lacking investment in.

The acceleration of labour productivity is mainly due to capital deepening (0.1 to 0.33 percentage points) and multi factor productivity growth (0.3 to 0.9 percentage points). Both categories are substantially influenced by IT usage and production. Nonetheless, the contribution of ICT to multi factor productivity growth is strongly disputed. It is argued that the increase in labour productivity is a normal, cyclical acceleration as the economy expands. If this cyclical contribution is deducted, then the contribution to multi factor productivity growth from the non-ICT-producing sector is negligible (or even negative). If productivity growth is confined to the ICT sector alone, but does not raise productivity in other sectors, it could be argued that there is no such thing as a “new” economy. Instead, 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.

Advocates of a more fundamental impact of ICT stress that productivity should have picked up at the beginning of the business cycle but not in the middle of it. The latter indicates that something structural in the economic process has changed. This productivity increase happens at exactly the same time as a significant increase in ICT spending was observable in USA. Furthermore, if the productivity increase is a cyclical phenomenon it should be evenly distributed across industries and not be connected to ICT usage in the industry.

Recent research rather emphasises the role of ICT investment for productivity growth: The evidence is growing that ICT does have a positive productivity impact in ICT-using industries. Studies from the USA and by OECD have demonstrated that both ICT producers and ICT users experienced significant productivity gains, consistent with the idea that ICT has real economic benefits. In contrast, industries which were not impacted by ICT initially made no contribution to the productivity revival.

The weak productivity performance in services – a heavy user of ICT – is related to well-known problems of measuring the output of services industries and the time it takes to implement ICT. To be successful, these technologies have to be coupled with organisational changes and upskilling of the labour force. Given the complementary investments necessary, it is not surprising that most of the evidence of the positive productivity impact of ICT usage was obtained only recently. 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.

In general – and also demonstrated by a number of studies – it has to be emphasised that there is no single factor to explain the divergence in growth performance between countries. Countries that have improved performance in the 1990s have generally been able to draw more people into employment, have increased investment, and have improved multi factor productivity (MFP). ICT investment is playing a crucial and probably growing role in setting the foundation for future growth. Policies to stimulate ICT investment and use have to ensure that competition (and regulation) will further lower prices for ICT equipment and services, and provide adequate skill upgrading which makes it possible to draw more people into employment and support complementary organisational innovation at firm level.

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# Chapter 5: The impact of innovation:
Evidence on the macro and sector level

**KARL AIGINGER**

## 5.1 Introduction

Differences in growth performance increased across countries during the nineties. This chapter investigates the influence of innovation - and of other determinants proposed in the last chapters - on growth. We report the main trends for macroeconomic growth, but focus on manufacturing, first at the aggregate level, then for sectors and industries. The role of innovation, of knowledge and of ICT as drivers of growth is clearly supported by the data. However, policies to combat unemployment and strategies to maintain the competitiveness of more slowly growing industries are also important. The industry pattern of growth is similar across countries and has recently become even more similar, with technology driven industries taking the lead in productivity increase now also in Europe. Individual countries build on different industrial structures, innovation systems and policies. Lagging European countries are catching up, albeit at a slow speed, some European countries are contesting the lead of the USA with respect to the drivers of growth.

We report differences in output and productivity across countries on the aggregate level in Section 5.2. and relate them in Section 5.3 to the forces expected to determine long term growth. like knowledge, ICT and capabilities. Then we investigate which industries increased productivity fastest, how close productivity growth is related to research intensity (Section 5.4), and how similar the sector pattern of growth is (Section 5.5). In Section 5.6 we combine data on growth, on growth drivers and on policy, to draw country profiles. Section 5.7 investigates which countries are leading with respect to the growth drivers, whether the lagging countries are catching up, and how Europe is performing relative to the USA.

**Box 5.1: Recent studies on growth performance and its underlying forces**

| Author/Institution | Title | Scope | Additional features |
|---|---|---|---|
| European Commission, 1998 | The competitiveness of European industry 1998 | Competitiveness in the triad | Taxonomies, small firms, multinationals |
| European Commission, 1999 | The competitiveness of European industry 1999 | Adaptability and change | Intangible investment, Asian crisis |
| European Commission, 2000 | The competitiveness of European industry 2000 | Competition in quality | Service inputs, pharmaceuticals |
| EUROSTAT, 1999 | Panorama of European business | Main trends for industries | Overview on structure and performance |
| Aiginger, K. et al., Enterprise DG, 1999 | Specialisation and (geographic) concentration of European manufacturing | Degree and change in specialisation and geographic concentration | Survey on trade theory, growth differences |
| Peneder, M., Edward Elgar, 2001 | Entrepreneurial competition and industrial location | Theoretical and empirical overview | Background for three taxonomies |
| Davies, St., Lyons, B., Oxford Press, 1990 | Industrial organisation in the EU | Strategies of leading firms | Matrix on 300 leading firms |
| Ilzkovitz, F., Dierx, A., European Economy, 2000 | European integration and the location of industries | Overview on studies concerning specialisation | Survey on liberalisation, growth differences |
| Aiginger, K. et al., Enterprise DG, 2000 | Europe's position in quality competition | Country shares in price or quality sensitive industries and in high/low price segments | Importance of quality competition for Europe |
| Braunerhjelm, P. et al., CEPR, 2000 | Integration and the Regions of Europe | Concentration and specialisation of regions | Policy impact on income differences agglomeration, catching up |
| OECD, 2001 | The New Economy: beyond the hype, Final report on the OECD Growth Project | Explaining differences in growth performance of OECD countries | Policy conclusions |
| OECD, 2001 | Growth Project, Draft Ministerial Paper | Explaining growth pattern | Specifically: ICT, Diffusion of technologies, human capital, firm creation |
| McMorrow, K., Roeger, W., European Commission, Economic papers no 150 | Potential Output: Measurement Methods | New Economy effect on Potential Growth | Growth scenarios for the EU and the USA |
| EU, EC/FIN European Economy 71/2000 | The EU Economy, 2000 Review | Is there a new pattern of growth emerging? | Prospects and challenges for Europe |

## 5.2 The productivity gap with respect to the USA increased in the nineties

The USA is again forging ahead in productivity growth. Following a longer period of more rapid productivity growth in Europe, productivity growth accelerated in the USA during the last decade and is higher than in Europe and in Japan. This is true not only for labour productivity, but also for multi factor productivity; the trend holds for the total economy, as well as for manufacturing. We combine evidence reported in the literature[72] with our own evidence, specifically extending the analyses up to the year 2000.

### Growth boosts productivity in the USA

Macroeconomic growth was strong enough in the USA to boost productivity. Real output increased by 3.3 % in the nineties, implying growth in labour productivity of 2 % p.a. Productivity growth in the second half of the nineties exceeded that of the first half by 1.3 %, driven by an acceleration of growth from 1.9 % to 4.3 % (see Table 5.1). In Europe, productivity growth in the nineties was only 1.5 % and *decelerated* from 1.9 % to 1.0 % between the two halves of the decade. This decline in productivity growth happened despite an

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[72] *Scarpetta* et al., 2000, *Bassanini* et al., 2000, *OECD* Growth Project 2001, *European Economy* 2000, *Mc Morrow - Roeger*, 2000. For the main results of the OECD Growth Project see Annex2.

acceleration in output growth of 1 percentage point (to 2.4 %) in the second half of the nineties (see Figures 5.1 - 5.3).

The highest macro-productivity growth was achieved by Ireland, Finland, Denmark, Portugal and Sweden (see Table 5.2A). The Nordic countries managed this on top of above average productivity levels at the start of the nineties. Ireland made a considerable jump upward during this decade and Portugal managed to close the gap. In the majority of European countries, productivity growth decelerated during the second half of the nineties (most strongly in Spain and Italy[73]). Higher productivity growth in the second half compared to the first occurred in Greece and Belgium. Cyclical factors and changes in policy towards labour seem to have shifted production (and influences measured productivity) between the first and second half of the nineties, in addition to innovation and productivity proper[74].

## Table 5.1: Productivity acceleration in the USA, but not in Europe

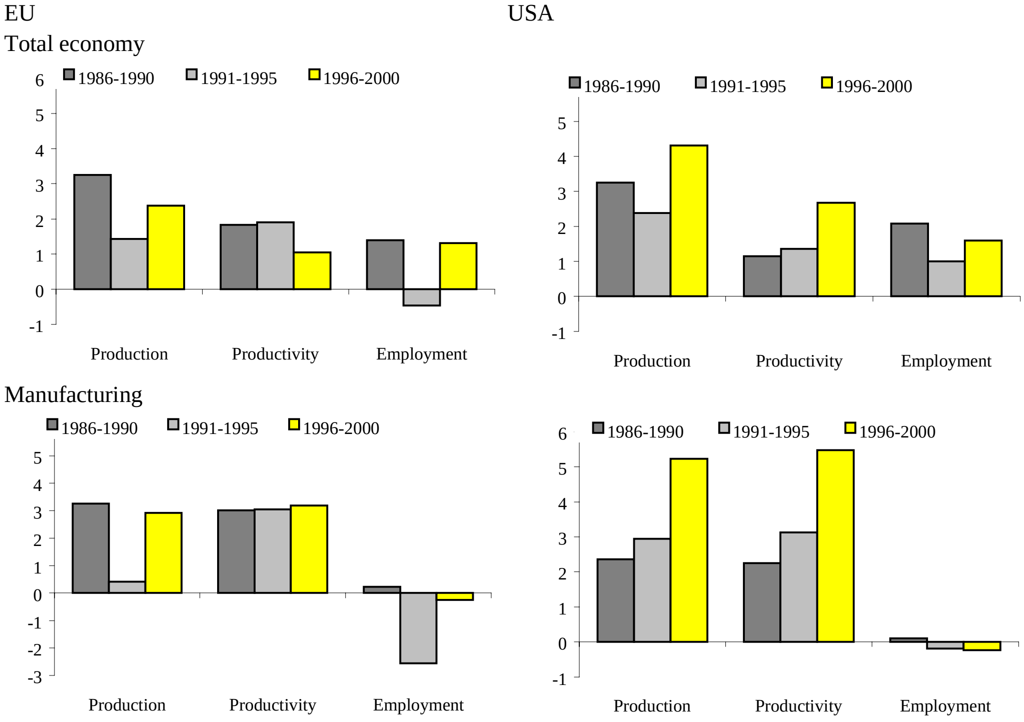
| | Total economy | | Manufacturing | |
|---|---|---|---|---|
| | EU | USA | EU | USA |
| | Growth p.a. in % | | | |
| Growth of output | | | | |
| 1986/1990 | 3.2 | 3.2 | 3.3 | 2.4 |
| 1991/1995 | 1.4 | 2.4 | 0.4 | 2.9 |
| 1996/2000 | 2.4 | 4.3 | 2.9 | 5.2 |
| 1991/2000 | 1.9 | 3.3 | 1.7 | 4.1 |
| Acceleration 2nd/1st half | 0.9 | 1.9 | 2.5 | 2.3 |
| Labour productivity | | | | |
| 1986/1990 | 1.8 | 1.1 | 3.0 | 2.3 |
| 1991/1995 | 1.9 | 1.4 | 3.0 | 3.1 |
| 1996/2000 | 1.0 | 2.7 | 3.2 | 5.5 |
| 1991/2000 | 1.5 | 2.0 | 3.1 | 4.3 |
| Acceleration 2nd/1st half | -0.9 | 1.3 | 0.1 | 2.3 |
| Trend growth of GDP per capita | | | | |
| 1981/1990 | 2.0 | 2.0 | | |
| 1991/1998 | 1.4 | 2.2 | | |
| Multi-Factor Productivity | | | | |
| 1981/1990 | 1.7 | 1.0 | | |
| 1991/1998 | 1.3 | 1.4 | | |

*Remarks*: Labour productivity is output per employee.
Output of total economy = GDP, output of manufacturing = production index.
Trend growth and multi factor productivity estimated by Bassanini et al. (2000).

*Source*: WIFO calculations using EUROSTAT (New Cronos); 1999-2000 estimate, Economic Forecasts 2000-2002 (EC); *Bassanini - Scarpetta - Visco*, 2000.

[73] Productivity also decelerated in Sweden rather strongly during the second half of the nineties, but this happened on top of an extreme jump during the first half.
[74] This is reflected in a higher standard deviation of the growth rates for the two halves as compared to the whole nienties.

**Figure 5.1: Macro productivity decelerates in Europe, is stable for manufacturing**




*Remark*: Macro productivity = real GDP per employee; manufacturing = production index per employee.

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

## Continued productivity growth in European manufacturing

Labour productivity increased in European manufacturing rather smoothly, at 3 % p.a. (Table 5.2B). In contrast to macro productivity, slight acceleration was evident between the first and the second halves of the nineties. However, European levels of acceleration and labour productivity growth were lower than in the USA. The highest levels of productivity growth in Europe during the nineties were achieved by Ireland, Finland, Austria and Sweden; in these four countries, productivity in manufacturing rose faster than in the USA. The lowest growth levels were for Portugal, Spain and France (less than 2 % p.a.). Taking productivity growth in the second half of the nineties separately, three countries managed to increase productivity faster than the USA. Eleven countries were not able to match US levels of productivity growth during the last five years; in Italy, productivity growth was near zero, in Spain it was decreasing.[75]

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

## Table 5.2A: Growth performance becomes more different: Total economy

| | Production of total economy | | | | | Productivity of total economy | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Growth p.a. | | | | Acceleration | Growth p.a. | | | | 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 | 3.0 | 1.3 | 2.3 | 1.8 | 1.0 | 1.9 | 1.3 | 1.8 | 1.5 | 0.5 |
| Denmark | 2.1 | 2.5 | 2.6 | 2.5 | 0.1 | 1.3 | 3.3 | 1.8 | 2.5 | -1.5 |
| Germany | 3.4 | 2.0 | 2.1 | 2.0 | 0.1 | 1.9 | 2.1 | 1.4 | 1.7 | -0.6 |
| Greece | 1.9 | 1.2 | 3.2 | 2.2 | 2.0 | 1.3 | 0.7 | 2.7 | 1.7 | 2.0 |
| Spain | 4.9 | 1.3 | 3.3 | 2.3 | 1.9 | 1.8 | 2.5 | -0.3 | 1.1 | -2.7 |
| France | 3.0 | 1.0 | 2.4 | 1.7 | 1.4 | 2.2 | 1.2 | 1.1 | 1.1 | 0.0 |
| Ireland | 5.5 | 6.1 | 9.7 | 7.9 | 3.6 | 3.7 | 4.4 | 4.0 | 4.2 | -0.4 |
| Italy | 3.0 | 1.1 | 1.5 | 1.3 | 0.4 | 2.6 | 2.2 | 0.7 | 1.5 | -1.5 |
| Netherlands | 3.0 | 2.1 | 3.1 | 2.6 | 1.0 | 0.7 | 0.4 | 0.3 | 0.3 | -0.1 |
| Austria | 3.2 | 2.0 | 2.5 | 2.2 | 0.5 | 2.6 | 1.4 | 1.5 | 1.5 | 0.0 |
| Portugal | 5.5 | 1.7 | 3.4 | 2.6 | 1.8 | 3.5 | 3.0 | 1.6 | 2.3 | -1.4 |
| Finland | 3.4 | -0.5 | 4.5 | 1.9 | 5.0 | 2.6 | 3.0 | 2.6 | 2.8 | -0.4 |
| Sweden | 2.3 | 0.5 | 2.2 | 1.3 | 1.7 | 0.9 | 2.9 | 1.2 | 2.0 | -1.7 |
| United Kingdom | 3.2 | 1.3 | 2.3 | 1.8 | 1.0 | 1.3 | 2.0 | 0.9 | 1.5 | -1.1 |
| EU | 3.2 | 1.4 | 2.4 | 1.9 | 0.9 | 1.8 | 1.9 | 1.0 | 1.5 | -0.9 |
| Japan | 5.2 | 1.5 | 1.1 | 1.3 | -0.4 | 3.7 | 0.9 | 1.2 | 1.0 | 0.3 |
| USA | 3.2 | 2.4 | 4.3 | 3.3 | 1.9 | 1.1 | 1.4 | 2.7 | 2.0 | 1.3 |
| Standard deviation EU countries | 1.15 | 1.48 | 2.02 | 1.63 | | 0.90 | 1.11 | 1.07 | 0.92 | |
| Standard deviation triade | 1.12 | 0.52 | 1.62 | 1.04 | | 1.30 | 0.52 | 0.91 | 0.50 | |

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

## Table 5.2B: Growth performance becomes more different: Manufacturing

| | Production of manufacturing | | | | | Productivity of manufacturing | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Growth p.a. | | | | Acceleration | Growth p.a. | | | | 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 |
| USA | 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 triade | 1.08 | 1.84 | 2.09 | 1.95 | | 0.86 | 1.22 | 1.37 | 1.15 | |

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

## Larger divergence of growth rates across countries

The divergence of growth rates increased for the total economy and for manufacturing[76]. Slow growing countries did manage barely more than 1 % for the decade; high growth countries about or above 4 %. The standard deviation increased by more than 50 % for macro growth, as well as for manufacturing.[77] Surprisingly, the standard deviation of labour productivity growth did not increase. This is due to the fact that several low growth countries, like Germany, the United Kingdom and Greece, decreased employment to maintain or regain competitiveness, specifically in capital intensive industries and firms with heavy restructuring.

## Multi factor productivity accelerated in the USA

During the nineties labour productivity (output per person) rose more strongly in the USA than in Europe (2.0 % vs. 1.5 %). Part of this productivity increase may be due to capital deepening, and in fact, the USA did increase its historically low investment ratio. This was partly driven by ICT, as shown in the past chapter. The business cycle also has an impact, since productivity rises pro-cyclically[78]. Measures of multi factor productivity try to correct for capital deepening and for deviation of actual from potential output, by relating the "trend output" to all inputs.

The OECD estimates that multi factor productivity increased in the USA from 1.0 % in the eighties to 1.4 % in the nineties (Table 5.3)[79]. For the EU, this study reports an increase of 1.7 % in the eighties, decreasing to 1.3 % between 1991 and 1998. The difference in the growth dynamics of the multi factor productivity is small, but the difference becomes important since the data indicate a deceleration for Europe during a period of acceleration in the USA. Experience differs according to countries. Within the European Union, four countries, namely Denmark, Finland and Sweden enjoyed an acceleration during the nineties relative to the eighties. Ireland, Denmark, Finland, the Netherlands and Portugal achieved higher growth in multi factor productivity than the USA.

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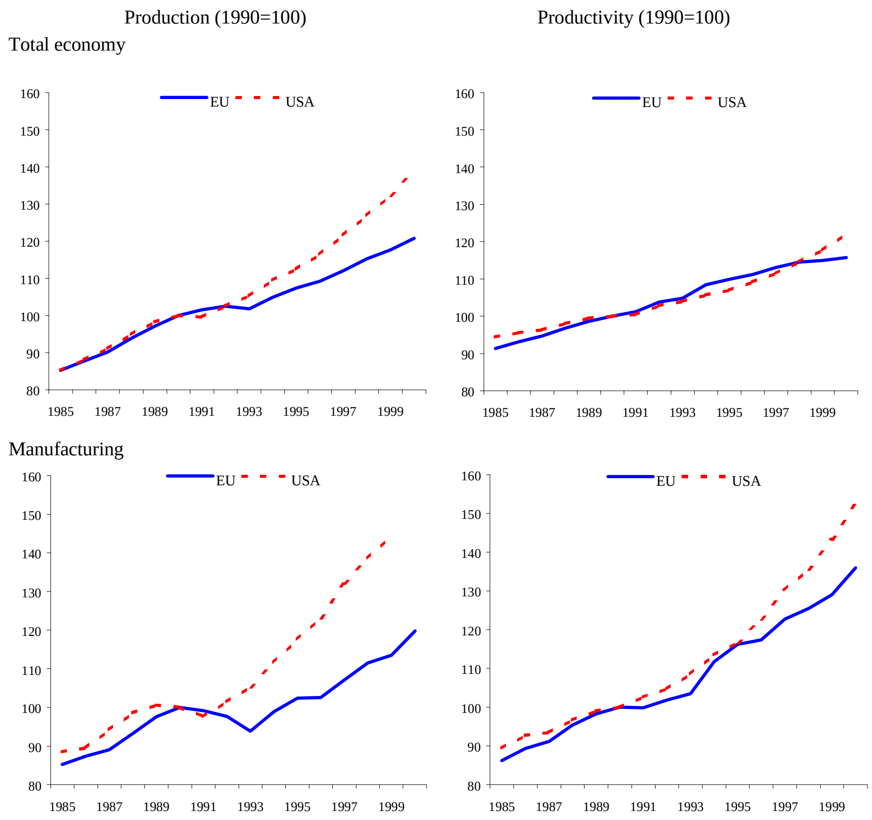
[76] *Scarpetta* et al. (2000) show this for the actual growth rate, trend growth and growth per capita for a wider set of countries, using data up to 1998.

[77] The growth variance increases also if we calculate the coefficient of variation instead of the standard deviation and if we exclude Ireland as an "outlier".

[78] Europe had to increase budgetary discipline (Maastrict criteria) and the central banks had to build up credibility to combat inflation; both had been done earlier in the USA; this allowed less restrictive fiscal and monetary policies in the nineties.

[79] Other non EU countries with increasing Multi-Factor Productivity are Australia, New Zealand, Canada and Norway. *Bassanini – Scarpetta - Visco*, 2000, p. 23, Table 3, hours adjusted version.

**Figure 5.2: Higher growth of output and productivity in the USA**



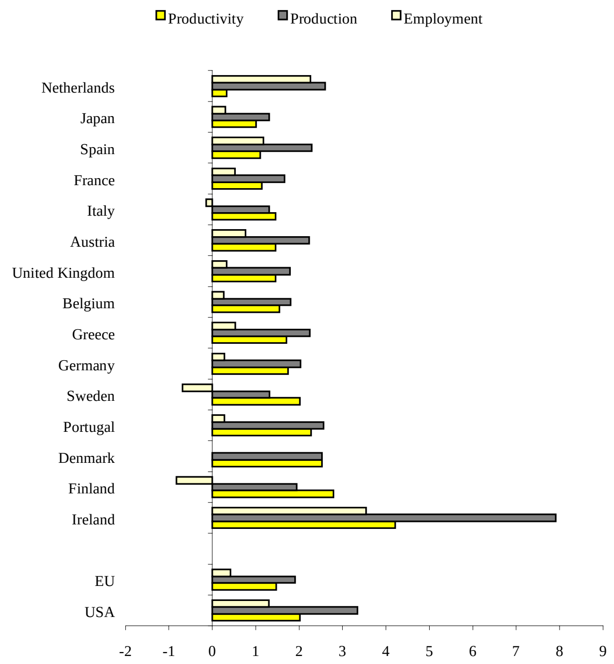

Production is GDP for total economy, production index for manufacturing; productivity is output per employee.

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

McMorrow and Roeger (2001) provide an estimate up to the year 2000, with trends similar to the OECD findings. For the USA, multi factor productivity is reported to accelerate from 0.9 % in the nineties, to 1.1 % in the first half of the eighties and to 1.4 % in the second half of the eighties. For Europe, the increase amounted to 1.1 % in the eighties and in the first half of the nineties, and 1.0 % in the second half of the nineties[80]. All these calculations use trend growth rates, which intend to eliminate cyclical factors, but may be late in detecting fundamental changes.

[80] *Mc Morrow - Roeger* apply several methods to eliminate trends and to measure inputs; we report the HP filtered trend.

## Figure 5.3: Growth - productivity options in European countries European countries ranked according to growth of macro productivity in the nineties, lowest first




*Source*: WIFO calculations using EUROSTAT (New Cronos); OECD.

## Table 5.3: Estimates of multi factor productivity

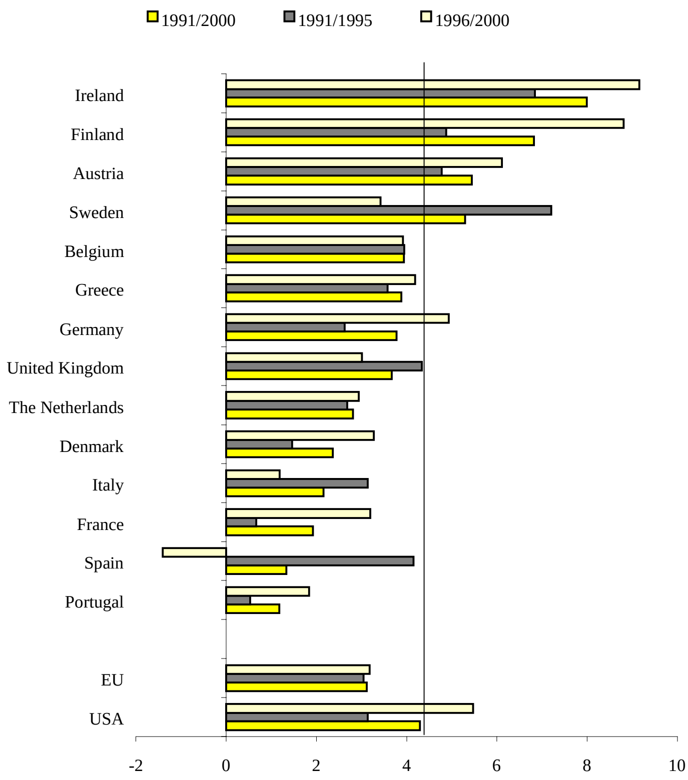
| | 1981/1990 | 1991/1998<br>Growth p.a. | 1996/1998 |
|---|---|---|---|
| Belgium | 1.4 | 1.0 | 0.8 |
| Denmark | 1.0 | 1.8 | 1.7 |
| Germany | 1.6 | 1.4 | 1.5 |
| Greece | 0.6 | 0.3 | 0.6 |
| Spain | 2.2 | 0.6 | 0.4 |
| France | 2.1 | 1.1 | 1.1 |
| Ireland | 3.9 | 3.9 | 3.6 |
| Italy | 1.5 | 1.2 | 1.0 |
| Netherlands | 2.2 | 1.7 | 1.2 |
| Austria | 1.2 | 1.1 | 1.4 |
| Portugal | 1.9 | 2.2 | - |
| Finland | 2.4 | 3.2 | 3.5 |
| Sweden | 0.8 | 1.3 | 1.3 |
| United Kingdom | - | 1.3 | 1.4 |
| EU[1] | 1.7 | 1.3 | 1.3 |
| Japan | 2.0 | 1.6 | 1.6 |
| USA | 1.0 | 1.4 | 1.5 |

[1] Weighted average over EU countries (weighted with real GDP 1990).

*Source*: WIFO calculations; *Bassanini – Scarpetta - Visco*, 2000.

In summary, the evidence of higher growth in multi factor productivity is not so strong that it can assuage all doubts which could arise due to issues of measurement or from assessments of the cyclical component. If the slowdown, which started in late 2000, proves stronger and last longer in the USA than in Europe, the estimate for "trend growth" will be revised later, perhaps eliminating the currently reported differences in multi factor productivity growth. Nevertheless, the overall performance of the US economy in the nineties was exceptional by many criteria. The USA forged ahead in growth, labour productivity, and multi factor productivity; at the same time it was successful in capital deepening and in increasing employment at a high rate. This combination is sometimes seen in catching up countries, after they have reached a taking-off point[81]. It is unusual for a country already leading in productivity. On the other hand, five European countries have managed to increase multi factor productivity as fast as the USA.

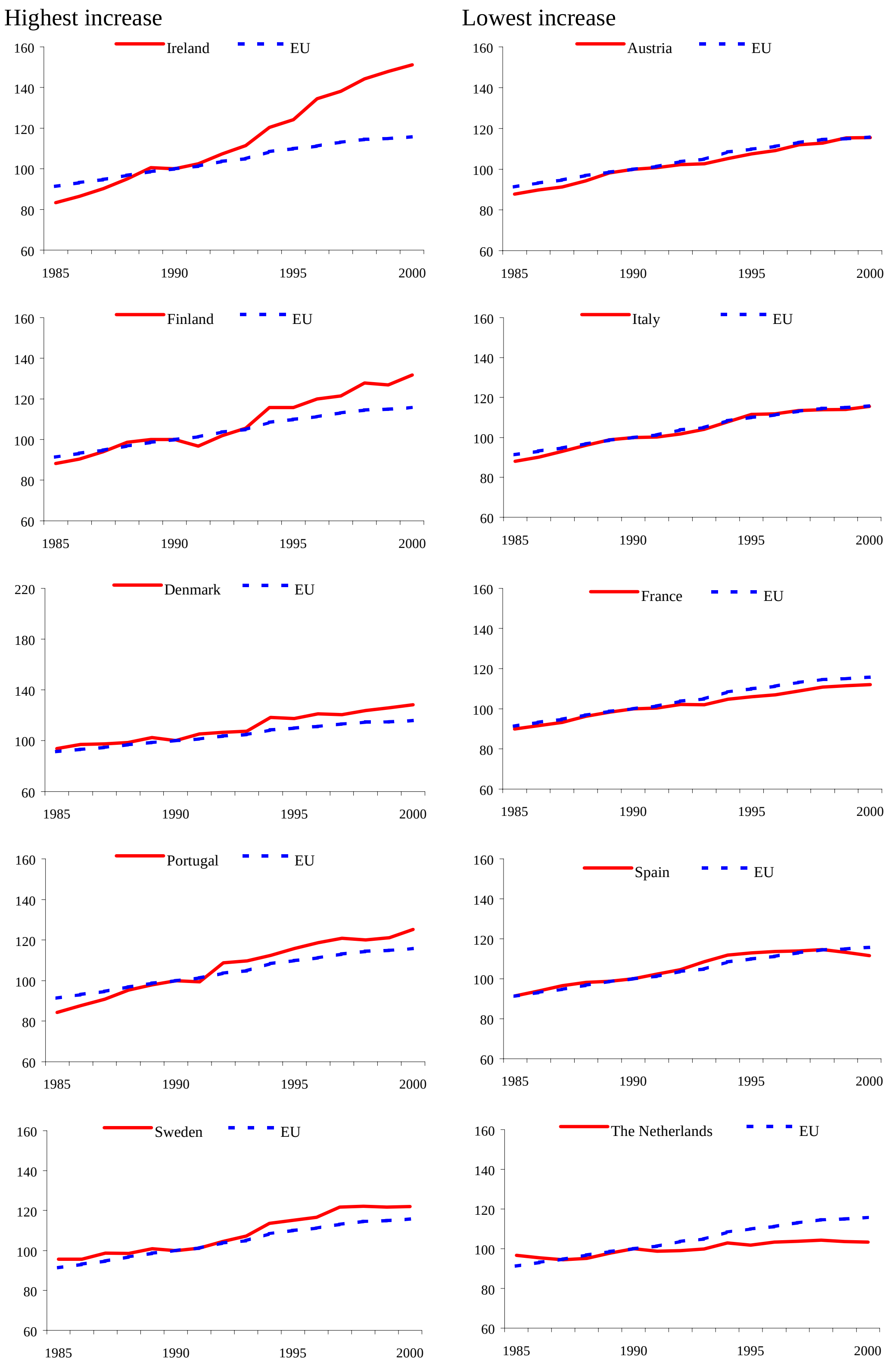
**Figure 5.4: Four countries match US productivity growth of manufacturing European countries ranked according to growth of productivity in the nineties, lowest first**




*Source*: WIFO calculations using EUROSTAT (New Cronos); OECD.

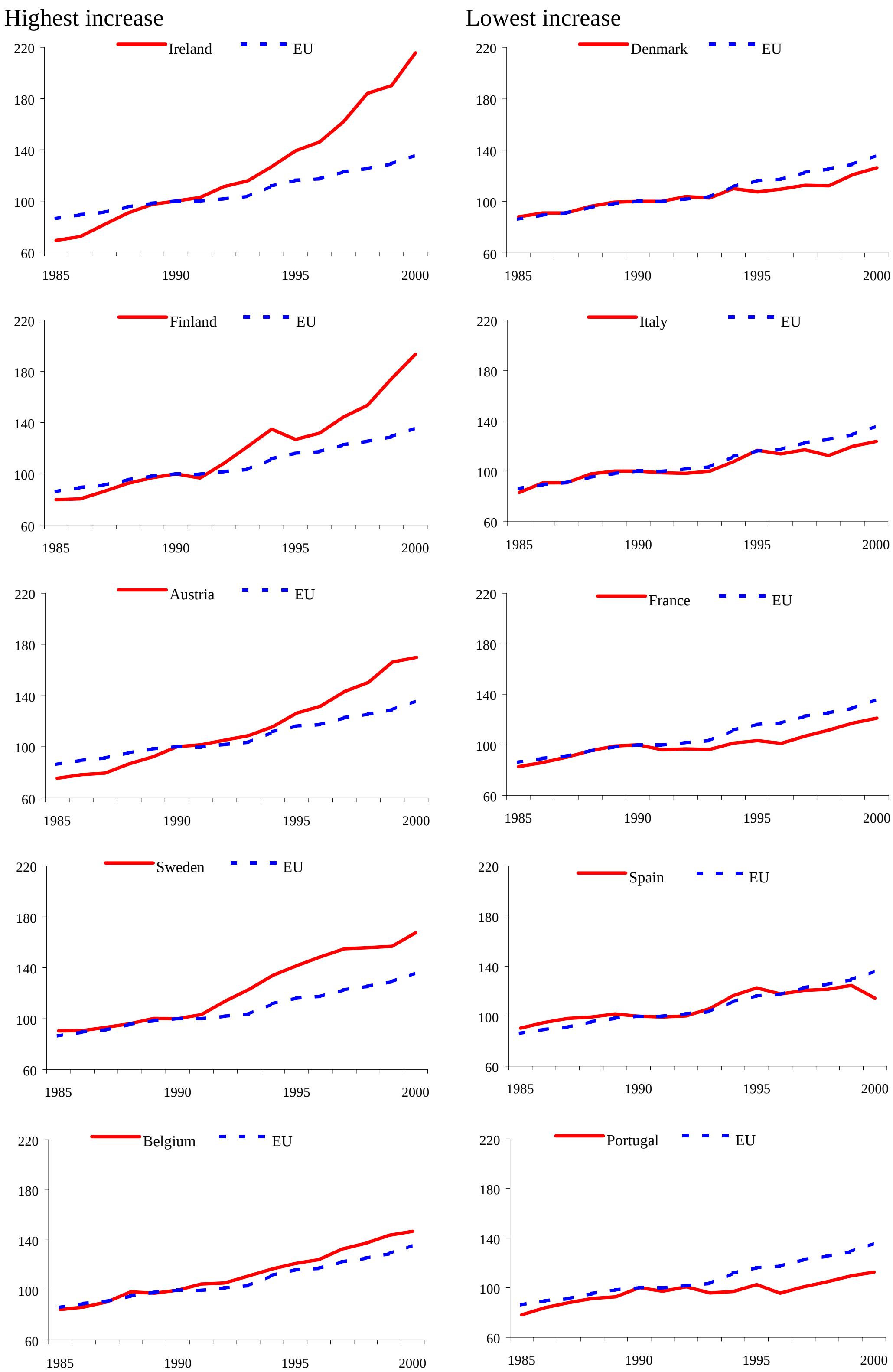
[81] A general pattern of growth according to all these indicators is not uncommon amongst successful catching up countries, but is very unusual for leading countries (*Scarpetta* et al., 2000).

**Figure 5.5: Countries with largest or lowest increase in labour productivity (total economy)**




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

**Figure 5.6: Countries with largest or lowest increase in labour productivity (Manufacturing)**




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

## 5.3 Towards the underlying forces

The factors proposed by the growth theory are indeed related to growth performance. Indicators on research, on the knowledge base, on ICT, on capabilities (growth drivers) are all positively related to growth of output and productivity. Each indicator is subject to measurement problems and can explain only some part of the growth differences, together they establish a system of growth drivers which explain a significant part of the performance differences of European countries in the nineties.

### Looking for indicators which proxies growth determiants

We will focus now on EU members and on the manufacturing sector for two reasons[82]. First, there is evidence that it is the manufacturing sector[83] which drives productivity growth and differentials, not the service sector. Secondly, it is for manufacturing that we can gradually add additional information by means of disaggregation to sectors and industries. Here, research intensity can be measured and firm data are available. We refer to labour productivity, if we do not specify otherwise. We use indicators related to knowledge, innovation and ICT, since these forces were described in the past chapters as relevant for growth and use information contained in the Community Innovation Survey to verify the importance of capabilities. 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 which follow.[84]

### Research indicators are (weakly) related to productivity in manufacturing

Growth of production and productivity is positively related to research input, patents and publications. The relations are not very close, significance is given for the relation between growth and publications and for productivity growth and patents (see Table 5.4)[85]. Sweden and Finland have top positions according to all indicators; Germany ranks high in patents and

---

[82] Results for macroeconomic growth is available in the OECD growth project (OECD 2001). Its main results and one of the core findings, that that the acceleration of Multi-Factor Productivity in the total economy is significantly related to increases in the business research intensity of OECD countries is reported in appendix 2.

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

[84] Though the indicators we chose are all linked to the theories and partly also to the empirical evidence presented in the last chapters, a certain ambiguity remains as to which indicators should be used, firstly because given indicators are poor proxies for the processes considered important; secondly, because we have to choose from a multiplicity of indicators, whereby each single one is flawed by measurement problems. We overcome these obstacles by using ranks (which are more robust than quantitative indicators) and by looking at the combined rankings of several indicators.

[85] However, most correlations are not significant by the usual standards. Production growth relates significantly to patents, education expenditure, working population with tertiary education, computers and internet hosts per resident,

research input, but has only a moderate position in output growth and productivity; the United Kingdom, which is among the leading countries with respect to research indicators, has slow growth. The southern countries – Greece, Spain, Portugal and Italy – rank low in R&D, although some achieve above average growth in output (Spain) and high growth in productivity (catching up – Greece). Ireland, the fastest growing economy, has increased its research input and output, and enjoys a high share of technology driven industries, but still lags behind in research intensive countries. Austria is far better ranked in growth than in research indicators.

### Knowledge base and ICT drive to country growth

As indicators of the knowledge base, we combine education indicators (secondary and tertiary education as proposed in Chapter 3) with indicators of the production and use of ICT. Sweden is ranked highest for human capital; Denmark and Belgium are ranked better due to high outlays, as well as greater shares for higher education. The United Kingdom falls back with respect to this category; Austria and Ireland are ranked better according to human capital than according to research and ICT (see Figure 5.7). For ICT, Ireland ranks first in the production and consumption share of ICT industries in manufacturing, but only moderately with respect to diffusion (internet hosts and computers per resident). Germany and Belgium lose ranks for production structure and computers per resident. The countries ranked lower are the same as for R&D. Again, all correlations are positive; significance is signalled for the share of the work force with tertiary educations; computers per resident and internet hosts are weakly significant in correlation with production growth.

innovation expenditures, co-operations and share of firms with continuous research. On the other hand, fourteen observations give a very small sample, it can happen that the relation exists, but the test does not reveal it.

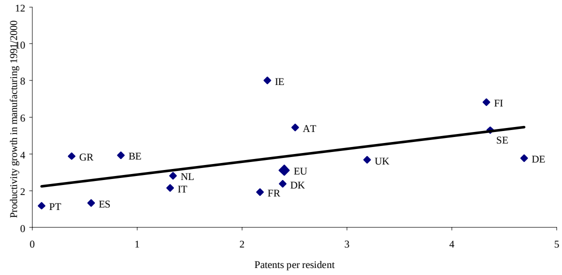
## Table 5.4: Closeness of fit between growth and growth drivers
**(Rank correlation coefficients, with p value below)**

| | Production growth manufacturing[1] | | Productivity growth manufacturing[1] | |
|---|---|---|---|---|
| R&D/GDP | 0.3319 | | 0.3187 | |
| | 0.2464 | | 0.2668 | |
| R&D personell in % of the labour force | 0.4374 | | 0.3626 | |
| | 0.1178 | | 0.2026 | |
| Patents per resident | 0.3670 | | 0.5253 | |
| | 0.1967 | | 0.0537 | * |
| Publications per resident | 0.4593 | | 0.3363 | |
| | 0.0985 | * | 0.2398 | |
| Public expenditure on education | 0.4813 | | 0.1736 | |
| | 0.0814 | * | 0.5528 | |
| Percentage of the population that has attained at least upper secondary education by age group (1998) | 0.3758 | | 0.4110 | |
| | 0.1854 | | 0.1443 | |
| Percentage of the population that has attained at least tertiary education (1998) | 0.4316 | | 0.4094 | |
| | 0.1234 | | 0.1460 | |
| Human resources in science and technology by country | 0.3451 | | 0.2703 | |
| | 0.2269 | | 0.3499 | |
| Working population with tertiary education | 0.4681 | | 0.3670 | |
| | 0.0914 | * | 0.1967 | |
| ICT expenditure in % of GDP | 0.3011 | | 0.2440 | |
| | 0.2955 | | 0.4006 | |
| ICT production in % of total manufacturing | 0.4559 | | 0.2967 | |
| | 0.1022 | | 0.3030 | |
| PCs per inhabitant | 0.6484 | | 0.4681 | |
| | 0.0121 | ** | 0.0914 | * |
| Internet users per inhabitant | 0.6088 | | 0.5341 | |
| | 0.0209 | ** | 0.0492 | ** |
| Cellular mobile subscribers per 100 capita | 0.4286 | | 0.2396 | |
| | 0.1263 | | 0.4094 | |
| Innovation expenditures in % of sales | 0.5431 | | 0.3444 | |
| | 0.0447 | ** | 0.2278 | |
| Share of new/improved products in % of sales | 0.4462 | | 0.3495 | |
| | 0.1098 | | 0.2207 | |
| Share of co-operations | 0.6084 | | 0.4596 | |
| | 0.0210 | ** | 0.0983 | * |
| Share of firms with continuous research | 0.7582 | | 0.6396 | |
| | 0.0017 | ** | 0.0138 | ** |
| Structural change indicator (speed of change)[2] | 0.4154 | | 0.4637 | |
| | 0.1397 | | 0.0949 | * |
| Combined indicator | 0.6264 | | 0.4593 | |
| | 0.0165 | ** | 0.0985 | * |

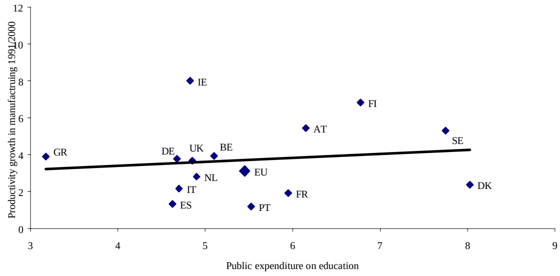
[1] Growth 1991/2000; 2 *Aiginger* (2001).
*Remark*: * (**) denotes significance at 10% (5%) level; for growth drivers average of the nineties (usually up to 1998).

## Figure 5.7: The underlying forces (growth drivers) for productivity growth

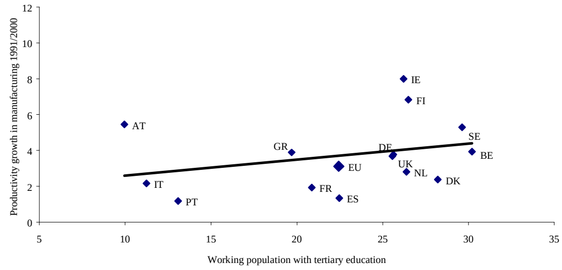
Relation between productivity growth and patents per resident



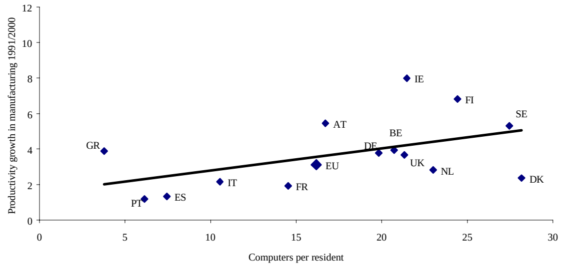

Relation between productivity growth and public expenditure on education



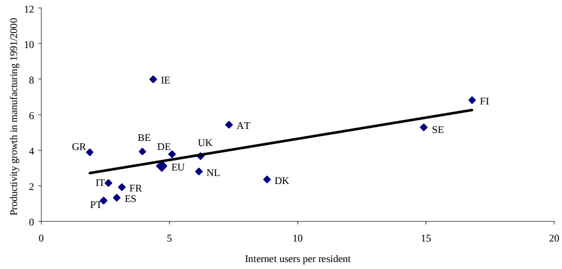

Relation between productivity growth and working population with tertiary education



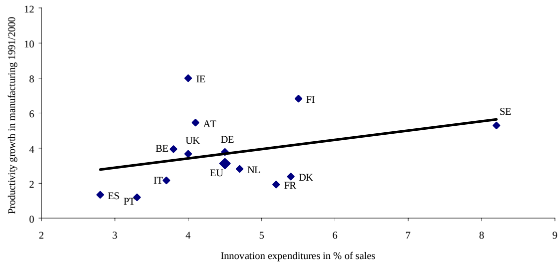

Relation between productivity growth and computers per resident



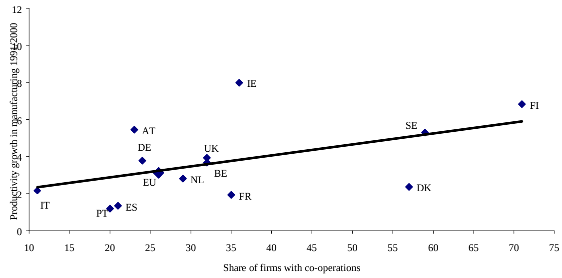

Relation between productivity growth and internet users per resident



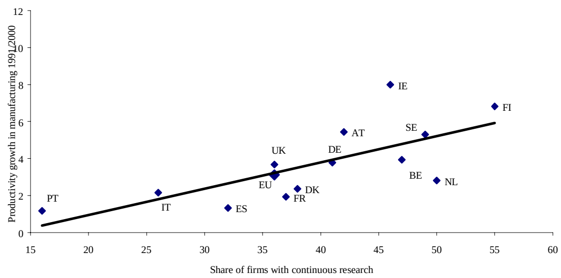

Relation between productivity growth and innovation expenditures in % of sales



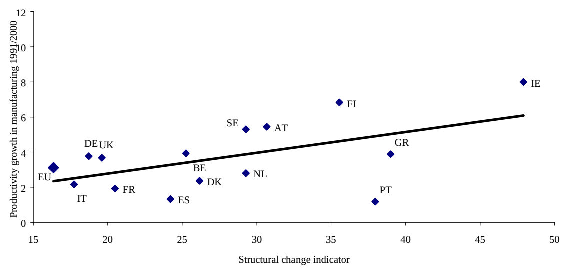

Relation between productivity growth and share of firms with co-operations



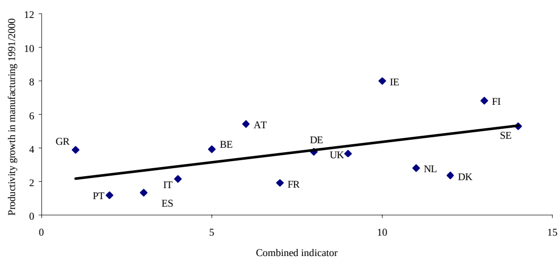

Relation between productivity growth and share of firms with continuous research




Relation between productivity growth and speed of change




Relation between productivity growth and the combined indicator



## Capabilities are important

Indicators which try to grasp the notion of capabilities are closely related to growth. There is a consensus that capabilities are decisive for the performance of firms, but that they are difficult to measure. We chose four indicators from the CIS innovation survey which could proxy some aspects of capabilities. Innovation expenses relative to sales[86], and the share of firms which report co-operative and continuous research are significantly related to production growth; the last two are also related to productivity growth. The share of new products in sales relates closely, but is just barely not significant.

According to the capability indicators, the Netherlands, Denmark and Austria are ranked higher than according to the research group. Austria ranks 3rd according to the share of new and improved products, and is above average in the share of firms with continuous research and innovation expenditures. Belgium ranks high in the share of firms reporting co-operative activities and in marketing intensive industries. The Netherlands ranks high with respect to the share of firms with continuous research and marketing driven industries.

## Growth and speed of change are interrelated

The speed of change of industrial structure is significantly related to productivity growth[87]. It is highest in Ireland, as is productivity growth. Finland has high productivity growth and is ranked fourth in speed of change. At the lower end, Germany, Italy and United Kingdom have slow speed of change and slow productivity growth. Austria's and Sweden's productivity has increased with less speed of change, probably due to laws restricting firm exits. In Portugal and Greece (and to some extent Spain), relatively high speed of change was not sufficient to raise productivity. High unemployment did lower the pressure to upscale productivity, as policy efforts to spread employment did in Denmark and the Netherlands.

[86] Innovation expenditures include software, acquisition of patents, know how, trademarks, training, industrial design etc. Some of these positions reflect activities which allow to build up a competitive advantage and make use of knowledge which is in principle available, but firms need specific abilities to get hold of. Thus innovative expenditures do signal elements addressed by the capability approach but not contained in research expenditures.

[87] 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 also indirectly measures rigidities. It was developed in *Aiginger* (2000) and in *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 levels (see *Aiginger*, 2001).

### What we have learned

First we have to remind that correlations indicate the closeness of relations, but prove no causality. Secondly, given the complexity of the relationship between the innovation system and productivity growth, no close statistical correlation between any single indicator and growth and productivity should be expected. If we combine the information on the suspected drivers of growth in a single indicator ("combined indicator"), we eliminate measurement errors in the individual series and attain a significant relation. It is interesting that in general, the indicators are more closely related to output growth than to productivity growth[88], indicating that productivity is not only related to its active "drivers", but also reflects the employment strategies of governments and the restructuring efforts of firms, which attempt to regain competitiveness in contested positions[89]. The close relation to indicators of capabilities supports the complementary importance of evolutionary theories and of approaches emphasising the absorbtive capacity of frims . The significance of the speed of change variable shifts attention to factors fostering, respectively preventing, the adaptation of supply to demand forces[90]:

## 5.4 The connection between research and development and productivity at the sectoral level

Productivity increased fastest in two groups of sectors. In the second half of the decade, this is the case for technology driven industries; in the first half of the nineties, productivity rose specifically fast in capital intensive industries. The first tendency contributes to a close connection between research intensity and productivity growth across sectors. The second tendency reduces the fit, since own research input is low in capital intensive industries. As an indicator of productivity growth, we take real value added per employee; as an indicator of research intensity, we use research outlays in relation to nominal production.[91]

---

[88] The significance is given at the 2 % level for production growth, and at the 10 % level for productivity growth (for the combined indicator).
[89] Evidence for this is the - relative to output – high productivity increase in slow growing countries and in capital intenisveindustries (see Section 5.4).
[90] 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, if we want to explain the acceleration of growth in the second half of the nineties, as compared to the first, we attain no satisfactory correlations. The reason is that the distribution of growth between the two halves of the nineties is determined by the business cycle, by shocks and measurement problems.
[91] We used the production index for measuring productivity for total manufacturing in section 5.2. For sectors and industries we switch to value added or production data, since only these are available on a more disaggregated level. Real value added had to be estimated by WIFO, using nominal value added by SBS and real value added for some industries in SBS. For research and development, we used ANBERD, for production STAN (both provided by the OECD). For the correlations, we used a combined indicator of productivity (with nominal and real value added and

## Technology and restructuring drives productivity

High tech industries with strong productivity growth in Europe include electronic equipment and medical equipment (see Figure 5.8). On the other hand, productivity increased very fast in capital intensive sectors like basic metals and pulp and paper, and chemicals. In the last two sectors, the passive character of productivity growth is revealed by an overproportional reduction in employment.[92]

The smallest increases were reported in apparel, in leather and in the food sector. Textiles are in between, with an average growth of productivity and a steep decline in employment. According to various measures, printing and publishing is a special case. Increases in productivity have been rather low, but it is the only sector in which employment has been increasing.

If If we look for the second half of the nineties, the impact of the technology driven industries on the productivity increase become stronger. Neither of the capital intensive sectors mentioned increased productivity growth between the first and second halves of the nineties[93].

We can see this shift, if we classify industries according to their main inputs. In the nineties, the greatest productivity increase took place in capital intensive industries (4.1 %), followed by the technology driven industries (3.4 %), with labour and marketing intensive industries trailing in productivity performance. If we focus on the latest years, technology driven industries increased productivity most strongly (4.8 %), implying that this sector also leads in acceleration. Capital intensive industries fell back to a level of 2 % growth in productivity (see Figure 5.9).[94]

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production value as the numerator), which should help to eliminate noise and measurement errors in each of the series. We report results which are robust for all indicators.

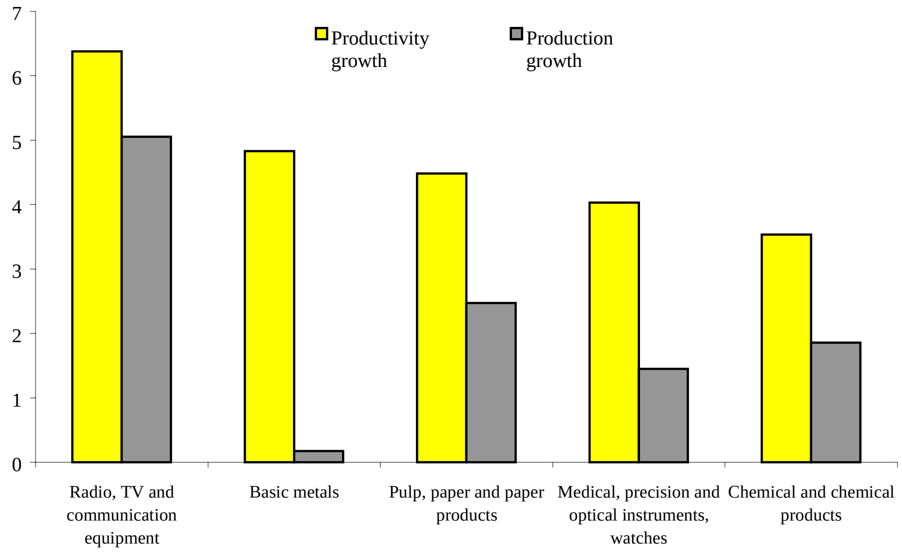
[92] If we take a look at industries, both telecom industries, electronic valves and motor parts are among the top ten, as are man made fibres, pulp and paper and tubes.

[93] Taking the acceleration of productivity as a criterion, reveals several industry specific and cyclical effects not driven by innovation: for example, the petroleum industry is accelerating productivity, while pulp and paper is falling back.

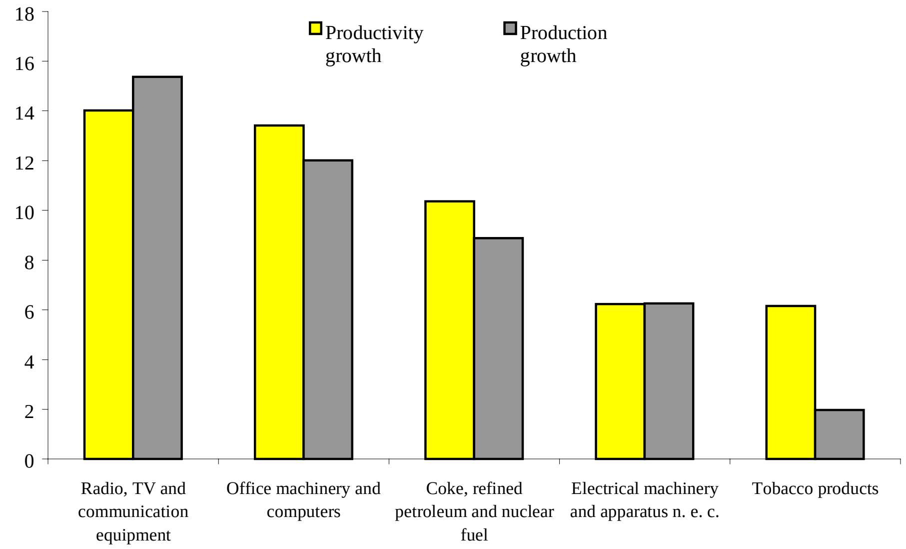
[94] All these tendencies are replicated if we use nominal data or a combined productivity indicator.

**Figure 5.8: Sectors with the highest increase in productivity in EU and USA**
(real value added per employment; 1991-1998)

EU



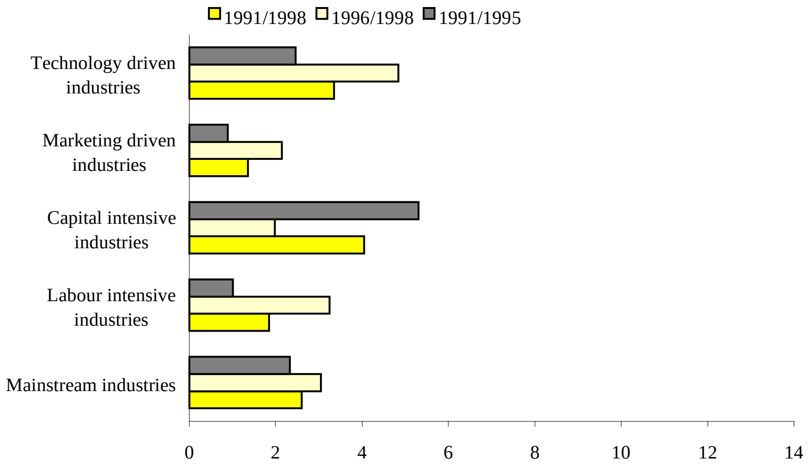

USA



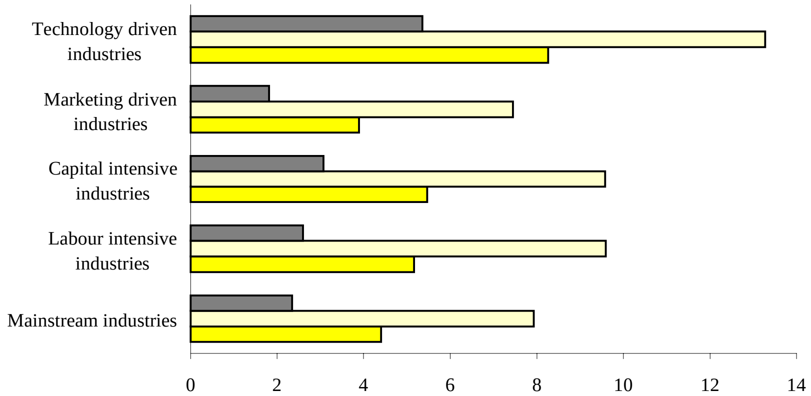

*Source*: WIFO calculations using EUROSTAT (New Cronos).

**Figure 5.9: Technology driven and capital intensive industries boost productivity in Europe**

EU




USA



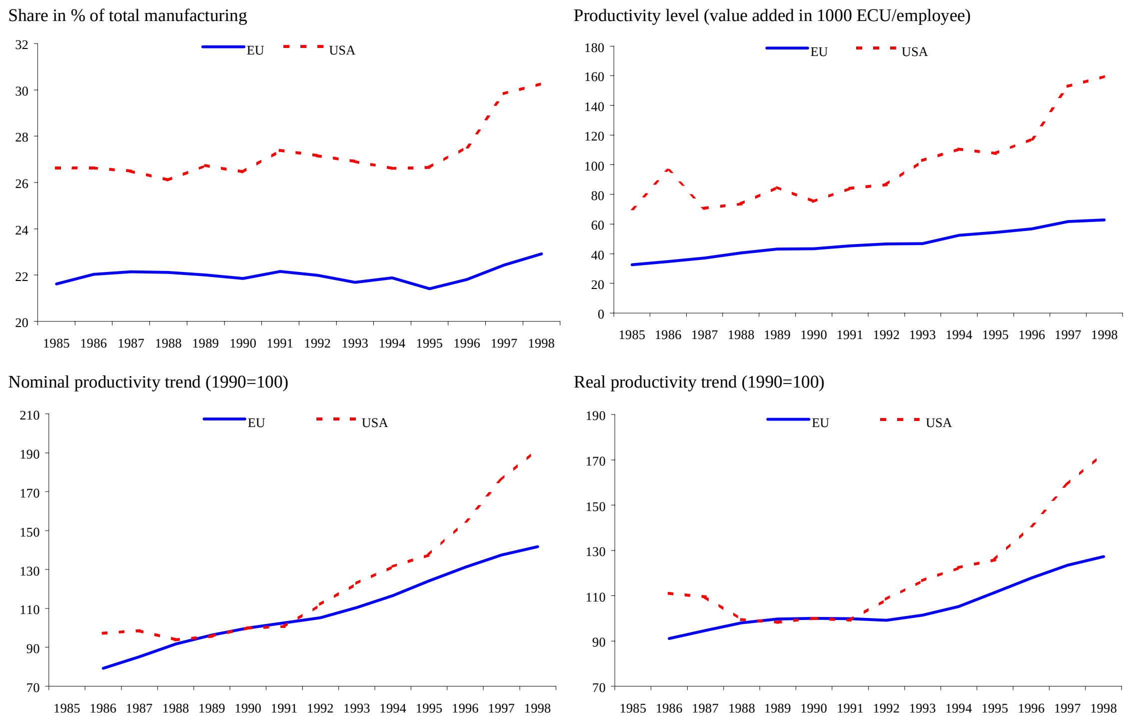

*Remark*: Productivity = real value added per employment

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

## The impact of technology is even more visible in the USA

In the USA, the role of high tech industries is even more pronounced. First, the share of technology driven industries is larger (Figure 5.10). Secondly, the technology driven industries increased productivity by 8.3 % in the nineties – a much higher level than the capital intensive industries achieved. Productivity accelerated from 5.4 % in the first half of the nineties to 13.3 % in the second. The USA had 14 industries in which productivity increased at double digit rates in the period 1996 to 1998; most of them are technology driven industries. In Europe, only four industries enjoyed double digit increases[95].

**Figure 5.10: Technology is more important in the USA**
**Share, productivity level, productivity growth of technology driven industries**




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

## Research intensity is similar across sectors, but higher in the USA

Telecom equipment has the highest research intensity of the European sectors, followed by other transport and instruments (see Figure 5.11). In the leading sectors, research relative to sales declined in the late nineties, while on the other hand, productivity growth increased.

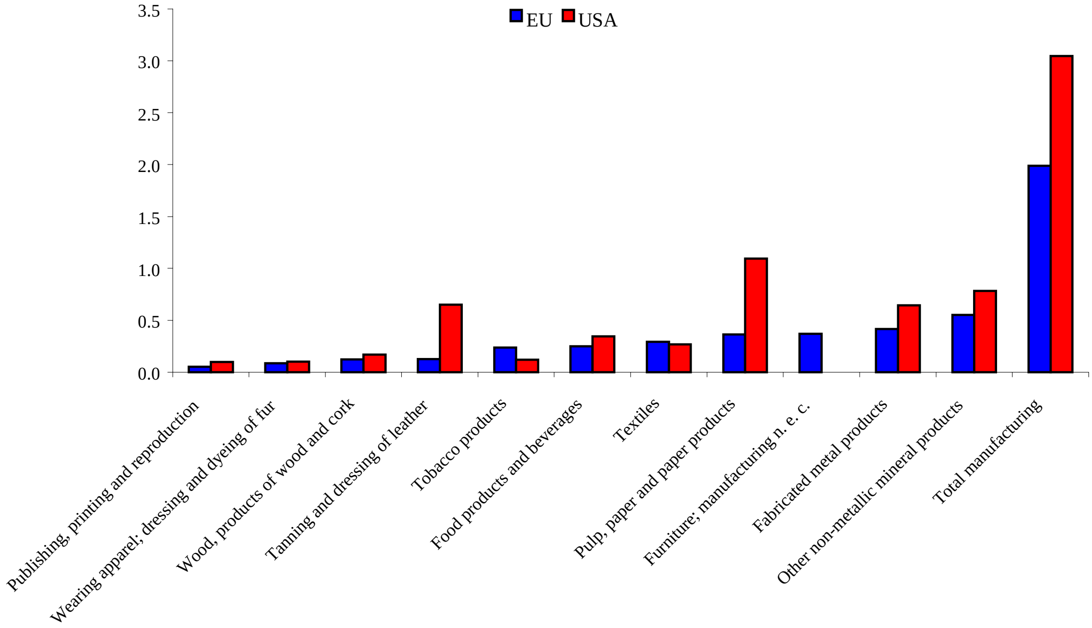
In the USA, office machinery, other transport, and telecom equipment are the most research intensive industries, with rising trends for the first two, and a decrease in the computer industry. Productivity - notoriously difficult to measure in these industries - increased during the nineties, partly in the second half (office machinery, aerospace), and partly in the first. The hierarchy of research intensity is otherwise very similar between USA and Europe, however the research intensity is higher in the USA in 16 of the 22 sectors. Three industries with rather low shares of

[95] Telecom equipment, motor vehicles bodies, weapons and ammunition, aircraft and spacecraft.

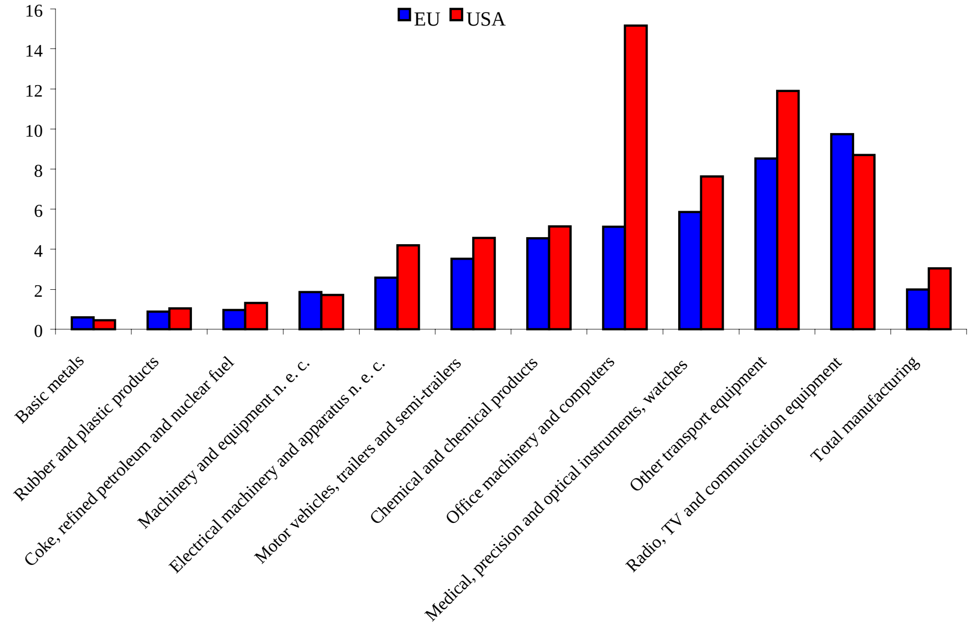
research are leading in increases: leather, textiles and printing had high increases. The reason could be that for example in textiles production is outsourced, while knowledge intensive functions are concentrated in the headquarters.

**Figure 5.11: Research intensity in sectors is similar in Europe and in the USA**

Low R&D sectors




High R&D sectors




*Source*: WIFO calculations using EUROSTAT (New Cronos); OECD (STAN).

## Table 5.5: Productivity and research intensity correlates for EU and the USA

### (Rank correlation coefficients, with p value below)

| | 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 | * |
| USA | 0.3066 | | 0.3427 | | 0.4771 | | 0.4579 | |
| | 0.1652 | | 0.1184 | | 0.0247 | ** | 0.0321 | ** |

*Remarks*: Contemporenous: 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).

## Research intensive sectors enjoy higher productivity growth

Productivity growth in the nineties and research intensity are significantly related across sectors (Table 5.5). This holds for the European Union, as well as for the USA, but not for the majority of the European countries. International spillovers of research could be one reason for the lack of correlation at the country level. Research does not relate closely to production growth – with the notable exceptions of Finland and Sweden. Lags do not change the closeness of fit.

Electronic equipment, instruments and computers are sectors with high research intensity and productivity growth.[96] Additionally, chemicals and motor vehicles are in the top third of the sectors for both indicators (see Figure 5.12). On the other side, 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 productivity is about average, competitive pressure leads to decreasing employment (-3.9 % between 1991 and 1998).

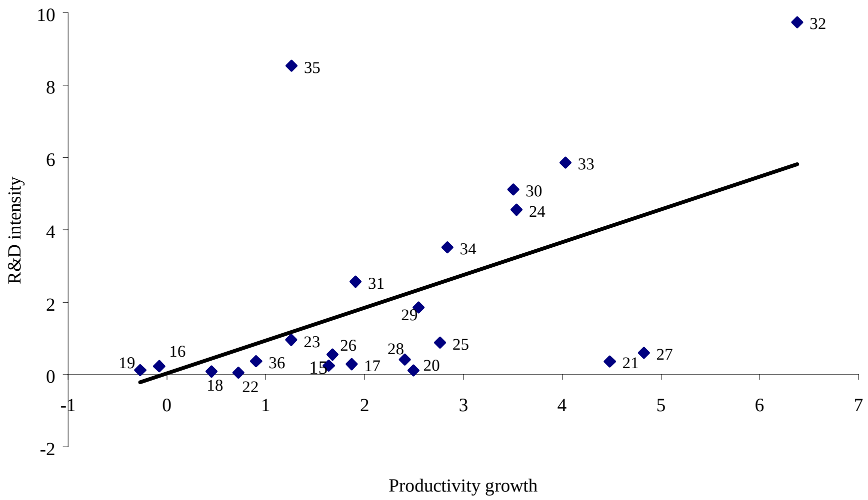
Other transport is the sector with the second highest research input, while production and productivity increases are reported to be low. However, data sets differ as to the extent, and this sector is very diverse (from aircraft and spacecraft to railways). In addition, the locations of research and production for this sector are not the same, and are sometimes even outside of Europe. Electrical machinery is within the top three in research intensity, and has a moderate position in productivity growth.

Publishing and printing is a sector with low direct research intensity, but it is implementing new forms of technology at a very fast speed, via technology investments embodied in machines and inputs. It is a high growth sector, but is also increasing employment, so that productivity performance is below average (even the fourth lowest, as measured by real value added per employee).

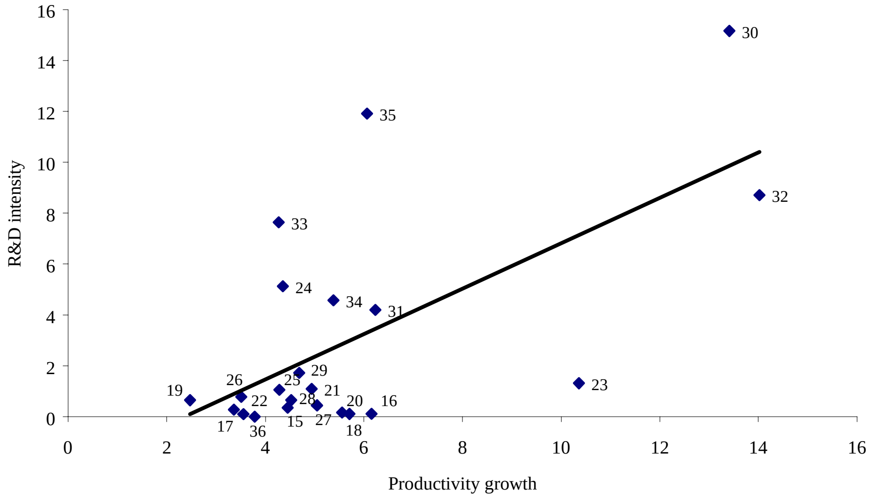
Table 5.6 classifies the sectors according to productivity and research intensity for the triad regions. For the relation of productivity and research intensity in the individual countries see Annex 3. Electronic equipment assumes a position of high research intensity and high productivity growth in 10 of 11 European countries. This favourable position is attained five times for instruments and three times for other transport. For motor vehicles, chemicals and office machinery, this "box" contains 2 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 insofar an exception, as in six countries research intensity and productivity growth are low, but production growth is rather high.

[96] The position varies according to the indicator. For the combined indicator (production value, nominal plus real value added) they attain ranks of 1, 3 and 7 among 22 sectors. Office machinery falls back due to its weak position in nominal value added.

**Figure 5.12: Productivity and research intensity relates across sectors for Europe and the USA**




USA




| | |
|---|---|
| 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. |

**Table 5.6: Innovation intensity and productivity growth: sectoral evidence**

| | Low productivity growth | High productivity growth |
|---|---|---|
| **EU** | | |
| Low research intensity | Food products and beverages<br>Tanning and dressing of leather<br>Wearing apparel; dressing and dyeing of fur<br>Publishing, printing and reproduction | |
| High research intensity | | Radio, TV and communication equipment<br>Medical, precision and optical instruments, watches<br>Office machinery and computers<br>Chemical and chemical products<br>Motor vehicles, trailers and semi-trailers |
| **USA** | | |
| Low research intensity | Food products and beverages<br>Textiles<br>Publishing, printing and reproduction<br>Furniture; manufacturing n. e. c. | Tobacco products<br>Wearing apparel; dressing and dyeing of fur |
| High research intensity | | Office machinery and computers<br>Other transport equipment<br>Radio, TV and communication equipment<br>Motor vehicles, trailers and semi-trailers<br>Electrical machinery and apparatus n. e. c. |

*Remark*: The criteria to be included in a box was, whether research intensity was in the lower or upper tercile (low, top seven) of the sectors, and productivity growth was in the lower or upper tercile in the nineties.

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

It is interesting to see which sectors are not placed in the expected boxes where low productivity and low research intensity or high productivity and high research intensity come together. Office machinery and other transport have high levels of research intensity and low production (and productivity) growth for several countries. This combination indicates a different specialisation pattern for research and production. Low research and high production and productivity growth is seen for several countries in wood products and apparel, showing how traditional industries succeed in staying competitive without direct research input.

## 5.5 Similarity of productivity growth across countries

The same industries are contributing to productivity growth in Europe and the USA. The similarity increased during the nineties and became even more pronounced over the last several years. Technology driven industries are partly behind this trend, but the improvement in their performance was greater in the USA, while capital intensive industries increased productivity more strongly in Europe. This extends the picture representative of sectors to the industry level.

### Productivity growth pattern becomes more similar

Productivity growth[97] across industries in Europe and in the USA differed significantly in the eighties, but was positive and significantly correlated in the nineties.[98] The similarity increased between the first and the second halves of the nineties, and the correlation reached its highest value in the very last years of this decade. Even the acceleration in productivity is significantly related, at least at the sectoral level (Table 5.7).[99]. Several factors are behind this picture. First technology driven industries which had a disappointing productivity performance in the eighties (see Solow paradoxon), started to increase poductivity in the early nineties. In Europe in this phase productivity in this sectors was rather week, this may have been a lag in technology or the result of the cyclical downturn and the currency crisis (see Figure 5.10). Competitive pressure on the other hand, boosted productivity in the capital intenisve sector. In the second half the productivity increased strongest in the technology driven sector in Europe as well as in the USA (albeit at a higher rate in the USA). The lower similarity in the early nineties was probably driven by the currency crisis at the European level, perhaps in addition to German unification and the competitive pressure from the Single Market programme. In the late nineties, technological forces seem to have determined the pattern.

### US performance is driven by technology

The impact of technology driven industries is greater in the USA. Productivity increased more strongly and accelerated faster in these industries. Secondly, at the beginning of the nineties, the share of technology driven industries was 22 % in EU and 26 % in the USA. Thirdly, the productivity lead of the USA – however difficult absolute productivity may be to measure – was specifically large in these industries, so that the dynamics of this sector took place on top of a strong starting position.

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[97] Remember that we use the average performance according to three variables to define productivity growth in these correlations and to smooth out measurement errors in each of the following: production per employee, and value added - nominal and real per employee.
[98] The rank correlation is 0.51 for sectors and 0.22 for industries (significant at the 1 %, respectively 3 % levels).
[99] The calculations were done by first calculating a 3-year moving average and then correlating the vectors of growth rates in productivity in Europe and the USA. 1997 therefore refers to growth during the period 1996 to 1998 in Europe versus growth during the period 1996 to 1998 in the USA.

**Table 5.7: Productivity growth in the EU and the USA becomes more similar**

Rank correlation between productivity growth in EU and the USA across sectors and industries

| | Sector level | | | Industry level | | |
|---|---|---|---|---|---|---|
| | R | | p-value | R | | 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 years moving average.
*Remark*: * (**, ***) denotes significance at 10% (5%, 1%) level.

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

Of the industries which are among the top 25 in both regions, three are electronic industries (equipment, computers, valves and tubes), two are motor vehicles industries, weapons and ammunition, and instruments are other high tech industries in which productivity increased faster in Europe and in the USA (Table 5.8). Most of the others are capital intensive industries, ranging from man made fibres, to steel industries, and pulp and wood. High tech industries with high productivity increases in Europe, which are not among the industries with high productivity growth in the USA, are pharmaceuticals, electronic apparatus, and recorded media. In general, of the 25 industries with the highest productivity increases in the nineties in Europe, 14 are also among the first 25 in the USA.[100] The concordance at the lower end of the spectrum is less impressive. Of the 25 industries with the lowest productivity increases in Europe, only 10

[100] Of the 25 industries with the highest productivity increases in Europe between 1996 and 1998, 12 are in the same groups as those in the USA.

are in the same group in USA; among these are five textile industries, oils and fats and motorcycles.

## Table 5.8: Industries with high productivity growth in the EU (Top 25)

| | Growth of productivity EU | | | | Share of value added EU 1990 | Growth of productivity USA | | | | Share of value added USA 1990 | Top 25 in EU and USA | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1991/1998 | | 1996/1998 | | | 1991/1998 | | 1996/1998 | | | 1991/98 | 1996/98 |
| | % 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 |
| Total manufactuirng | 2.6 | | 3.0 | | 100.0 | 5.5 | | 9.9 | | 100.0 | | |

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

## The similarity in productivity growth for individual countries

If we compare the European countries with the EU total, we see that productivity growth is rather similar: in 11 countries during the nineties, the ranks are significantly related between a country and the EU[101]. The only countries without significant relations are Denmark, Ireland and Finland. For France, Spain, the Netherlands and Austria, the correlation is significant for sectors as well as for industries. Three small countries (Belgium, Portugal and Sweden) have, together with two large countries (France and Spain) the closest conformity to EU productivity growth.[102]

[101] As a criterion, we use the rank correlation for productivity growth (combined indicator), and significance of 90% at a minimum of one level of aggregation (sectors or industries).

[102] The relations between country and EU performances in increasing productivity remain close if we focus on the short period 1996 to 1998, and are better if we focus on the acceleration of productivity growth during this period vs. the first half of the nineties (see Table 5.7). Only four countries exhibit no significant relation between the acceleration of productivity and that of the EU: they are Belgium, Ireland, the Netherlands and Greece.

## Structure matters, but not too much

If there is a strong pattern of variation in productivity growth across industries, countries with a higher share of industries which boost productivity could have higher growth. This is partly the case. For example, if the USA had had European production structures, its increase in productivity would have been slower by half a percentage point in the nineties. The reason is that the high productivity growth in the technology driven industries would have had less weight. On the other hand, if the EU had had US production structures, it would not have had a higher productivity increase, since then several of the capital intensive industries, in which productivity increases were specifically strong, would have had less weight. Of the EU countries, Greece (due to its high share of capital intensive industries) and Ireland (due to its high share of technology driven industries) would have lost most, the highest gains in productivity would have been realised by the Netherlands and Belgium.

## 5.6 Country profiles

We draw pictures of growth and productivity for the individual member countries. The profiles combine information on the drivers of growth, as presented in Section 5.4, with results indicating the impact of research on productivity in Section 5.5 and the specialisation of industries.[103] We add furthermore indicators used in the innovation and performance ratings of the European Commission[104]. Two figures ("cobwebs") summarise the information graphically. The first reports growth in the nineties and its drivers; the second presents absolute figures (e.g. per capita GDP for 1998) plus policy variables. Each variable is standardised, so that points outside the unity circle indicate a better performance than the EU average. The cobwebs pin down a dynamic and changing picture into two figures, where growth over the nineties is visualised together with recent information on growth drivers and policy variables.

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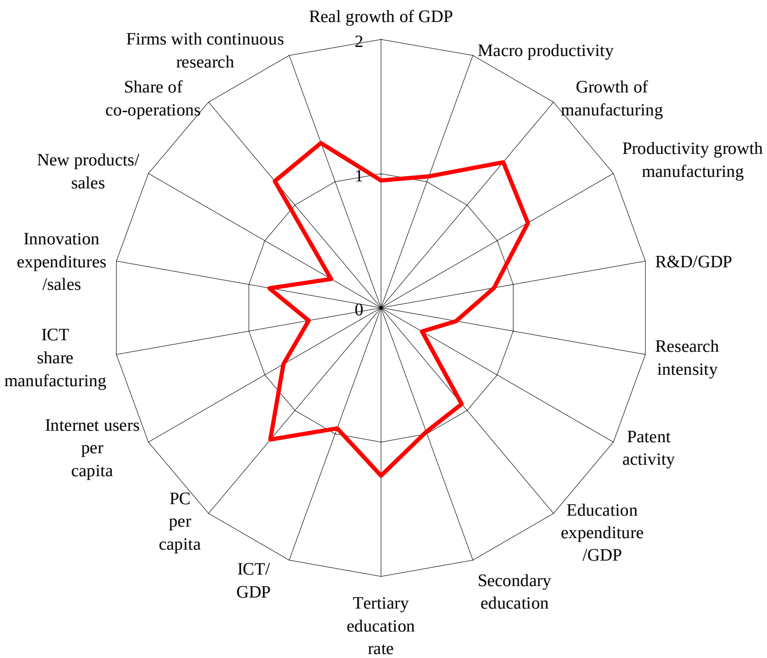
[103] *European Commission* (1999), *European Commission* (2000), *Aiginger* et al. (1999), *Aiginger* (2000), *Aiginger - Davies* (2000).
[104] *European Commission*: Innovation in a knowledge driven Economy, Annex: European Innovation Scoreboard, Brussels, (2000), pp. 567 and *European Commission*: Realizing the European Union's Potential (Stockholm Report) Brussels, 2001, Appendix 2. The Section 5.5 uses also material from Aiginger (2000 B) and from the OECD Country reports published in 2000 and 2001.

## Figure 5.13: Country profiles: Belgium





*Remark*: Each indicator outside the circle shows a superior performance of the country relative to EU average; growth rates for the nineties, for other indicators most recent information.

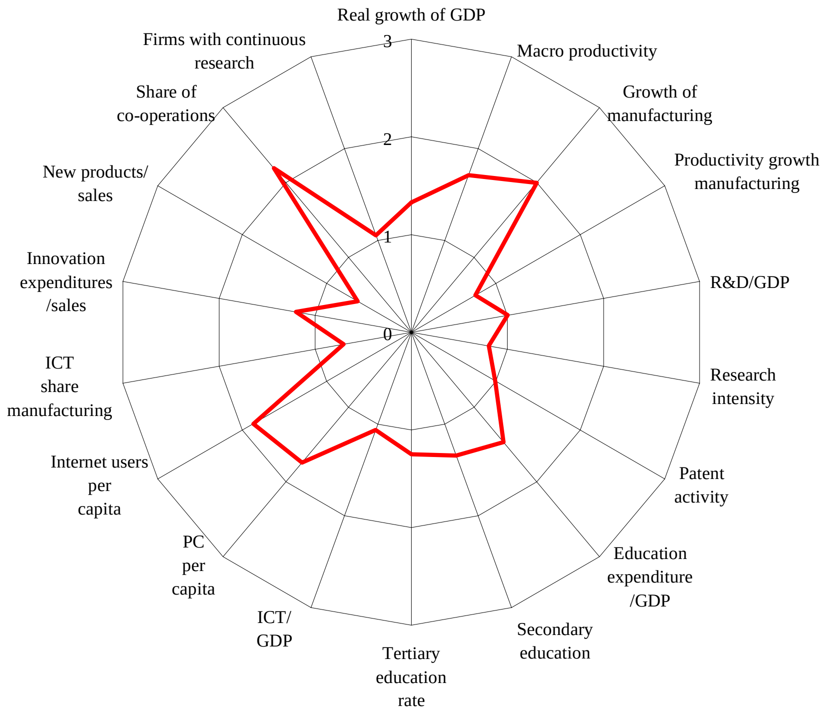
## Belgium: Capabilities substitute own research

Belgium's total economic growth, as well as productivity increases, are about average. In manufacturing, a lead in production of half a percentage point was transferred into a somewhat larger lead in speeding up productivity, which led to a top position in value added per employee among the European countries.

Belgium has low research expenditures, a lower share of IT industries and internet use, and its ICT expenditures are on average. The share of higher education is large. Capability indicators, such as the share of co-operative ventures, help to explain the excellent productivity performance. Belgium is an open economy, tendering follows EU rules, however prices for telecom are rather high. A low employment rate coincides with high tax wedges; passive measures account for two thirds of labour market policy. The situation is complicated by the distribution of responsibility between central and regional authorities. Voluntary measures to reduce the workweek and to allow for career breaks are under way, in order to increase labour flexibility (*OECD*, 2001, p.14).

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 and has a high share in capital intensive industries (steel, cement). The chemical sector provides 17 % of value added and is the largest industrial sector in Belgium. Exports in pharmaceuticals are booming and the 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. Publishing and printing is a marketing driven industry with high growth. The share of skill intensive industries is low, and the unit value of exports is stagnating, which is in contrast to the high and rising productivity and the highest wage level per employee. The lower skill input and the higher capital intensity, in addition to the high productivity, may to some extent reflect a skill drain precipitated by the well paid administrative jobs in the capital.

## Figure 5.14: Country profiles: Denmark





*Remark*: Each indicator outside the circle shows a superior performance of the country relative to EU average; growth rates for the nineties, for other indicators most recent information.

## Denmark: Catching up with the leaders

Total economic and manufacturing growth in Denmark was above average, specifically in the first half of the nineties, at which time several other countries were suffering currency crises and business slumps. Measured productivity in manufacturing expanded more slowly during this period, while the acceleration during the second half was strong.

Denmark surpassed the EU average in research during the last several years and excelled in the rankings for computers and servers per capita. It has a high share of innovation expenditures and placed third in co-operations. Education is an asset, reflected by high expenditures and skilled employees[105]. Denmark shares with the Netherlands a policy of job creation via part time work and sabbaticals, with the objective of spreading the same number of work hours among more employees. Denmark thus achieved - as one of only four countries - a stabilisation of employment in manufacturing. Some indicators show high prices for network industries, and financial markets (with low venture capital and capitalisation rates), which are not fully competitive. Overall, Denmark has improved its position with respect to most of the drivers of growth, and is now ranked third for the indicators of research, knowledge, education, and capabilities.

Denmark has a high share of skilled and marketing driven industries. The last tendency is being driven by the food sector, which supplies 19 % of output and 23 % of exports (3rd highest in Europe after Greece and Ireland). The second largest sector is machinery. Furthermore, Denmark is specialised in wood products and furniture. It has a rather low share in capital intensive and technology driven industries, and both tendencies are contributing to below average productivity. High tech industries with relatively large export shares are pharmaceuticals and medical equipment. The fastest growing industries are wood products, tobacco and motor vehicles. Summing up, Denmark is a country with a rather small industrial sector, and with high per capita wages. Denmark is deeply integrated in the EU, with a high and rising intra trade share. It has been successful in maintaining employment in manufacturing, partly through higher growth and partly at the expense of higher productivity. It is preparing for future productivity gains by investing in the drivers of growth; with respect to information technology, its position is near to that of the leading countries.

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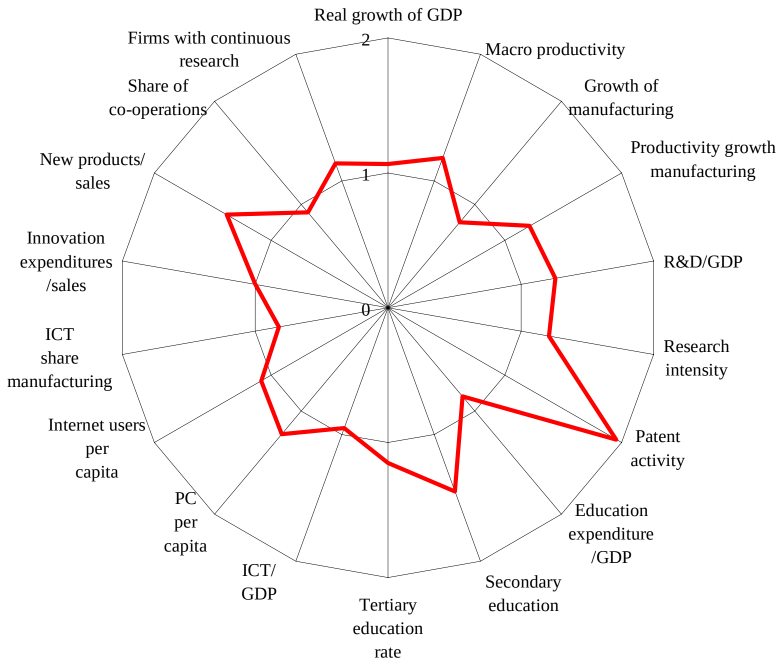
[105] Even if it is criticised for its excessive length and the consequently high average age of persons entering the work force (*OECD*, 2000, p. 15).

## Figure 5.15: Country profiles: Germany





*Remark*: Each indicator outside the circle shows a superior performance of the country relative to EU average; growth rates for the nineties, for other indicators most recent information.

## Germany: Unification as a burden for the quality leader

Germany's growth pattern heavily reflects the problems and progress of unification. Growth was above average in the first half of the nineties, but fell below the European average during the second half. Productivity in manufacturing accelerated, reflecting restructuring and internationalisation of firms. Germany is a leader in European research and in the share of new and improved products. However, its R&D ratio has decreased and during the nineties, Germany fell in rank for several indicators of research, education and ICT. Germany has an excellent supply of human capital, but does not match the performance of the leading countries in the information society. Subsidies are rather high, and tendering is not yet open to international competition. The internationalisation of large German firms was lagging, due to the different structures of government and low capitalisation relative to Anglo Saxon firms, but this has been changing since the late nineties. Economic policy is dominated by the costs of the unification. The catching up of the new states has slowed down during the most recent years. The productivity gap is still high, and the competitive base of the new states is hampered by the overexpansion of the construction sector (*OECD*, 2001, p. 95) and the decreasing base in manufacturing.

Germany produces 30 % of the value added of European manufacturing; the figure decreases to 24 %, relative to GDP (the third largest behind Ireland and Finland). The trade balance amounts to more than three fourths of the EU trade surplus. Value added per employee is 10 % higher than the EU average, and wages per capita are 20 % higher, imposing pressure on costs and pushing up quality. The unit value of exports reflects Germany's potential in high quality segments. Germany's real strength is in skill intensive and mainstream industries. The share of low skill industries is the smallest among member countries, and the share of exports in the highest price segment is 62 %, second only to Ireland (*Aiginger*, 2000B). 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 market shares are below average and are declining in the telecom industries. Aircraft and spacecraft, instruments, and electronic components increased their market shares. Apart from motor vehicles, the highest degree of specialisation is in machine tools, electrical apparatus, and measuring and musical instruments. In general, Germany is extremely well positioned in skill intensive, mainstream industries; firms are pursuing a strategy of increasing quality, often within a given industry structure.

## Figure 5.16: Country profiles: Greece


*Remark*: Each indicator outside the circle shows a superior performance of the country relative to EU average; growth rates for the nineties, for other indicators most recent information.

## Greece: Heading towards the Monetary Union

Greece is catching up, albeit at a low speed and with turbulences. Real GDP, as well as labour productivity, increased in the nineties a little faster than the EU average. Substantial efforts made in connection with the goal of entering the European Monetary Union have decreased macroeconomic imbalances, and growth was above the European average during the second half of the nineties.

Productivity in manufacturing increased fast despite slow growth, reflecting the increased competitive pressure. 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. Greece has the smallest share of manufacturing in GDP of all European countries. Wages and the productivity level have now reached nearly one half of the European average.

Greece is lagging in most indicators of research and ICT, with the exception of telecommunication expenditures. It has a relatively high share of higher education, but is in general lagging in outlays on education. Pressure to upgrade skills and the share of female workers is low. Unemployment persists, and workers are staying in the production process rather longer. Prices for telecommunications and electricity are low, reflecting liberalisation efforts. Raising equity is easier than in many other countries; tenders are open, subsidies below average. The OECD criticises the regulation of output and the labour market, and calls for improving skills and competencies (*OECD*, 2001).

Greece has less capital inflow and higher extra EU exports, even when compared to other peripheral countries.[106] It is an open economy, although exports in manufacturing amount to only one third of imports. The breakdown of Yugoslavia has increased transport and transaction costs with core European countries and the transformation of former socialist countries has increased competitive pressure in former strongholds of Greek industry, and induced involuntary structural changes. Normalisation in both areas and membership in the European Monetary Union will help to decrease the "economic distance" and foster the ongoing catching up process.

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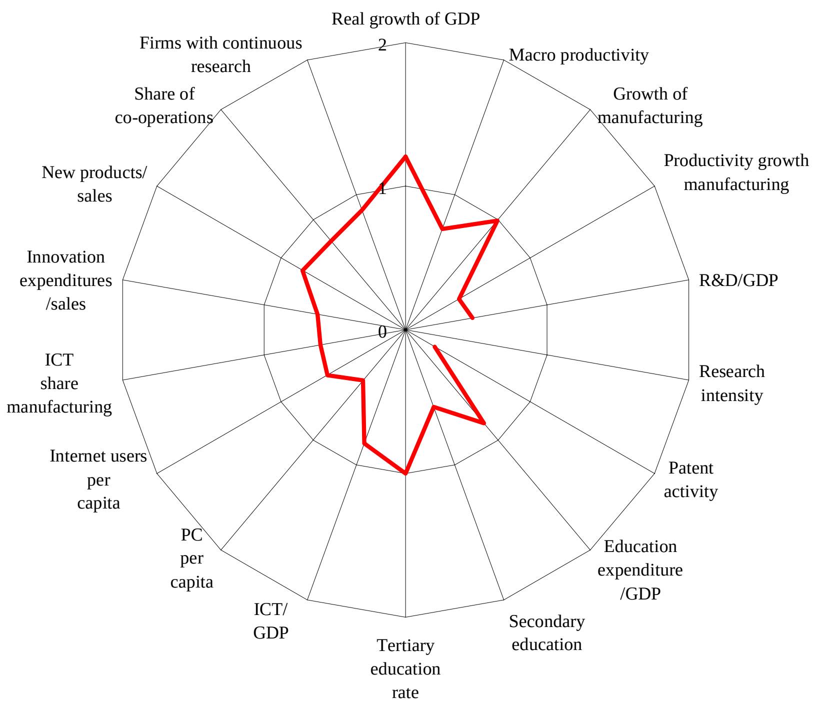
[106] Extra EU exports made up 50% of total exports in 1998, singular for member countries. This reflects high and growing trade shares with Cyprus, Bulgaria, Macedonia and Turkey, but also with other Eastern European countries and Russia.

## Figure 5.17: Country profiles: Spain





*Remark*: Each indicator outside the circle shows a superior performance of the country relative to EU average; growth rates for the nineties, for other indicators most recent information.

## Spain: Integration plus cars combat unemployment

Spain managed to grow faster in GDP, and in manufacturing, growth was at approximately the European average. The low productivity increase – and even the negative rates in measured labour productivity – were partly the consequence of a policy to reduce unemployment by spreading work.

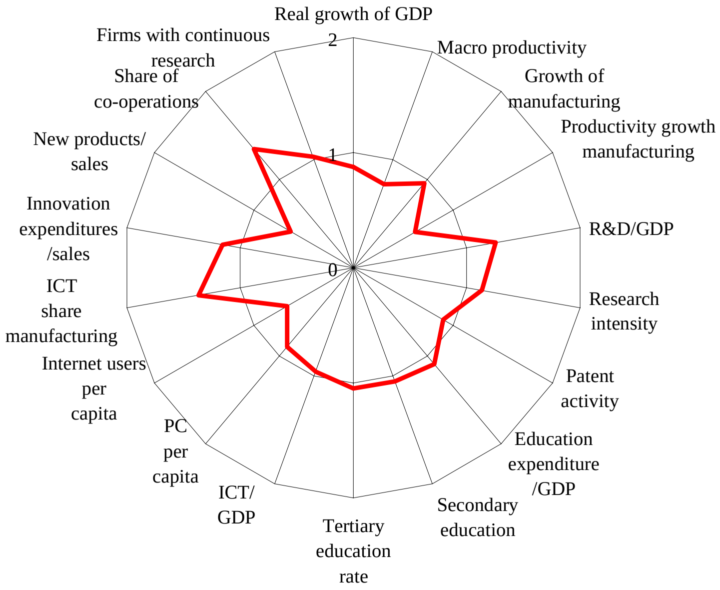
In manufacturing, three sectors with high shares – food, apparel and leather – exhibited a specifically sluggish performance in productivity. Two capital intensive (basic metals and chemicals), and two high tech industries (computers and medical equipment) increased productivity sharply.

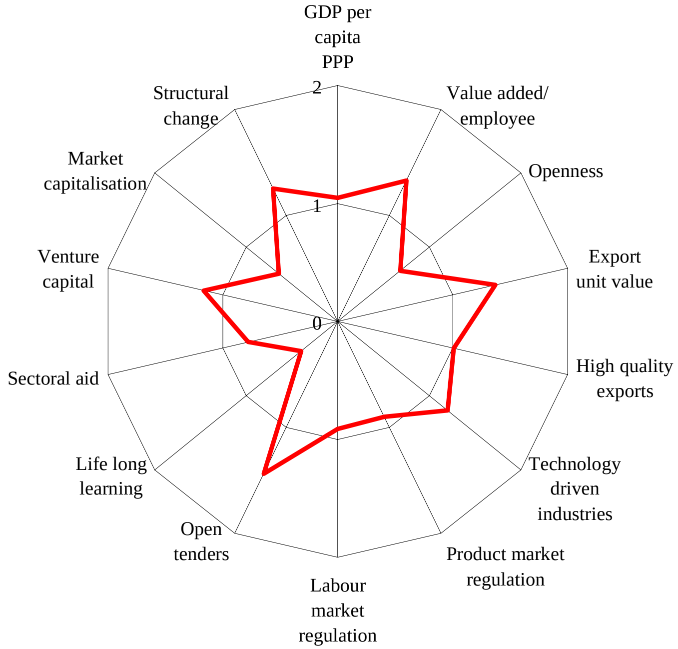
The performance of the car industry was excellent and it is becoming Spain's largest sector. It doubled its production share and is now the second largest in export and second largest in production. It is a sucessful example of inward foreign direct investment leading to structural change without own reasearch.[107] . Ten percent of European car exports come from Spain. Food is also an important sector for exports: fish, fruits and vegetables have double digit market shares in European exports. Chemicals is now third in production and exports. The high shares of pharmaceutical industries, audio and video apparatus and medical equipment reflect successful clusters of high tech industries, often in the form of plants owned by multinational firms, which are supplying leading technologies. Spain is an economy on the periphery, enjoying strong and increasing ties with the other EU countries. It is successfully catching up, partly thanks to investments by the subsidiaries of multinational firms.

Spain is consistently among the bottom 5 countries with respect to indicators for research and human capital. Spain has a low ranking for ICT use, but the highest expenditures on telecommunications. Spain is in a moderate position regarding the share of new and improved products, indicating a good performance in gradual innovation, and its share of higher education ranks 10th. Exports are growing by 10 % p.a., led by intra European exports. Exports are lower than imports; the deficit is rising, but can be compensated by Spain's strength in tourism. The share of industry in GDP is now below average. Productivity and wages are low, and the unit value of exports increased more strongly than the European average.

[107] The net effect is somewahlt less, since import of cars (and parts of motor vehicles is rising too).

## Figure 5.18: Country profiles: France




*Remark*: Each indicator outside the circle shows a superior performance of the country relative to EU average; growth rates for the nineties, for other indicators most recent information.

### France: Slow growth in productivity, and centre for air- and spacecraft

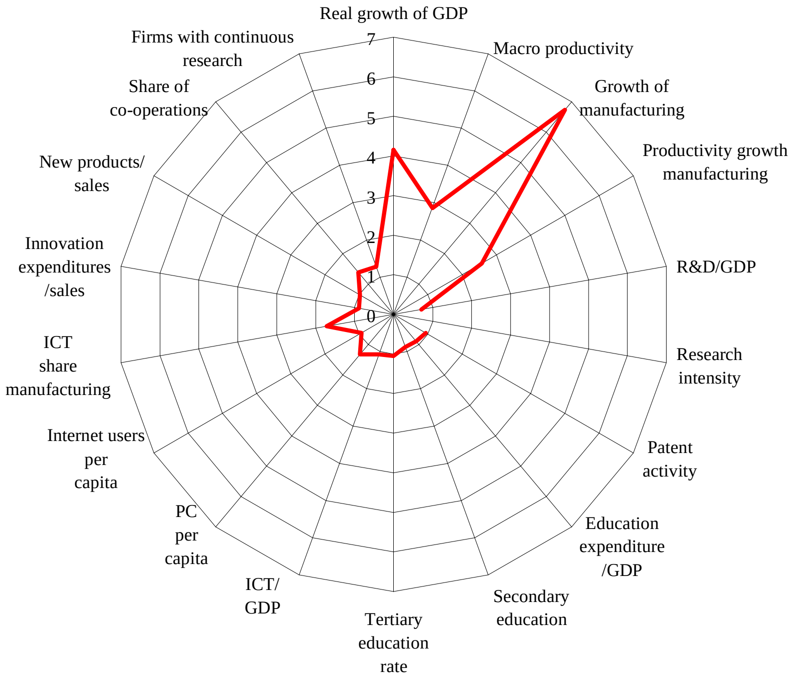
France exhibited slow growth in the first half of the nineties and average during the second. Labour productivity increased slowly, and growth in multi factor productivity declined. Manufacturing is expanding less than in the European average - as is the case for most large countries. The share of manufacturing in total production declined to 18.5 %

The specific success of France in aircraft and spacecraft is shown in the sector "other transport": Eighteen percent of value added and 45 % of total European exports are attributed to France, reflecting trans-European projects in spacecraft and aircraft. Productivity is increasing in this sector, as is the case in another stronghold, namely chemicals and plastic.

France is strong in research and innovation outlays, but research relative to GDP is decreasing. Indicators of human capital show a position slightly above the European average. France cannot match the leading countries in ICT, although French ICT sectors are above average in production. Sectoral aid is large, efforts regarding life long learning are low. Privatisation and liberalisation are not high on the agenda, network prices are not specifically low. A specific feature of French macroeconomic policy has been to reduce unemployment by means of a cost guided reduction in work time, with specific arrangements for firms of various size.

In general, the industrial structure of France is more similar to that of Europe as a whole, compared to other large countries. The share of technology driven industries is higher in France, as is the share of industries characterised by high inputs from knowledge-based services, while mainstream industries have lower shares. France has strongholds in large industries; in the two largest - chemicals and food - it is expanding further; motor vehicles and machinery are the third and fourth largest sectors. Cars and other transport are leading in exports, together supplying more than one quarter of total exports. The greatest market shares are being achieved in food and electrical machinery. Ships and boats, watches and clocks, luggage and handbags, and beverages and dairy products are industries in which France supplies more than one fifth of total European exports. In chemicals, the areas of predominance are pesticides and other agricultural products and perfumes.

# Figure 5.19: Country profiles: Ireland





*Remark*: Each indicator outside the circle shows a superior performance of the country relative to EU average; growth rates for the nineties, for other indicators most recent information.

## Ireland: Skills meet foreign capital

Growth of real GDP was 8 % , about half of which was in productivity and employment growth. Two thirds of the double digit growth of manufacturing was channelled into productivity growth. Production as well as productivity growth of manufacturing accelerated in the second half of the nineties. GDP per capita is today above the EU average.

Ireland still has low levels of research and education expenditures[108]. Skills are highly rated, due to an efficient education system and a high share of tertiary education; efforts have succeeded in raising the number of skilled persons. Ireland has a large share of ICT industries in production; the use of PC's and internet has surpassed the EU average. According to the indicators, excellence has been reached in the quality of products[109] and with respect to capabilities: the shares of new and improved products, and of firms co-operating with others and engaged in continuous research are high. Ireland has built its remarkable catching up process on the import of foreign capital, low wages and low taxes, but has ingeniously connected inward investments with local strengths. It attracted dynamic high tech industries, developed programs to upgrade qualifications and to cluster firms around the subsidiaries of multinational firms. The financial support and the reliance on low wages would not have been able to create the strength and competitiveness of today's Ireland, if they were not combined with a supply of skilled labour, a supportive climate for innovation and change, and the policy focus on establishing upstream linkages between foreign firms and indigenous companies.

The share of manufacturing is rising, and is now, at 32 %, by far the highest in Europe. Exports, specifically to the USA, to Japan and to Switzerland are rising. The share of extra EU exports is, however, still below average. Ireland produces 1.7 % of total European manufacturing, and export market shares have doubled, now reaching 3 %. Export relative to production is the highest of all member countries. Value added per employee is the highest of the EU countries.[110] The share of production in marketing driven and technology driven industries is high. Chemicals is the largest sector, with basic chemicals and pharmaceuticals each supplying about 15 % of Irish exports. Computers are second in exports, telecom equipment third. Fifteen percent of European computer exports and 10 % of chemicals come from Ireland. The production share of food has dropped from 26.7 % to 20.1 %, its export share is now about 10 %.

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[108] Multinational firms are still performing a larger share of research in their home country as compared to production.

[109] Ireland is leading according to 11 of 14 quality indicators developed in *Aiginger* (2000A).

[110] This position of excellence may contain an element of inflated transfer prices, but the dynamics of the Irish economy, and its quantitative and qualitative success is beyond statistical doubt.

## Figure 5.20: Country profiles: Italy


*Remark*: Each indicator outside the circle shows a superior performance of the country relative to EU average; growth rates for the nineties, for other indicators most recent information.

## Italy: A two-tier economy with imbalances and deficits in drivers of growth

Despite sluggish growth, labour productivity in the total economy grew parallel to that of other countries. In manufacturing, productivity growth was lower than the EU average during the nineties, specifically in the second half, when production fell one point and productivity two points below the European average. Italy is therefore one of the four European countries with a deceleration in productivity growth and is low ranked for most "drivers of growth".

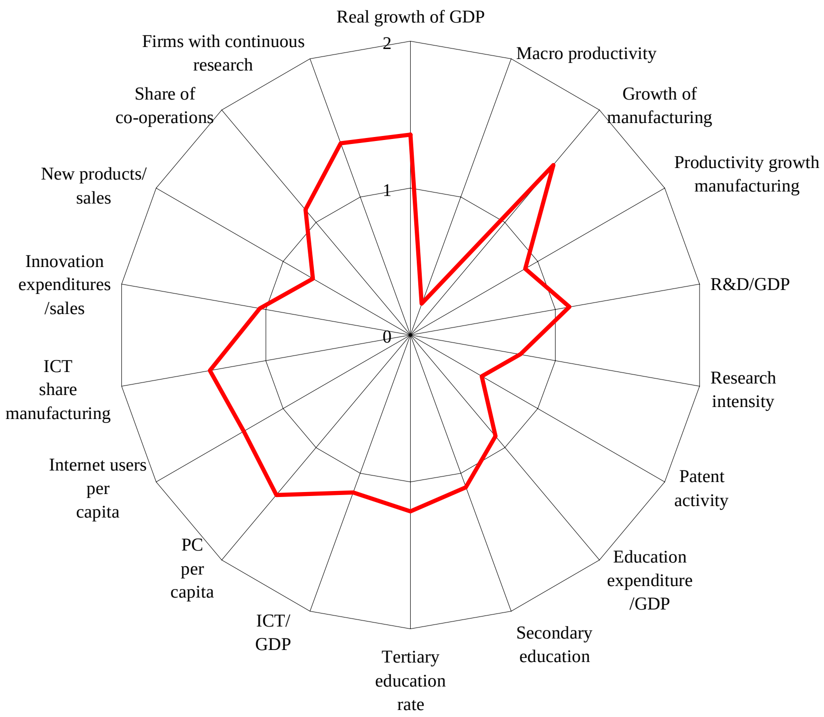
Productivity rose in electronics and computers, as well as in basic metals, paper, and metal products. In the textile industries - which are much larger in Italy - productivity did decrease, but real term figures underestimate the upgrade in quality and fashion. In machinery, productivity climbed slightly. Thus the ranks for productivity growth are very similar to those of other countries; average growth is, however, lower. Consequently, Italian manufacturing kept employment rather constant, despite the very slow growth of output. Italy has the slowest speed of change in industries.

With respect to all variables considered to be drivers of growth in an advanced economy, Italy is almost consistently below the European average. In the combined indicator, Italy is ranked number eleven, very close to the other southern countries. This is specifically the case for indicators of research, human capital and new technologies. An exception is the high share of new and improved products and the production of ICT. The share of higher education in Italy is the second lowest in the EU; Italy's share of open tenders is also comparatively low. The differences between the North and the South pull nationwide figures down, but also determine the growth potential.

Italy produces about 12 % of European manufacturing products. The export ratio and openness are smaller, reflecting strong domestic demand for consumption and investment goods. Italy has a two-tiered industrial structure. On the one hand, the share of labour intensive and low skill industries is larger than in most other member countries; on the other hand, high skill and mainstream industries are also strong. Technology driven and marketing driven industries are underrepresented. Italy has a large textile sector, with high export unit values indicating high fashion products.[111] Machinery - a skill intensive, mainstream sector - is the largest single sector, followed by chemicals in production and by cars in exports.

[111] The three textile sectors account for 12% of production and 17% of Italian exports. These shares are decreasing slightly, as compared to total exports. Since, however, in other countries this sector has contracted, or fragmented, or been outsourced, 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.

## Figure 5.21: Country profiles: Netherlands





*Remark*: Each indicator outside the circle shows a superior performance of the country relative to EU average; growth rates for the nineties, for other indicators most recent information.

## The Netherlands: Flexible labour and high ICT

The Netherlands grew faster in the nineties than the EU average, but productivity growth was lower. Low productivity specifically in the non manufacturing sector was the result of a strategy intended to spread employment and increase part-time work. The double strategy to cope with unemployment and to increase competitiveness was set down in the Polder model, a consensus between the government and social partners. It led to high growth in employment and even signs of a tightening in the labour market at the end of the decade. Overall employment on a full time basis remained low. Parts of the program included reducing social contributions for low paid jobs, increasing labour flexibility through, inter alia, variable working hours for contracts with limited duration, and Regional Training Centres (*OECD*, 2000, p. 59).

The Netherlands has a low research intensity in manufacturing, good performance according to indicators of human capital, and excels in information and communication technology. Expenditures on innovation are high and there is a large share of firms engaged in continuous research. Liberalisation has been promoted; the Netherlands has extremely high shares of exports and imports.[112] The lack of openness in tenders is one of the few negative points in the country ratings for the Stockholm summit, in which the Netherlands achieved the first position (*EU Commission*, 2001).

The number of capital intensive and low skill industries is somewhat higher than the average, so is the share of marketing driven industries. Technology driven industries have a lower 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 from the Netherlands contributes to 14 % of total European exports, although the market share is declining. The publishing industry is in third place and is raising its share in value added. The tobacco industry accounts for the highest market share in EU exports - for which the Netherlands provides one third of European exports - and the petroleum industry contributes one fifth.

[112] Note, however, that the volume of imports and exports could be overestimated, since the Netherlands are an important trade hub ("Rotterdam effect").

## Figure 5.22: Country profiles: Austria


*Remark*: Each indicator outside the circle shows a superior performance of the country relative to EU average; growth rates for the nineties, for other indicators most recent information.

## Austria: Quality upgrade and productivity growth

Following a period of above average growth, Austria's performance was average during the nineties. The manufacturing sector is increasing its market share, ranking fourth in growth of output and productivity. Productivity growth accelerated, reaching 6 % in the second half of the nineties. Absolute value added per employee is now the third highest in Europe.

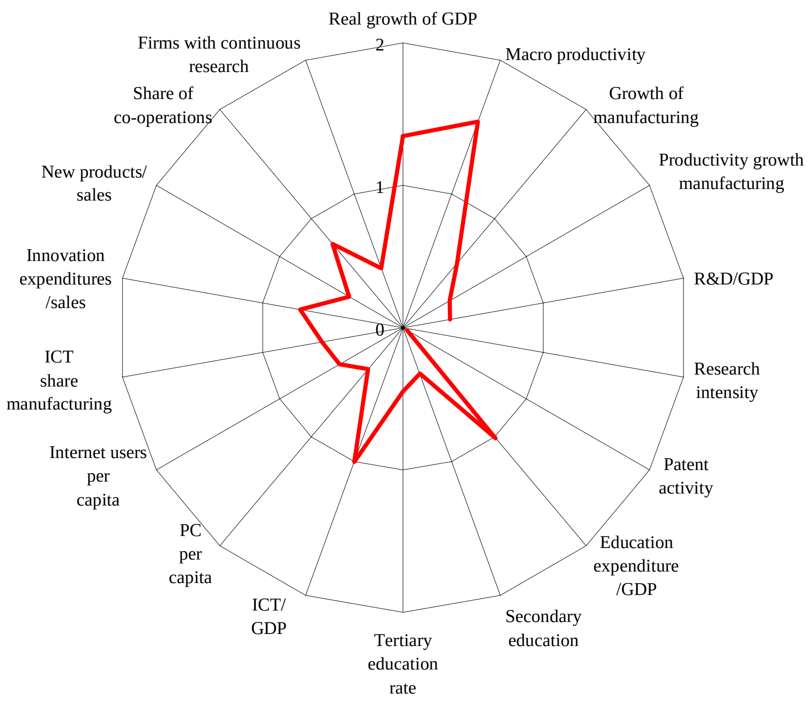
Austria has a traditional deficit in R&D, however it is now approaching the European average. Expenditures on education are high, while the share of workers with higher education is low. Austria has a high density of mobile phones, but in general assumes a moderate position with respect to other ICT indicators. Austria ranks third in the share of new or improved products, reflecting - similar to Belgium - strength in small innovations and capabilities.

The privatisation of manufacturing firms speeded up in the mid nineties, after a period of heavy losses. The liberalisation of telecom and privatisation started rather late. The capital market is underdeveloped, and the shares of equity to GDP and venture capital are low. Prices are high in telecom, and tenders are not sufficiently open; competition policy is underdeveloped.

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, gaining in dynamics thanks to the increasing trade surpluses with the accession countries in Central and Eastern Europe, as well as also to exports to the USA. The degree of openness is high, even when compared with other small countries.

Austria's performance is less convincing from the perspective of unit values, and the share of technology driven industries is rather low. This stems from a persistence of the production structure to remain in traditional strongholds. However *within* industries, exports are moving into higher quality segments. The largest sector is machinery. Motor vehicles are now second in exports; Austria supplies sophisticated parts to European and US car manufacturers. Above average market shares are in 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 market shares, reflecting insufficient research outlays and headquarters. Austria attracted new firms for media reproduction and is developing here a cluster around subsidiaries of multi national firms.

## Figure 5.23: Country profiles: Portugal





*Remark*: Each indicator outside the circle shows a superior performance of the country relative to EU average; growth rates for the nineties, for other indicators most recent information.

## Portugal: Europe-based catching up

Portugal is catching up at a faster rate than Greece in total and per capita growth, but not in manufacturing.[113] In the sectors larger than in the EU, such as food and textiles, there has been virtually no increase in productivity, probably due to a sheltered domestic sector and the attempt to keep employment high. In 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 enjoying stable employment. A high productivity increase was also evident in office machinery, which however is very small in Portugal.

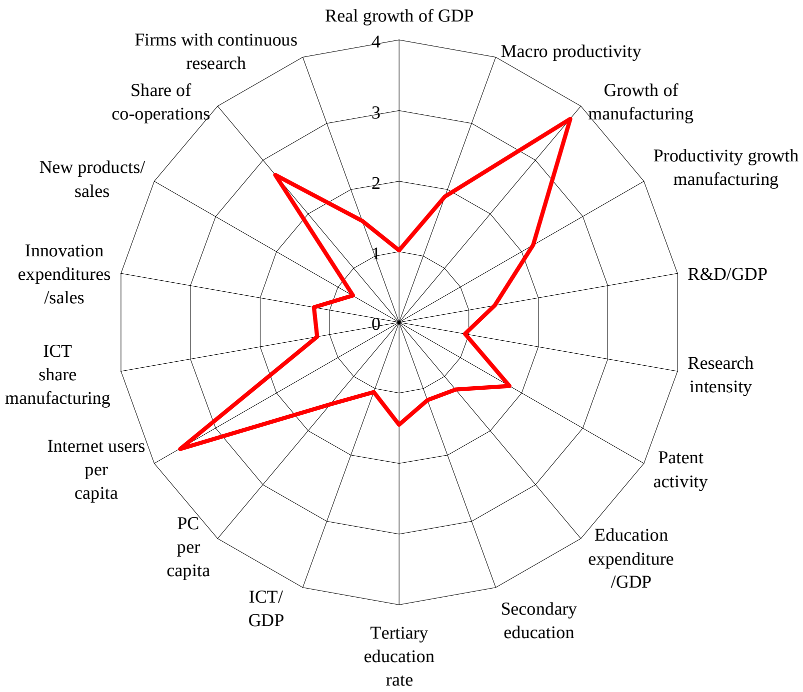
The share of Portugal's three textile sectors - textiles, apparel, and leather - decreased from 24 % to 19 %; nevertheless, this share is still the second largest after that of Greece. Cars are now the largest export industry. Telecom equipment has attained the fifth largest export share; tobacco, wood (specifically cork), and made up textiles are industries with high market shares. In general, low skill and labour intensive industries still dominate, but the catching up process is under way in productivity and wages. 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.

Relative to GDP, the industrial sector is large, accounting for 23 % of GDP. Productivity and wages are the lowest of member countries, but are catching up. The development is being driven by the EU; the intra share of exports is the largest among member countries, and is growing faster than extra 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. It is considered by the OECD to be the main threat to economic stability.

According to research indicators, expenditures on information technology are low, and the dispersion of computers and internet in Portugal is sparse. Telecommunication expenditures are high, public expenditures on education are about average, with a deficit in higher education. Network industries are liberalised and prices are low. Public procurement follows the EU rules, market capitalisation is relatively high.

[113] To a certain extent, the results differ between the production index (worse performance) and the value added, which indicates higher growth.

## Figure 5.24: Country profiles: Finland





*Remark*: Each indicator outside the circle shows a superior performance of the country relative to EU average; growth rates for the nineties, for other indicators most recent information.

## Finland: The strongest leap forward

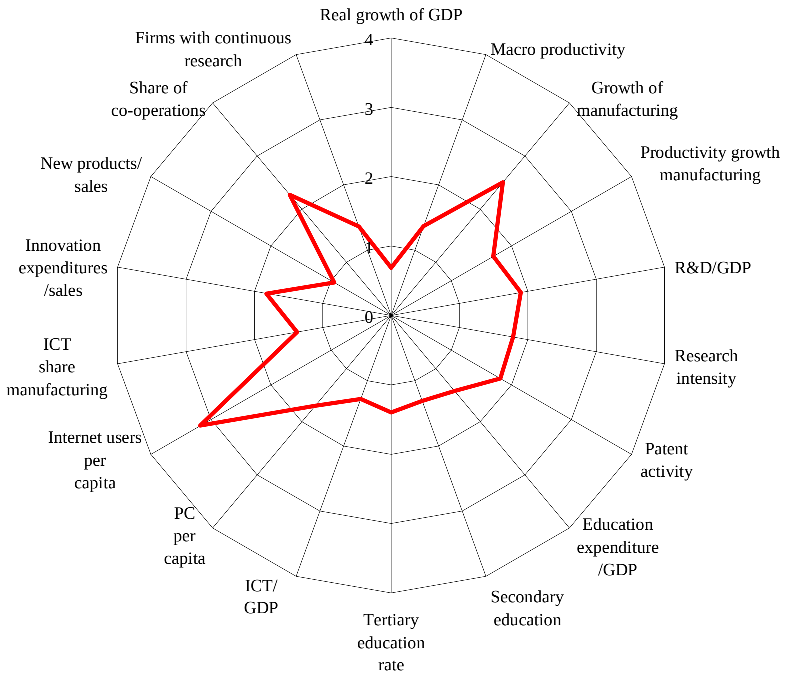
Finland was specifically hit by the crisis in the beginning of the nineties, lost a substantial part of its geographic and product markets, and had to devaluate its currency. Economic growth accelerated so fast in the second half of the nineties that the growth in output and productivity for the entire decade is still far above the European average. Finland made the most significant leap forward in the growth driving factors, and in 15 of 20 indicators is now among the top five, and is leading in six.

Finland placed priority on research - even during its crisis - and is now one of the countries with the best performance in research and ICT. Outlays on education are somewhat smaller than in Sweden, but the share of higher education is large. Finland focuses on academic research at a limited number of locations, has created science parks, and has enforced engineering oriented educations (*OECD*, 2000, p. 13). The liberalisation of telecom started early, with competition in long distance telephony in the eighties. Early and well operated programs brought the information society into schools, the government and institutions. Including subcontractors, Nokia accounts for 4 % of GDP, 20 % of exports and one third of research. Nevertheless, Finland's progress is not based solely on this one successful firm. With respect to capability indicators, the share of new and improved products has a moderate position among the reporting countries. Open tenders and capital markets are areas in which improvements are considered to be important.

Measured according to absolute productivity, wages per capita, and the unit value of exports, Finland's position is moderate. Finland was previously among the low unit value countries, reflecting its high share of resource-based goods. Its share of manufacturing in GDP is the second largest (26 %), and in contrast to other countries, it was not lower in 1998 than in 1985.

Productivity increased fastest in electronics, for basic metals, paper and wood products. Electronic equipment jumped from rank 15 to rank 2 in production. Finland gained market shares in electrical machinery and in printing and publishing; both are sectors in which the old and new economy meet. Finland maintained strongholds in capital intensive industries. Pulp and paper is still the most important sector, one third of exports are in the wood and paper sector. The "forestry cluster" is even increasing its share of value added, partly through complementary services, technology centres and headquarter functions (backward and forward integration).

## Figure 5.25: Country profiles: Sweden





*Remark*: Each indicator outside the circle shows a superior performance of the country relative to EU average; growth rates for the nineties, for other indicators most recent information.

## Sweden: The leader in drivers of growth

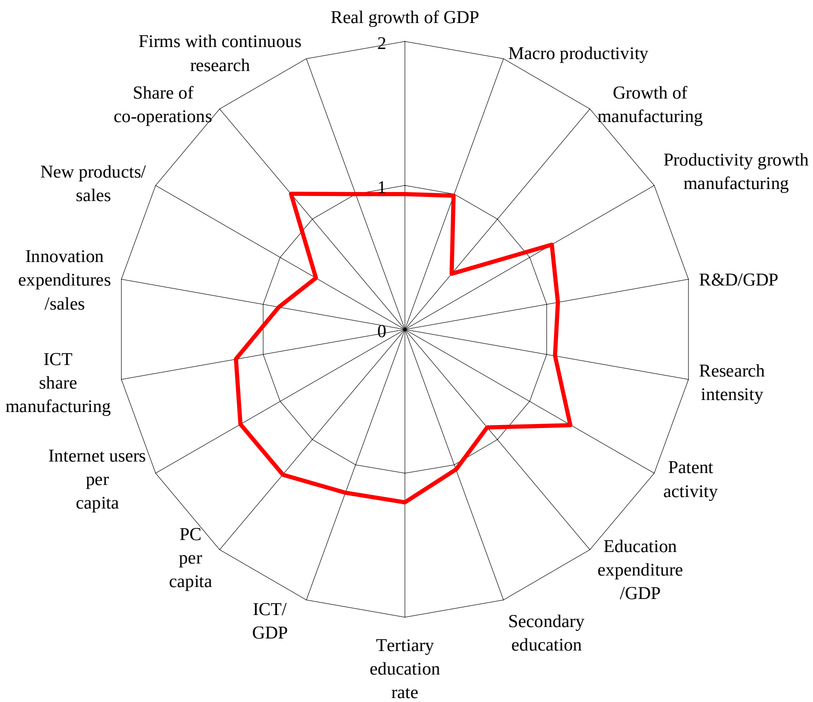
Sweden was hit by the crisis in the early nineties. It had to cut its budget deficit, adapt the welfare state and devaluate its currency. Growth fell below the EU average, but over the decade, productivity nevertheless increased faster than the EU average. Growth of manufacturing – as measured by the production index - is above average and the productivity increase is the third highest. Since measured productivity was boosted during the crisis, the second half shows no specific acceleration. Sweden is among the top 5 countries for most of the drivers of growth, leading in about half, and improving in most of them, despite high research, education and ICT use, even at the beginning of the nineties.

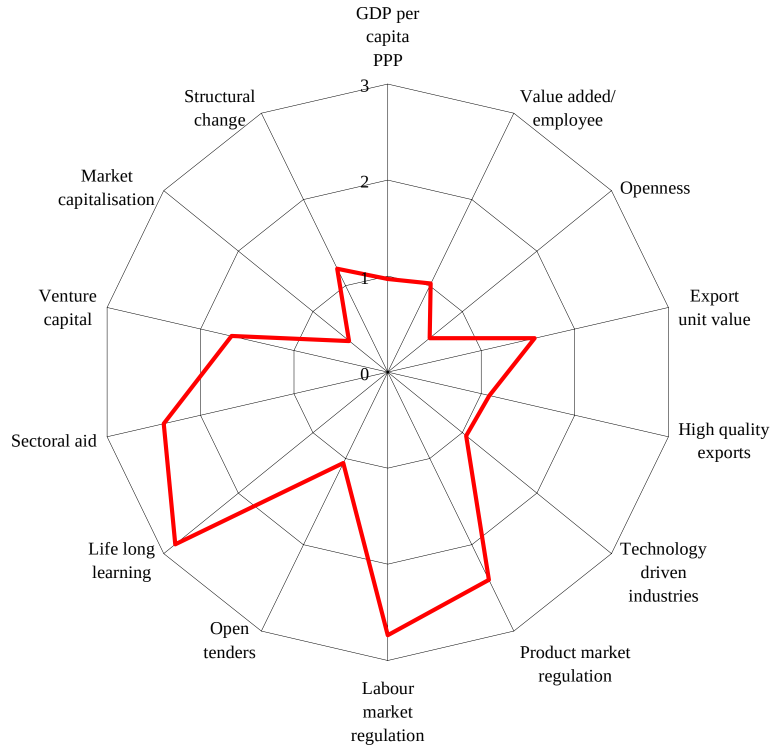
The highest increase in productivity occurred in two strongholds. In electronic equipment, where Sweden enjoys a ten point higher share in production than the EU average, productivity increased by 10.3 %. This sector now accounts for 15 % of exports, which is as much as wood and paper together. For motor 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 placed third, and is losing production shares (in contrast to Finland). Basic metals have higher market shares in Europe than total manufacturing, and the trend is on the rise.

Sweden has top ranks in research, in ICT, and in education. It developed a specific program to foster the information society, and to spread its impact to small firms and less advantaged groups. Sweden invests in human capital and gives firms tax brakes for training and for the distribution of computers to employees for private use. The only indicators in which Sweden is not ranked as excellent are speed of change in industry structure and share of new and improved products. Sweden has a moderate position in venture capital and a low capitalisation rate (and specific voting rules) for stock companies. Overall, Sweden is leading in many rankings of innovation and for the new economy within European countries. Compared to the USA, the ratings are close; Sweden is leading in some, the USA in others.

Extra EU exports are growing faster than intra EU exports. The productivity level and wages are in line with the average of the member countries (taking devaluation into account), as is the unit value of exports, due to the large share of capital intensive industries. 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.

## Figure 5.26: Country profiles: United Kingdom




*Remark*: Each indicator outside the circle shows a superior performance of the country relative to EU average; growth rates for the nineties, for other indicators most recent information.

### The United Kingdom: Headquarter services and ICT fosters productivity

The macroeconomic performance of the United Kingdom is average with respect to GDP growth and productivity. In manufacturing, growth is lower, but productivity increases are higher. This performance has to be rated against an increasing productivity gap in comparison to other advanced countries up to the nineties. Value added per employee is near the European average, while wages per employee in manufacturing are lower.

The United Kingdom is strong in research indicators, but as in other large countries, R&D expenditures are declining in comparison to GDP. The United Kingdom is ranked high in production, as well as use, of ICT. Public expenditures on education are below average, as are the innovation expenditures of firms and the share of firms with ongoing research. The share of venture capital is high. Gas prices are rated as low; early privatisation and liberalisation did not result in low prices in electricity and telecom, according to the Commission rating. Labour market policy encouraged a series of "New Deals" targeted at problem groups, but no specific measures were taken to intensify the job intensity of growth. Product and labour markets are less regulated than in other countries.

The United Kingdom produces 15 % of European manufacturing output, the second largest production share among member countries. The United Kingdom enjoys the second highest unit value of exports, reflecting structural change towards industries characterised by high inputs from knowledge-based services, and also profits from 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; chemicals, machinery, and vehicles follow. A specific 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 the EU come from the United Kingdom. High market shares have also been attained by office machinery and telecom equipment.

## 5.7 Convergence for drivers of growth and productivity

European countries are converging with respect to the main drivers of growth – albeit very slowly. Whether Europe is catching up with the USA is less clear. The top European countries are improving their positions with respect to the USA, leading in about one third of the indicators. For the total EU, this is definitely the case for mobile phone users and telecom expenditures. For the other indicators, the USA is maintaining its lead, while the gap is declining for some indicators, and expanding for others. A final judgement on the issue of convergence is for some indicators specifically difficult, since the faster US growth in the nineties may not only be a consequence of the "drivers" of growth, but higher revenues may have been reinvested into the growth drivers. This cumulative nature seems for example to be the case for research intensity in manufacturing.

### Table 5.9: Convergence of countries within EU according to 20 drivers of growth

| | Top5/EU First year | Top5/EU Last year | Low5/EU First year | Low5/EU Last year |
|---|---|---|---|---|
| Total expenditure on R&D in % of GDP 1992/98 | 1.481 | 1.474 | 0.511 | 0.508 |
| Business Enterprise Expenditure on R&D (BERD) in % of GDP 1992/98 | 1.622 | 1.613 | 0.418 | 0.420 |
| R&D personell as a % of the labour force 1985/98 | 1.393 | 1.158 | 0.481 | 0.665 |
| Research intensity in manufacturing 1990/98 | 1.090 | 1.112 | 0.486 | 0.528 |
| Publications per inhabitant 1992/99 | 1.594 | 1.504 | 0.458 | 0.542 |
| Patents per resident 1990/97 | 1.668 | 1.776 | 0.331 | 0.308 |
| Public expenditure on education 1995/98 | 1.237 | 1.263 | 0.807 | 0.801 |
| Percentage of the population that has attained at least upper secondary education by age group (1998) | 1.390 | 1.219 | 0.568 | 0.769 |
| Percentage of the population that has attained at least tertiary education, by age group (1998) | 1.395 | 1.144 | 0.649 | 0.848 |
| Human resources in science and technology by country 1994/99 | 1.368 | 1.318 | 0.703 | 0.768 |
| Working population withl tertiary education - ISCED 5-7 1992/99 | 1.279 | 1.170 | 0.674 | 0.645 |
| ICT expenditure in % of GDP 1992/2000 | 1.175 | 1.068 | 0.777 | 0.978 |
| Information technology (IT) expenditure in % of GDP 1992/2000 | 1.299 | 1.340 | 0.621 | 0.618 |
| Telecommunication (TLC) expenditure in % of GDP 1992/2000 | 1.166 | 1.132 | 0.885 | 0.881 |
| PCs per inhabitant 1992/99 | 1.874 | 1.400 | 0.617 | 0.642 |
| Internet users per inhabitant 1992/99 | 2.143 | 1.581 | 0.223 | 0.707 |
| Cellular Mobile Subscribers per 100 capita 1992/99 | 2.147 | 1.190 | 0.202 | 0.851 |
| Share of technology driven industries in nominal value added 1990/98 | 1.335 | 1.404 | 0.635 | 0.663 |
| Share of skill intensive industries in nominal value added 1990/98 | 1.332 | 1.301 | 0.655 | 0.646 |
| Share of ICT industries in nominal value added 1990/98 | 1.423 | 1.426 | 0.615 | 0.545 |

*Remarks*: First year (last year) means that year in the nineties for which earliest (or latest data) are available (both are indicated after the name of the variable). For the percentage of population that has attained secondary and tertiary education the older (45-54) and the younger (25-34) age groups are compared. Top 5 and low 5 are determined for each indicator according to ranks at the beginning (usually an average 1992-1994).

We apply 20 indicators to assess convergence within Europe (Table 5.9); 16 indicators enable us to compare the position of Europe relative to the USA. The indicators are those which were related to growth performance in manufacturing in Section 5.3, and used for the country profiles.[114] We defined as the top five, those countries leading in Europe at the beginning of the nineties; the bottom five are those countries ranked lowest at that time. Therefore, the individual countries within the upper and lower groups change according to the indicator. However, Sweden's excellence is reflected insofar as it is within the top 5 for all but one indicator, and is

[114] We had to exclude those which are not available for the beginning of the nineties (specifically the capability indicators). For the others, we compare performance at the beginning of the nineties (usually a year between 1990

first in seven. It is followed by the Netherlands, the United Kingdom, Finland, and Germany, as far as the number of ratings among the first five are concerned. The southern European countries tend to be among the bottom five.

### European countries converge: specifically, there is successful catching up

The bottom five countries improved their positions in 14 of 20 indicators (see Table 5.9 and Figures 5.7a, b). The speed of catching up is rapid for the information technology indicators; catching up is evident in secondary education and for four of the six research indicators. Expenditures on telecommunication equipment in countries lagging at the beginning of the nineties are now partly above average, reflecting heavy investment in infrastructure. Catching up is not visible in the share of jobs demanding the highest qualifications, in skill intensive industries, and in patents.

The top five countries are increasing their leads in patents, education, the research intensity of manufacturing, as well as in technology driven industries and in information technology expenditures. This reflects to a large extent the strong positions of Finland and Sweden in research and ICT. In PC and internet use and in secondary education, the relative lead decreased, reflecting increasing market saturation in the foremost European countries and the catching up of the followers. Nevertheless, the countries which are ahead are noticeably persistent. Sweden, which was among the leading five countries for 16 indicators at the beginning of the nineties, is now among the top five in all but one; for the Netherlands the corresponding figures are eleven in the early nineties and eight in the late nineties. Finland increased its number of leading positions from twelve to 15, Denmark from ten to eleven. The large countries in general lost ranks, Germany lost five of 15 positions among the top five , the United Kingdom seven out of 15, France did not loose leading positions, but lost in the combined ranking (Table 5.10).

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and 1992) to the most recent available information (a year between 1997 and 2000). The exact years are shown in Table 5.9.

## Table 5.10: Leaders in Europe according to 20 drivers of growth

| | Number of position 1 | | Number of position 1-5 | | Average rank | |
|---|---|---|---|---|---|---|
| | First year | Last year | First year | Last year | First year | Last year |
| Belgium | 0 | 0 | 4 | 3 | 7.50 | 7.95 |
| Denmark | 3 | 2 | 10 | 11 | 5.10 | 5.20 |
| Germany | 3 | 2 | 13 | 8 | 4.65 | 7.10 |
| Greece | 0 | 0 | 1 | 2 | 11.90 | 11.20 |
| Spain | 1 | 1 | 1 | 4 | 10.90 | 9.60 |
| France | 1 | 0 | 7 | 9 | 6.35 | 6.75 |
| Ireland | 2 | 0 | 5 | 6 | 7.20 | 7.25 |
| Italy | 0 | 0 | 2 | 3 | 10.55 | 9.80 |
| Netherlands | 2 | 0 | 11 | 8 | 5.35 | 6.35 |
| Austria | 0 | 0 | 6 | 5 | 8.35 | 8.10 |
| Portugal | 0 | 1 | 2 | 3 | 11.20 | 10.75 |
| Finland | 1 | 6 | 12 | 15 | 5.40 | 3.75 |
| Sweden | 7 | 8 | 16 | 19 | 3.00 | 2.00 |
| United Kingdom | 0 | 0 | 15 | 8 | 4.60 | 6.20 |

*Remark*: Position of countries for the 20 variables in Table 5.9; first year (last year) means that year in the nineties for which earliest (or latest data) are available (both are indicated after the name of the variable). For percentage with secondary and tertiary education the older (45-54) and the younger (25-34) age groups are compared.

The coefficient of variation increases in about half of the indicators. However, decreases are much stronger than increases, underlining the dominant trend of convergence.[115] For example for research and development indicators, the coefficient increases, if we relate the difference in country performance to the unweighted average of countries, but decreases if we compare the variance to the weighted average. The economic force behind this is the reduction of the research expenditures relative to GDP in the large European countries (France, Germany, the United Kingdom and Italy), while the small countries are increasing research expenditures sharply. The share of the working population with tertiary educations also increased slightly, due to upward jumps by Ireland and Finland[116]. Structural indicators also reveal a slight divergence, as technology driven industries and ICT industries become more concentrated (dominated by the higher shares of Ireland, Finland and Sweden). The strongest convergence is evident for the indicators of secondary education[117] and in the use of mobile phones and internet.

[115] Seven of 10 increases are less than 10%, eight of 10 increases in the coefficient of variation are larger than 10%.
[116] The variance of education expenditures has grown since the bottom five did not increase their positions.
[117] This indicator measures the share of secondary education attained by the older age group vs. that in the younger.

**Figure 5.27a: Convergence in Europe, gap to the USA declines only for top five countries (Performance for 16 drivers of growth)**

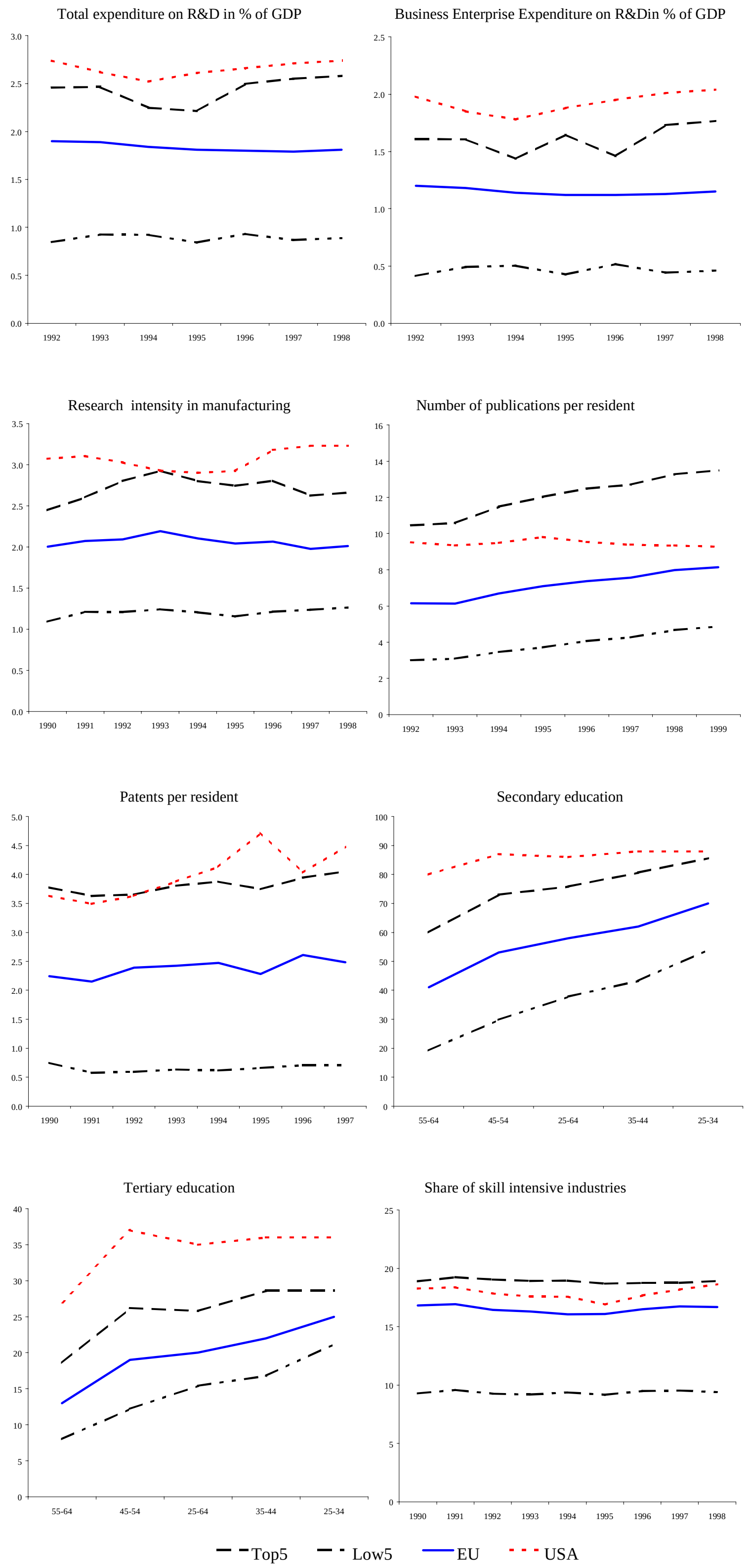


**Figure 5.27b: Convergence in Europe, gap to the USA declines only for top five countries (Performance for 16 drivers of growth)**

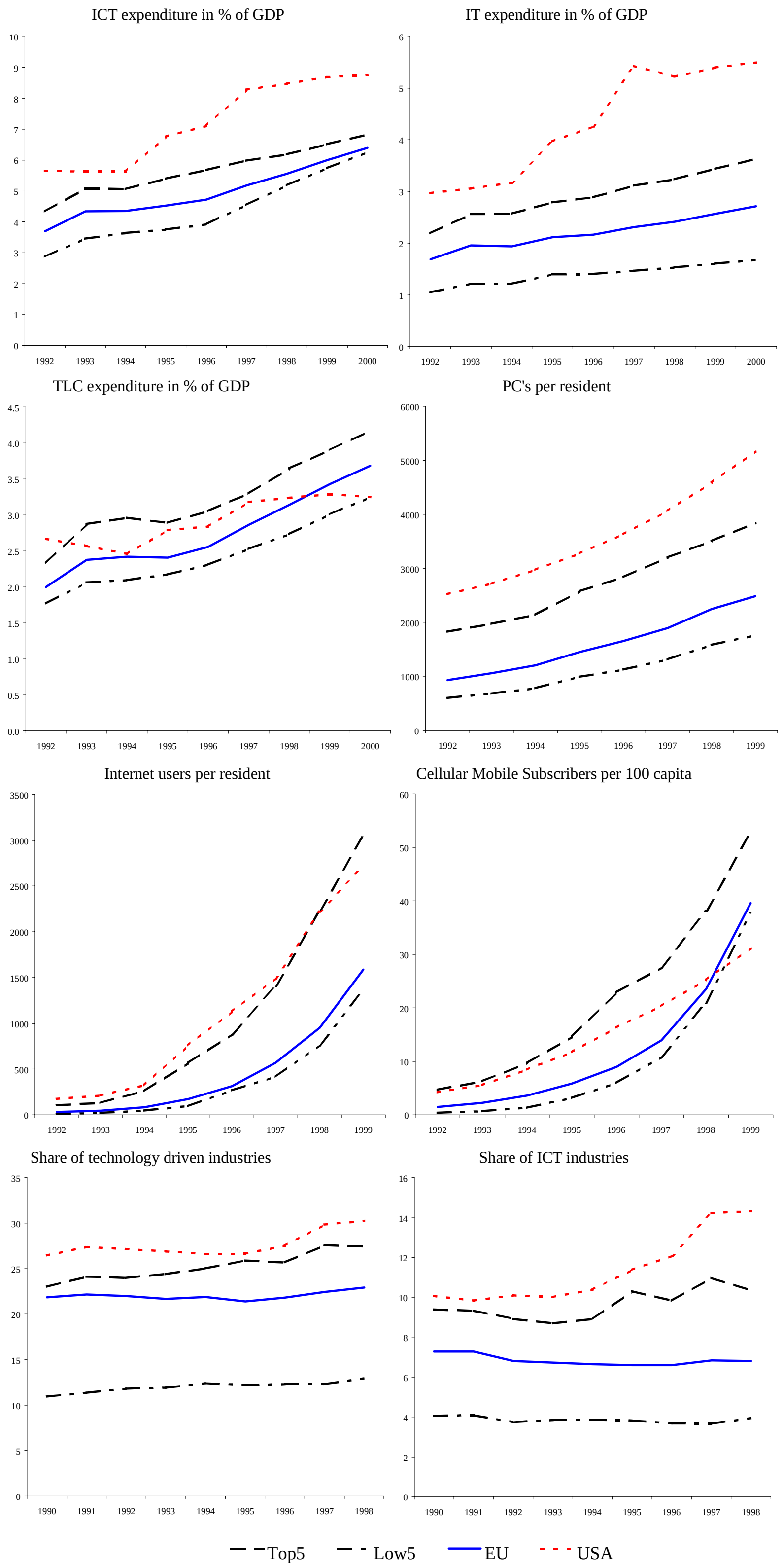
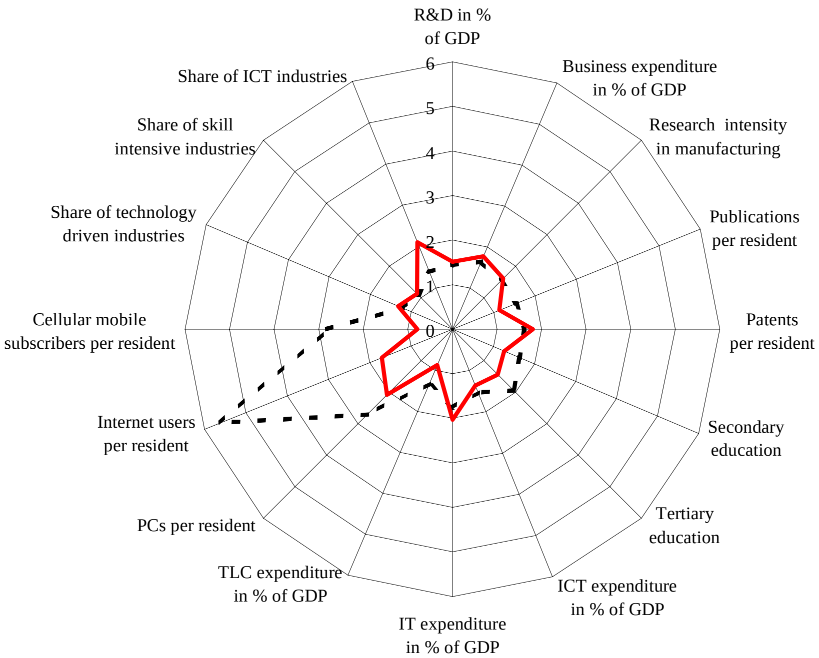
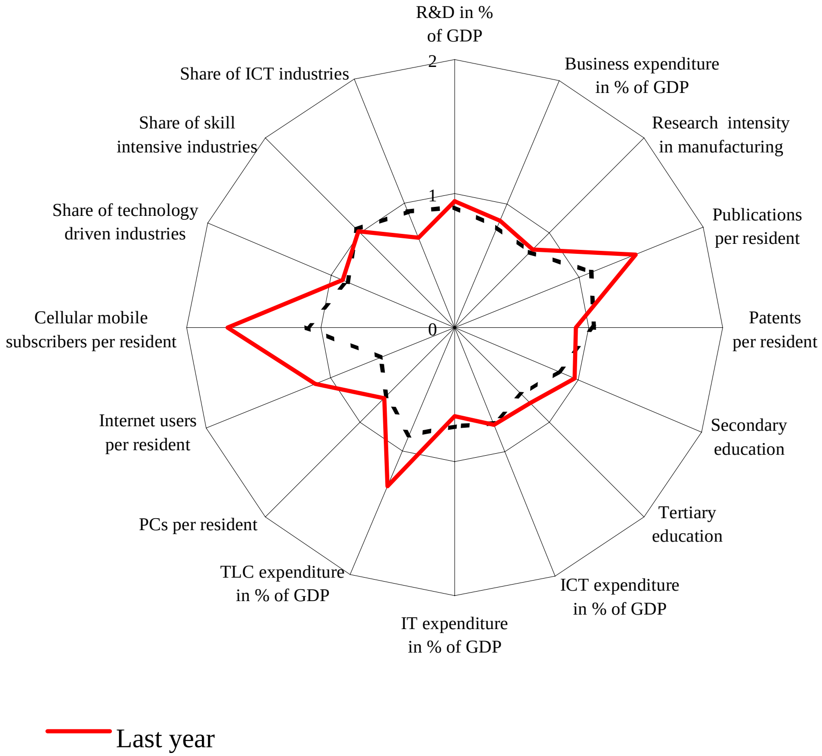


**Figure 5.28: The USA leads according to many growth drivers, but the top five EU countries improve their positions**

USA relative to Europe




EU top five relative to the USA



### Europe is closing the gap to the USA only with respect to a few drivers for growth

A comparison with the USA is possible for 16 indicators. Europe has taken the lead in mobile phones per capita and for expenditures on telecommunications (TLC)[118] relative to GDP. In both cases, Europe has a considerable lead today, while it was lagging in the early nineties. In the other 14 indicators, the USA has maintained its lead, and in none is its margin less than 10 %.

Europe is catching up with the USA significantly in publications, in secondary and tertiary education and in internet and PC use (see Table 5.11 and Figure 5.28). The gap with respect to US figures widened in IT expenditures, in the share of ICT industries, technology driven industries, and skill intensive industries. Europe is not catching up in patents. For research, the gap widened, if we measure total expenditures relative to GDP. This is because the large countries (Germany, France, the United Kingdom, and Italy) had lower research ratios in 1998 than in 1992. The smaller countries have increased their expenditures, so that a comparison of the unweighted means of European countries with the USA would indicate a catching up. For the research intensity of manufacturing, Europe did catch up at first, but according to the latest information, the difference later widened, which would not be unusual during a period of higher growth in the USA.

### The leading countries improve their positions for 12 indicators

The picture is definitely better for the leading European countries.[119] The top 5 European countries have improved their positions relative to the USA for twelve of 16 indicators. The leading European countries surpassed the USA in publications, internet use and the share of skill intensive sectors (in addition to mobile phones and telecom expenditures, where Europe was already ahead). The only areas where the top 5 European countries are not improving their relative positions is patents, the share of IT expenditures and the share of ICT industries in production (Table 5.11).[120] A similar result is given if we relate the performance of the best three countries to that of the USA, this time taking the performab´nce of Sweden, Finland, and Denmark for all indicators. This and the relation of the largest countries (Germany, France, and the United Kingdom) to the USA is shown in Figure 5.29.

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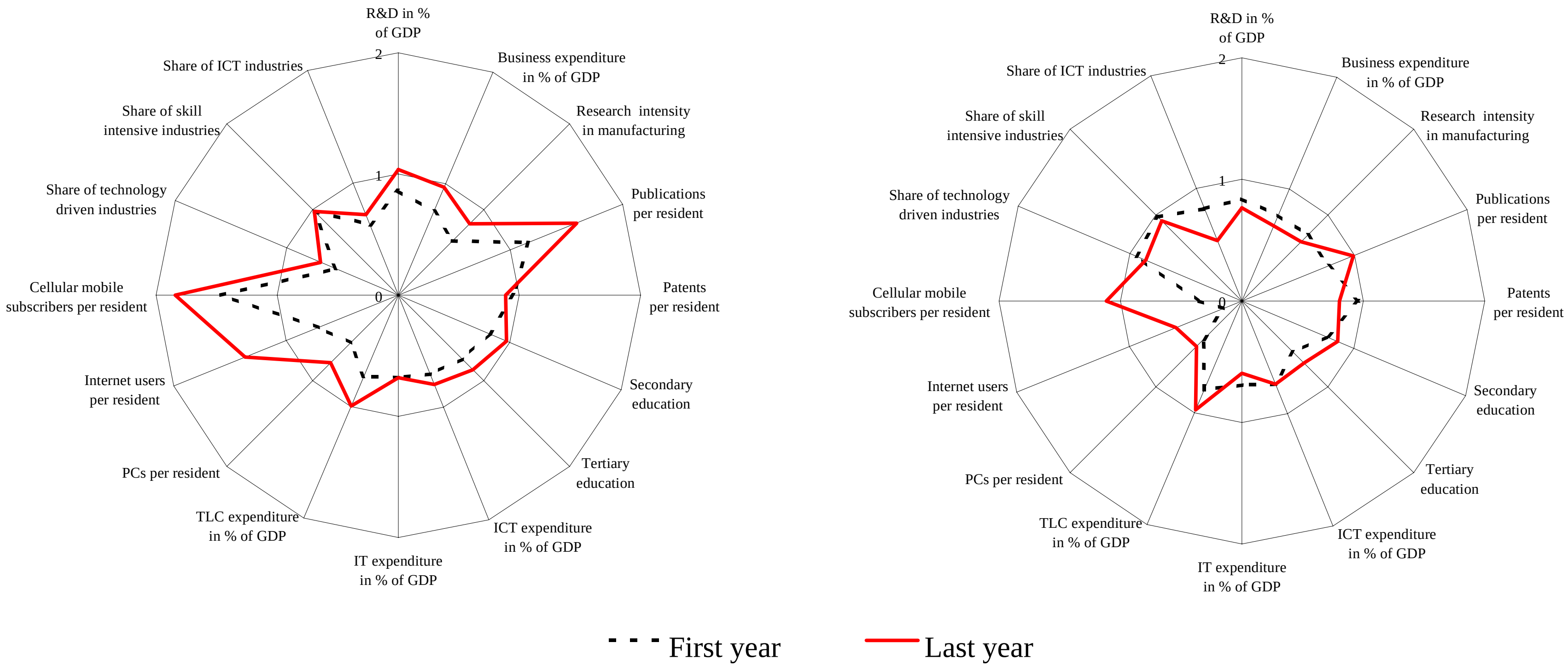
[118] This indicator shares with some other the problem that is measures input but not output.
[119] Remember that the top 5 were determined at the beginning of the nineties; and that they vary according to the indicators.
[120] The top 5 European countries are falling back marginally in their shares of skill intensive industries.

**Figure 5.29: The development of the top three and of the large three countries vs. USA**

EU top three fixed relative to the USA

EU large three relative to the USA




*Remark*: Top 3: Sweden, Finland, Denmark (for all indicators the same countries; fixed).

**Table 5.11: Position of EU vs. USA according to 16 drivers of growth**

| | Position of EU to USA | | Position of leading 5 EU to USA | |
|---|---|---|---|---|
| | EU/ USA First year | EU/ USA Last year | Top5EU/ USA First year | Top5EU/ USA Last year |
| Total expenditure on R&D in % of GDP 1992/98 | 0.693 | 0.661 | 0.897 | 0.942 |
| Business Enterprise Expenditure on R&D (BERD) in % of GDP 1992/98 | 0.606 | 0.564 | 0.812 | 0.866 |
| R&D personell as a % of the labour force 1985/98 | - | - | - | - |
| Research intensity in manufacturing 1990/98 | 0.652 | 0.623 | 0.797 | 0.823 |
| Publications per inhabitant 1992/99 | 0.646 | 0.878 | 1.099 | 1.456 |
| Patents per resident 1990/97 | 0.617 | 0.554 | 1.040 | 0.905 |
| Public expenditure on education 1995/98 | - | - | - | - |
| Percentage of the population that has attained at least upper secondary education by age group (1998) | 0.609 | 0.795 | 0.839 | 0.973 |
| Percentage of the population that has attained at least tertiary education, by age group (1998) | 0.514 | 0.694 | 0.708 | 0.794 |
| Human resources in science and technology by country 1994/99 | - | - | - | - |
| Working population withl tertiary education - ISCED 5-7 1992/99 | - | - | - | - |
| ICT expenditure in % of GDP 1992/2000 | 0.654 | 0.731 | 0.768 | 0.781 |
| Information technology (IT) expenditure in % of GDP 1992/2000 | 0.568 | 0.493 | 0.738 | 0.660 |
| Telecommunication (TLC) expenditure in % of GDP 1992/2000 | 0.749 | 1.135 | 0.873 | 1.284 |
| PCs per inhabitant 1992/99 | 0.369 | 0.481 | 0.723 | 0.744 |
| Internet users per inhabitant 1992/99 | 0.178 | 0.584 | 0.596 | 1.123 |
| Cellular Mobile Subscribers per 100 capita 1992/99 | 0.356 | 1.271 | 1.103 | 1.694 |
| Share of technology driven industries in nominal value added 1990/98 | 0.826 | 0.757 | 0.870 | 0.907 |
| Share of skill intensive industries in nominal value added 1990/98 | 0.920 | 0.895 | 1.034 | 1.015 |
| Share of ICT industries in nominal value added 1990/98 | 0.723 | 0.475 | 0.932 | 0.722 |

*Remarks*: First year (last year) means that year in the nineties for which earliest (or latest data) are available (both are indicated after the name of the variable). For percentage with secondary and tertiary education the older (45-54) and the younger (25-34) age groups are compared.

## 5.8 Summary

During the nineties, growth performance varied not only between Europe and the USA, but also across EU member countries. The variance in growth increased for the total economy, but grew even larger for manufacturing, which plays a central role in determining performance differences. The growth in EU manufacturing is indeed related to the factors which economic theories suggest are relevant: research, human capital, knowledge, capabilities and the use of ICT technology. However, the competitive pressure was strong in the nineties for low growth countries, as well as for mature, capital intensive industries. This implies that the variance of productivity differences did not increase parallel to that of the growth differences, and that productivity increases were not driven only by innovation but also by needs for restructuring (passive change). Furthermore, the nineties spanned a period of severe external shocks, including the currency crisis in the first half, and the Asian crisis in the second. European integration went an important step further, evolving from the Single Market to the Monetary Union. Individual countries pursued various strategies to combat high unemployment and to cut budget deficits. These factors make it difficult to carve out the exact influence of innovation on growth in output and productivity.

The strongest increase in productivity occurred in technology driven industries, where not only the research intensity, but also innovation outlays in general are specifically high, thus establishing a correlation between innovation and growth across sectors and industries. However, specifically in Europe, and during the first half of the nineties, productivity also increased quickly in capital intensive industries. Some labour intensive industries managed to remain competitive by increasing productivity and quality, as did mainstream industries in which Europe is specifically strong. The acceleration of productivity between the first and the second halves of the nineties was, nevertheless, mainly driven by the technology intensive sector.

Manufacturing in the USA excelled in several respects during the nineties. Growth was higher, productivity increased more strongly and accelerated faster than in Europe during the second half of the decade. The impact of technology seems to have been stronger, or at least more direct, than in Europe: the share of technology driven industries has been historically higher, and the productivity lead - however difficult to measure - is highest in these industries. In the USA, many high tech industries, and the group of technology driven industries as such, enjoyed double digit annual growth rates in labour productivity during the second half of the nineties.

The industry pattern of growth is therefore related between the USA and Europe, but not completely. This is also true for individual European countries. We have drawn country profiles, showing in which industries countries are specialised, how they perform according to drivers of future growth, which contribution is made by innovative activities and how policy are aimed at increasing growth and competitiveness. Having illustrated all the differences across countries, we can venture to the tentative conclusion that policies and performance do seem to be converging a little within European countries, however at a very slow speed and with trials, experiments and errors. For most drivers of growth, the USA is leading during the nineties, and due to the cumulative nature of causes and effects, the gap will not close without specific policy efforts in Europe. However, the top countries in Europe are managing to close the gap on an individual basis and are successfully contesting the USA in an increasing number of fields.

While we have progressed in this study first from the aggregate level, to sectors and industries, we know that decisions about innovation are done at the firm level. We will therefore try to contribute additional information about the impact of innovation on performance at the firm level in the next chapter.

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# Chapter 6: The impact of research and development on output and productivity: Firm level evidence

**ROBERT WIESER**

## 6.1 Introduction

This chapter presents evidence on the contribution of R&D to productivity performance at the micro level. The expansive body of empirical literature is surveyed. We find a large and significant impact of research and development on firm performance. The extent of the impact differs widely; the median private rate of return on research and development is 27%. We apply a meta-analysis to determine on which factors the results depend, and present our own evidence for a sample of 2167 large, publicly traded firms in Europe and the US.

Since *Solow´s* (1957) decomposition of economic growth, many empirical studies have concentrated on the contribution of research and development (R&D) activities to the economic performance of firms. Indeed, R&D activities add to the existing stock of accumulated knowledge at the firm level. This knowledge stock aims at improving the quality or at reducing the production costs of existing goods and services. As a consequence, R&D activities are likely to affect the productivity performance of firms.

However, in an increasingly global economy, there might be different attitudes towards the efforts in R&D undertaken by firms in various nations. In theory at least, many factors may explain differences in behaviour towards R&D. Geographic localisation, government policies, industry and opportunity effects, as well as firm specific characteristics may be important factors in the decision to devote resources towards R&D activities.

One of the central tenets of the 'new growth theories' is that R&D activities not only affect the productivity of the firms that undertake them, but also have repercussions on the economic performances of other firms. These R&D spillovers or technological externalities arise because of the partially "public-good" nature of knowledge. Government involvement in research and development (R&D) is generally justified on the grounds that the incentives of the private sector to invest in R&D do not adequately reflect the value society derives from that R&D. The larger the divergence between the social and private returns on R&D (spillovers), the stronger is the case for government involvement.

It is now well-known that both the governments of and private firms in most industrialised countries have devoted an increasing amount of resources to R&D. One of the main objectives of economic analysis is to evaluate whether the returns on this investment justify the initial expenditure. To this end, the relationship between R&D and productivity growth has been investigated at different levels of aggregation: economy, sector, industry and firm. Studies at the firm level have focused on very few countries, mostly France, Japan and the United States, where data on R&D expenditures at the firm level has been available for over twenty years.

The chapter is organised as follows. Section 6.2 introduces the R&D-productivity model, as well as the econometric framework to be implemented, in order to estimate the R&D contribution to productivity at the micro level. Specific attention is paid to variable measurement and estimation issues that are particular to this kind of application. Then, in Section 3, we summarise the most prominent empirical findings of selected econometric studies on the R&D-productivity relationship at the firm level. In order to attain more valid conclusions from the wide range of estimates, we additionally present the results of a meta-analysis of the studies under investigation. The section closes with a short review of studies at the firm and industry levels, which have tried to estimate the contribution of R&D spillovers to productivity growth.

Our own empirical findings are discussed in Section 6.4. Section 6.4.1 aims at presenting the construction and main characteristics of the Global Vantage database (and the constructed sub-samples). A first set of results reflecting the R&D contributions of and structural differences between firms which report R&D and firms which do not report R&D are presented in Section 6.4.2. Econometric estimates of the returns on R&D are presented in Section 6.4.3.

## 6.2 R&D and productivity: Empirical framework

Economists have used two distinct approaches in assessing the contribution of research and development (R&D) expenditures to economic performance: case studies and econometric analysis. While case studies try to identify the benefits from and costs of a particular innovation, the econometric approach concentrates on the contribution of R&D to performance at a higher level of aggregation. The main advantage of the case study approach is its transparency and provision of detailed knowledge about one single firm or one single project. The main disadvantage is its lack of representativeness. Since case studies tend to concentrate on selected successful projects, it is not possible to draw general conclusions from their findings. For the purpose of this report, we therefore concentrate on econometric methods, of which the production function framework and the associated productivity framework are the most widely used in assessing the contribution of R&D to economic growth.

### 6.2.1 The empirical framework

Unlike most case studies, econometric studies also incorporate unsuccessful R&D projects in their expenditure of stock figures. The higher level of aggregation at the firm, industry or economy-wide level, coupled with the use of statistical techniques, makes it easier both to draw general conclusions from their findings and to measure the external effects of the R&D-activities, which are accrued by other firms, industries and nations. However, the use of econometric techniques has numerous limitations. Many relate to the availability of data. Measurement issues arise both in the case of outputs and in the case of inputs. There is the problem of `quality change´ in the construction of price indices and, most prominently, there are no data on R&D capital stocks in the official accounts, so researchers occasionally have to calculate their own R&D stocks.

Most econometric studies estimate the relationship between R&D and either output (the production function approach) or production costs (the cost function approach). A variant of the production function approach relates R&D to factor productivity (productivity approach). All of these methods treat R&D just like any other factor of production, such as labour or physical capital. However, there are differences in the underlying assumptions and in the data requirements as well.[121] Table 6.1 provides an overview of the most widely used frameworks.

In the production function approach, as well as in the (variable) cost function approach, **R&D capital** is related to output or variable costs, whereas productivity studies relate **R&D intensity** (the ratio of R&D expenditures to value added (output) or sales as an approximation of R&D investment) to the rate of growth of labour productivity or to the rate of multi factor productivity growth (MFP studies). This has two implications. In the production function and (variable) cost function approach, we need a measure of R&D capital in the list of the explanatory variables, in

[121] Under duality theory, these approaches are related to each other. In theory at least, a cost function can be derived from a given production function and vice versa. In practice, the direct estimation of a production function suffers from the problems of a simultaneity bias that are avoided when estimating cost functions. However, cost function estimations are considerably more complex, as they typically necessitate the estimation of both the cost function and its associated factor demand equations as a full system. Therefore, data requirements are not easily fulfilled in practice. Among others, *Mohnen – Nadiri - Prucha* (1986), *Bernstein - Nadiri* (1988, 1991), *Bernstein* (1989), and *Mohnen - Lépine* (1991) have implemented the dual approach at the meso-economic level. A limited number of studies employ other approaches. For example, *Jaffe* (1986) uses a model that is related to production and cost functions – the profit function, while *Hall* (1993) uses Tobin´s q to estimate the stock market´s valuation of R&D investment. As there are only a few studies of this kind and a variety of techniques is used, the following review does not summarise all of these methodologies.

addition to the usual factors of production. The fact that there are no data on R&D capital stocks in the official accounts, which are equivalent to physical capital stock figures, raises the problem of obtaining an R&D capital stock estimate for the units under observation (firms, industries and countries). To circumvent the major issues involved in measuring such forms of `capital´, productivity studies rely on R&D expenditures which are more easily available.

In the production function approach, it is assumed that the estimated elasticities of R&D are constant across cross-sectional units, whereas in the productivity approach it is assumed that the `rate of return´ on R&D is constant across cross sectional units. As pointed out by *Capron* (1993), this alternative (R&D intensity) approach turns out to be more consistent with the optimal R&D behavioural choice of firms, compared to the elasticity approach that assumes a common elasticity of output with respect to R&D capital, when the relationship is estimated across firms. Indeed, to the extent that the production technology is specific to each firm, firms will use different factor shares, and if inputs are used at their competitive equilibrium levels, firms are unlikely to have the same output elasticities.[122]

The assumptions underlying productivity studies are that the `rate of return´ on R&D is estimated as a component of productivity growth, that inputs used in production (including R&D) are substitutes and not complements (e.g. Cobb-Douglas case), and that the benefits of R&D occur immediately and not over time. Additionally, it is assumed that the value of knowledge does not decline over time (that is, the rate of knowledge depreciation is zero) and that R&D intensity approximates the underlying net growth in the R&D capital stock. MFP studies additionally assume that output is a constant returns to scale function of capital and labour.[123]

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[122] See *Griliches - Mairesse* (1998) for a discussion of the `identification problem´ in the measurement of production functions.
[123] See Box 6.1 for a short exposition of the production function framework and the associated productivity framework.

## Table 6.1: R&D and productivity: Main econometric approaches

| | |
|---|---|
| **Production function** | **Output** of the firm, industry or economy<br>*is a function of*<br>- labour used in production<br>- physical capital used in production<br>- materials used in production<br>- own R&D capital (aggregation of inputs used in R&D)<br>- R&D spillover pool (external stocks of R&D) |
| **Productivity studies** | **Growth** in **Total Factor Productivity (TFP)**<br>*is a function of*<br>-R&D intensity (ratio of total R&D expenditure to output)<br><br>**Growth** in **Labour Productivity (LP)**<br>*is a function of*<br>- R&D intensity (ratio of total R&D expenditure to output)<br>- labour used in production<br>- physical capital used in production<br>- materials used in production<br>- R&D spillover pool (external stocks of R&D) |
| **Variable cost function** | **Variable cost of production**<br>*is a function of*<br>inputs that vary with output:<br>- labour used in production<br>- physical capital used in production<br>- materials used in production<br>etc.<br>factors that do not vary with output:<br>- own R&D capital (aggregation of quasi fixed inputs used in R&D)<br>- R&D spillover pool (external stocks of R&D) |
| **Total cost function** | **Total cost of production**<br>*is a function of*<br>inputs that vary with output:<br>- labour used in production<br>- physical capital used in production<br>- materials used in production<br>etc.<br>- own R&D capital (aggregation of inputs used in R&D)<br>factors that do not vary with output:<br>- R&D spillover pool (external stocks of R&D) |

### 6.2.2 Methodological and data issues

An important difficulty raised by the production function framework is related to the ***construction of the R&D capital stock*** at the firm level. Actually, the perpetual inventory method (PIM) originally proposed by *Griliches* (1979) is the most commonly used method for constructing firm knowledge capital. This method assumes that the current state of knowledge is a result of present and past R&D expenditures discounted by a certain rate of depreciation.[124]

However, this formulation suffers from several drawbacks. First, the magnitude of the depreciation rate is unknown. It is conceivable that the rate at which private knowledge becomes obsolete, or depreciates, may well differ from the rate at which social knowledge depreciates. For example, industrial knowledge may no longer be of use to the industry concerned, but it may still be of some benefit to other industries or society in general.[125]

Second, since the available history of R&D is usually not very long, we need a method by which we can construct the initial knowledge stock. Unfortunately, the initial R&D capital stock figures are quite sensitive to the growth and depreciation rates used (see *Coe - Helpman* (1995)).[126]

Another well-known issue encountered when estimating the contribution of R&D relates to the problem of ***'double counting'***. Irrespective of whether R&D is measured as a stock, expenditure or intensity figure, expenditures on labour and physical capital used in R&D should be removed from the measures of labour and physical capital used in production. *Schankerman* (1981) clearly demonstrates that the failure to remove this double counting biases the estimated coefficients downwards.[127] That is, the true returns are likely to be *higher* than those estimated. When the coefficients (elasticities) are converted to marginal products, this difference is magnified even more.[128]

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[124] See Box 6.2 for the construction of the R&D capital figures as proposed by *Coe - Helpman* (1995).

[125] As Griliches (1979, pp. 101-102) points out: `The question of depreciation is much more complicated for social research and development capital measures at the industry or national level. The fact that private knowledge loses its privacy and hence its value is a private loss, not a social one. The real problem here is our lack of information about the possible rates of such depreciation. The only thing one might be willing to say is that one would expect such social rates of depreciation to be lower than the private ones.´

[126] While the magnitude of the estimated stock may vary according to the depreciation rate, it does not follow that the elasticity estimates themselves are sensitive to the stock figure. Using a wide ranging sensitivity test on the rate of depreciation (from 0 to 100 per cent), *Hall - Mairesse* (1993) demonstrate that the choice of depreciation rate in constructing R&D capital does not make much difference to the R&D elasticity estimates, although it does change the average level of measured R&D capital greatly, and thus the implied rates of return.

[127] This finding has been confirmed by a number of other studies, including *Cuneo - Mairesse* (1984), *Griliches - Mairesse* (1984), *Hall - Mairesse* (1993) and *Mairesse - Hall* (1996).

[128] Virtually all of the MFP studies, plus most of the earlier studies, do not adjust for this double counting and, based on *Schankerman* (1981), their estimates are likely to be lower than if they had done so (all other things being equal).

In addition to the issues specific to the R&D variable, problems also arise in the ***measurement of output and the other inputs*** entering the production function. Regarding output, one of the most acute issues, at least at the micro level, is the way in which it is deflated. The first major drawback is that price deflators are usually not available at the firm level. Instead, more aggregate price indexes are used, in general at the two-digit industry level, which raises several problems for industries characterised by imperfect competition or for large, multi-product firms which have subsidiaries in many countries.[129] The second shortcoming is that such price deflators do not incorporate changes in output quality, and as a result underestimate the `true´ output.[130]

Regarding the measurement of the traditional inputs, allowances should also be made for corrections of quality differences in labour and physical capital. For instance, if the substantial quality improvements achieved by the computer industry are not taken into account, the contribution of such devices to the productivity gains of the firms using them as inputs in the production function will be underestimated. *Griliches* (1979, p. 106) terms this mismeasurement of where the actual productivity gain occurs a 'productivity transfer' and it reflects the fact that quality improvements are not fully reflected in the official price indices. Furthermore, according to *Griliches - Mairesse* (1984), as long as the inputs are not corrected by the maximal production capacity rates, variations in these inputs affect the measurement of productivity.[131]

Another major issue is that of "**spillovers**", the effect of knowledge capital outside the firm or industry in question on the within-industry productivity.[132] Most empirical studies do not account for potential spillover benefits between and within industries. Clearly, the degree of

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However, many of these studies are subjected to countervailing biases, so the net effect is less certain. For example, due to their use of R&D expenditure figures, most of the MFP studies do not allow for depreciation. This would lead to an overestimation of the return on R&D, in comparison to the situation had depreciation been taken into account.

[129] For instance, if a firm manufactures two products, one in country A and the other in country B, which price deflator of which country should be used if we only observe total sales? Moreover, if these products are in two different two digit level industries, e.g. a drug and a chemical product, which price deflator of which industry should we retain?

[130] *Hall – Mairesse* (1995) use a hedonic price index for computers, which captures the substantial quality improvement achieved by this industry during the last two decades. They report an estimated R&D capital elasticity of 25% which is much higher than the corresponding result of 4% obtained by deflating output via the more conventional GNP deflator. However, as *Mairesse - Mohnen* (1995) emphasise, with panel data, quality differences can be captured by time and sector dummies, even in the absence of good prices.

[131] Here also, If we assume that these rates of capacity utilisation are more or less similar among firms within a given industry and for a given time period, then such business cycles effects should be attenuated by including appropriate industry and time dummies.

[132] As Griliches (1979, p. 103) comments: `The level of productivity achieved by one firm or industry depends not only on its own research efforts but also on the level of the pool of general knowledge accessible to it. Looking at a cross section of firms within a particular industry, one will not be able to distinguish such effects. If the pools of knowledge differ for different industries or areas, some of it could be deduced from inter-industry comparisons over time and space. Moreover, the productivity of own research may be effected by the size of the pool or pools it can draw upon.´

transferability of knowledge depends on the type of knowledge and the industries involved. Insufficient data exists to adequately differentiate between intra-industry flows of embodied and disembodied R&D, and between process and product R&D. To deal with this, researchers implicitly assume that all knowledge is embodied R&D or that the usage of knowledge between industries mirrors the usage of commodities between industries.

In most studies, the R&D capital stock of an industry is merely the sum of the R&D capital stocks of each firm contained in that industry. Instead of just adding together the stocks of R&D capital to derive a pool of potential spillover benefits, some researchers weight them according to their 'technological proximity' — a measure of how transferable knowledge is between industries. The weights indicate how relevant the R&D of one industry is likely to be to the current industry, with a higher weight indicating that its R&D is likely to have greater relevance to the current industry. The weights are typically calculated using one of two approaches, although other methods may be used.[133]

The first method involves identifying those industries that are likely to benefit from patents taken out and those industries taking out the patents. The use of patents makes this approach more plausible for embodied knowledge than for disembodied knowledge, and for product R&D, as opposed to process R&D. The major drawback of this approach is that it is resource intensive, as it requires a considerable amount of information and is extremely time consuming. It also involves some subjective judgement. *Cohen* - *Levin* (1992, pp. 1063–1064) discuss in detail the problems associated with using patents in this manner. The major studies using ***patents as measures of technological proximity*** include *Griliches* - *Lichtenberg* (1984b), *Scherer* (1982, 1983, 1984, 1993), *Englander et al*. (1988), *Sterlacchini* (1989) and *Mohnen* - *Lepine* (1991).

The second method used to calculate the weights for technological proximity is based on ***input-output linkages***. One justification of this approach is that the usage of commodities in production may reflect the usage of the knowledge associated with that commodity. This line of reasoning is more plausible for embodied knowledge than it is for disembodied knowledge, and for product R&D, as opposed to process R&D. Examples of studies using this method include *Goto* - *Suzuki* (1989), *Sterlacchini* (1989) and *Terleckyj* (1974, 1980).

[133] Whilst both methods of measuring technological proximity are open to criticism, they are an improvement on the assumption that knowledge is 'homogeneous'.

### 6.2.3 Econometric estimation methods

Among the different approaches to estimating the relationship between R&D and productivity, many studies have adopted panel data econometric methods. In such a setting, the typical dataset contains observations on a cross section of firms over several time periods.[134] This double dimension confers to panel data several advantages with respect to purely cross section or time series data. The main advantages to be mentioned are more informative data, more variability, less collinearity among the variables, more degrees of freedom and more efficiency. However, the main benefit is identification, i.e. the possibility of holding unobserved productivity components in a firm constant (*Baltagi*, 1995).[135]

To ease the comparability of the studies reported in the next section, they have been ranked according to whether the variables entering the production function are taken in levels or in time series dimensions (i.e., growth rates or within transformations). The \`cross section estimates´ of the relationship between R&D and productivity are obtained from regressions that are carried out for variables in levels for a given year. Level estimates may also be obtained by so-called \`total´ regressions over all firm-year level observations by means of OLS. Regressions which are based on the means of the growth rates of variables for individual firms over several years provide \`between´ estimates, while \`within´ estimates are obtained from the deviations of the variables from their firm means. Regressions may also use first differences or long differences, which also wipe out firm specific effects which are constant over time.

## 6.3 The contribution of R&D to the productivity of firms: Review of selected studies

This section reviews some of the main econometric studies that have investigated the relationship between R&D and productivity at the micro level. It draws heavily on a limited number of high quality reviews that implement a more or less consistent approach.[136] Most studies reveal a large and significant impact of R&D on productivity. We summarise the literature and estimate a median and mean for the elasticity, as well as for the private rate of return. A meta-analysis shows how far the results depend on the periods, the countries and the industries investigated.

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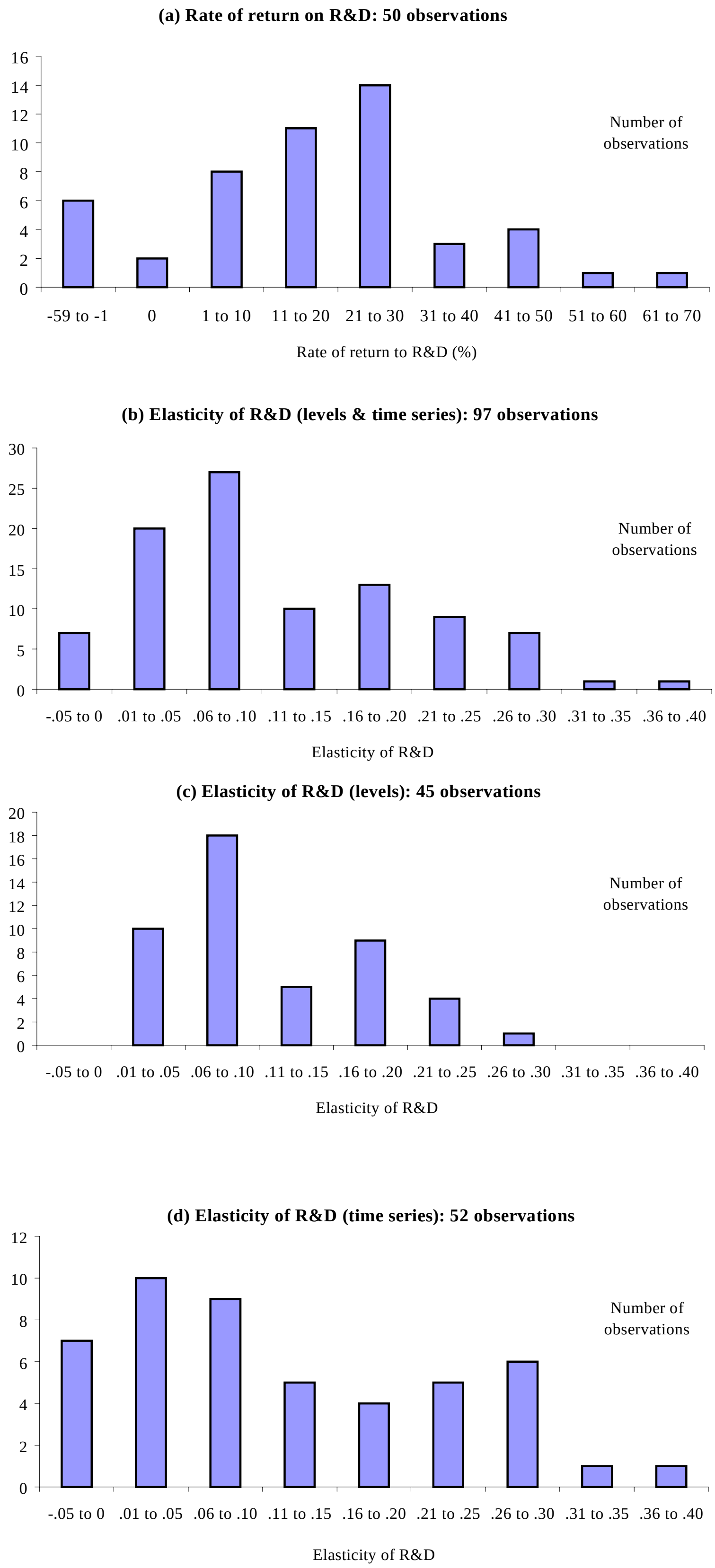
[134] The cross-sectional variation is in most cases much larger than the temporal one, i.e. the main source of heterogeneity is found across firms.

[135] See Box 6.3 for a short discussion of the most important econometric issues in panel data estimation.

[136] Principally, *Mairesse - Sassenou* (1991), *Nadiri* (1993), *Australian Industry Commission* (1995), *Mairesse – Mohnen* (1995) and *Cincera* (1998). Although similar studies have been undertaken for the agricultural sector, this review only covers industrial R&D.

# Figure 6.1: Distributions of private returns on industrial R&D



The studies surveyed use two groups of specifications. The first group measures the percentage increase in output or (multi) factor productivity that occurs in response to a one percent increase in R&D (the elasticity of R&D); the second group measures the change in total output or (multi) factor productivity that results from a one (ECU) unit increase in R&D (the marginal product or rate of return of R&D). Let us remember the two main differences between these specifications. The latter formulation assumes, first, that it is the rate of return on R&D which is constant across firms and not the elasticity of the R&D capital stock, and, second, that the rate of depreciation of this capital is negligible.

As the *Australian Industry Commission* (1995) points out, it is virtually impossible to be entirely consistent between studies because of the wide range of factors, including the use of different methodologies, a lack of clarity in the way findings are presented, major structural differences in the countries covered, differences in the time periods covered, and whether the returns on R&D are estimated from specifications that use R&D stocks or flow expenditure figures. Despite these drawbacks, we will attempt to gain an impression of the magnitudes observed thus far, by taking a look at a brief descriptive summary of the returns on R&D. We will then turn to a more detailed discussion of the main empirical findings on the different specifications, followed by a presentation of a short meta-analysis. The last section summarises a range of studies at the micro and industry levels, which have directly estimated the spillovers associated with R&D, i.e. the difference between the social or total returns and the private returns.

### 6.3.1 Direct (private) returns on R&D

Figure 6.1 illustrates the distribution of the private rates of return and the elasticities of R&D, obtained from the studies presented in Tables 6.2 to 6.5 below. Panel (a) and (b) include the frequency distributions of all observations on the rates of return and the elasticities; panels (c) and (d) group the elasticity estimates into, respectively, level and time series estimates.

Table 6.2 provides summary statistics on the distributions. The overall average private rate of return on R&D, with respect to the studies presented in Table 6.3, if significant, was 28.8% per year, with a standard deviation of 13.3 percentage points. The overall mean elasticity of R&D from Tables 6.4 and 6.5, if significant, was .152, with a standard deviation of .088. If we partition the distributions of the elasticity estimates into those resulting from level estimates and those resulting from times series estimates, the mean elasticities were .122 in levels and .188 in the time dimension, with the associated standard deviations of .066 and .099, respectively.

**Table 6.2: R&D and Productivity: Ranges of estimates in selected studies**

| Estimate | Number of observations | Mean | Std | Median | Minimum | Maximum |
|---|---|---|---|---|---|---|
| Rate of Return (%) | | | | | | |
| significant only | 29 | 28.8 | 13.3 | 27.0 | 7.0 | 69.0 |
| all observations | 50 | 16.7 | 22.8 | 20.1 | -55.0 | 69.0 |
| Elasticity: levels & time series | | | | | | |
| significant only | 73 | .152 | .088 | .115 | .027 | .380 |
| all observations | 97 | .121 | .095 | .100 | -.016 | .380 |
| Elasticity: levels | | | | | | |
| significant only | 40 | .122 | .066 | .102 | .027 | .292 |
| all observations | 45 | .111 | .069 | .099 | .008 | .292 |
| Elasticity: time series | | | | | | |
| significant only | 33 | .188 | .099 | .185 | .041 | .380 |
| all observations | 52 | .112 | .112 | .100 | -.016 | .380 |

**Estimates of the rates of return on R&D**

The first set of studies reported in Table 6.3 directly estimates the `rate of return´ on R&D. In this approach, the rate of growth in output or multi factor productivity is related to the R&D intensity. All the results reported by these studies (except the ones by *Griliches* - *Mairesse* (1984) and *Bartelsman et al.* (1996)) are based on pooled first differenced regressions, i.e. total first difference estimates. As pointed out by *Mairesse* - *Mohnen* (1995), the interpretation of this kind of estimate lies between the cross sectional and the temporal dimensions of data, since the growth of multi factor productivity is related to the firm's R&D intensity, the variability of which is much higher across firms than over time.

Three main conclusions emerge from the estimates reported in Table 6.3. First, the results give evidence of a positive relationship between the intensity of R&D investment and the growth of multi factor productivity. Indeed, the average estimated rate of return on R&D (performed on the basis of the estimates in Table 6.3 that are statistically significant) is about 29%, with a lower bound of 7% (*Link*, 1981) and an upper bound of 69% (*Sassenou*, 1988).

Secondly, we can conclude from these estimates that downward biases arise when no corrections are made for the double counting of R&D (*Hall-Mairesse*, 1995) and when industry dummies are introduced to the productivity model (*Odagiri* – *Iwata*, 1986, *Griliches* – *Mairesse*, 1983, *Griliches* – *Mairesse*, 1990, *Sassenou*, 1986).

A third outstanding feature is the rather comparable rates of return on R&D obtained for firms in different countries. In particular, *Griliches* – *Mairesse* (1983) and *Griliches* – *Mairesse*

(1990) estimate the contribution of the R&D intensity of French, Japanese and US firms to the growth rate of sales by controlling for specific industry effects. These studies indicate that the rates of return on R&D do not differ to a great extent across countries (estimated rates of return on R&D are about 31% for French firms, 30% for Japanese, and 27% for US firms).

## Table 6.3: Firm level econometric estimates of the gross rate of return to R&D

| Study | Country | Time period covered | Number of firms, industries | Specification[b] | Econometric model[c] | Rate of return | s.e.[d] |
|---|---|---|---|---|---|---|---|
| Minasian (1962) | USA | 1947-57 | 18 firms, Chemicals | TFP - VA | pooled, F.D. | .25 | (.04)* |
| Mansfield (1980) | USA | 1960-76 | 16 firms, Petrol. & Chemicals | TFP - VA | pooled, F.D. | .275 | (.067)* |
| Odagiri & Iwata (1986) | Japan | 1966-73 | 135 firms | TFP - VA | pooled, F.D. | .201 | (.109)** |
| " | " | " | " | TFP-VA-ID | " | .17 | (.135) |
| " | " | 1974-82 | 135 firms | TFP - VA | " | .169 | (.059)* |
| " | " | " | " | TFP-VA-ID | " | .113 | (.059)** |
| Griliches & Mairesse (1984) | USA | 1966-77 | 133 firms | Sales | pooled, calc. | .35 | |
| " | " | " | " | " | within, calc. | .64 | |
| Odagiri (1983) | Japan | 1969-81 | 123 firms, scientific sectors | TFP-Sales | pooled, F.D. | .256 | (.096)* |
| " | " | " | 247 firms, other sectors | " | " | -.475 | (.295) |
| Link (1981) | USA | 1971-76 | 174 firms | TFP - VA | pooled, F.D. | .00 | (.03) |
| " | " | " | 19 firms, Transport | " | " | .15 | (.21) |
| " | " | " | 33 firms, Chemicals | " | " | .07 | (.03)* |
| " | " | " | 34 firms, Mechanical | " | " | .05 | (.07) |
| Lichtenberg & Siegel (1991) | USA | 1972-85 | 5240 firms | TFP-Sales-ID | pooled, F.D. | .132 | (.021)* |
| Griliches & Mairesse (1983) | USA, France | 1973-78 | 343 US + 185 French firms | Sales | pooled, F.D. | .28 | (.06)* |
| " | " | " | " | Sales-ID | " | .12 | (.06)* |
| " | USA | " | 343 firms | Sales | " | .19 | (.11)** |
| " | " | " | 57 firms, Drugs | " | " | .41 | (.23)** |
| " | " | " | 62 firms, Chemicals | " | " | -.10 | (.36) |
| " | " | " | 65 firms, Electronics | " | " | -.06 | (.19) |
| " | " | " | 47 firms, Electrical equipment | " | " | -.44 | (.33) |
| " | " | " | 112 firms, Machinery | " | " | .11 | (.27) |
| " | France | " | 185 firms | " | " | .31 | (.07)* |
| " | " | " | 47 firms, Drugs | " | " | .27 | (.15)** |
| " | " | " | 30 firms, Chemicals | " | " | .00 | (.23) |
| " | " | " | 37 firms, Electronics | " | " | .12 | (.11) |
| " | " | " | 34 firms, Electrical equipment | " | " | .45 | (.24)** |
| " | " | " | 39 firms, Machinery | " | " | -.55 | (.38) |
| Griliches & Mairesse (1990) | Japan | 1973-80 | 406 firms | Sales | pooled, F.D. | .56 | (.23)* |
| " | " | " | " | Sales-ID | " | .30 | (.21)** |
| " | USA | " | 525 firms | Sales | " | .41 | (.09)* |
| " | " | " | " | Sales-ID | " | .27 | (.10)* |
| " | Japan | " | 406 firms | Sales | pooled, F.D., calc. | .20 | (.21) |
| " | USA | " | 525 firms | " | " | .25 | (.10)* |
| Sassenou (1988) | Japan | 1973-81 | 394 firms | Sales | pooled, F.D. | .69 | (.19)* |
| " | " | " | " | VA | " | .22 | (.11)* |
| " | " | " | " | VA-ID | " | -.02 | (.07)* |
| Link (1993) | USA | 1975-79 | 302 firms | TFP-Sales | pooled, F.D. | .06 | (.04) |
| Goto & Suzuki (1989) | Japan | 1976-84 | 13 firms, Drugs | TFP - VA | pooled, F.D. | .42 | (.118)* |
| " | " | " | 5 firms, Electrical | " | " | .22 | (.094)* |
| " | " | " | 3 firms, Motor vehicles | " | " | .33 | (.138)* |
| Fecher (1990) | Belgium | 1981-83 | 292 firms | TFP-Sales-ID | pooled, F.D. | .04 | (.059) |
| " | " | " | 113 firms, scientific sector | " | " | .05 | (.042) |
| Hall & Mairesse (1995) | France | 1980-87 | 197 firms | VA | pooled, F.D. | .231 | (.053)* |
| " | " | " | " | VA-DC | " | .273 | (.059)* |
| " | " | " | " | VA | L.D. | .036 | (.053) |
| " | " | " | " | VA-DC | " | .065 | (.060) |
| Bartelsman & al. (1996) | Netherlands | 1985-89 | 209 firms | VA-DC | L.D. | .218 | (.085)* |
| " | " | 1989-93 | 159 firms | " | " | .173 | (.082)* |
| Cincera (1998) | World | 1987-94 | 625 firms | Sales | pooled, F.D. | .38 | (.060)* |
| " | " | 1989-93 | 2445 firms (unbalanced) | " | " | .05 | (.037) |
| Wakelin (2000) | UK | 1988-96 | 98 firms | Sales | | .34 | (.18)* |
| " | " | " | " | Sales-ID | " | .28 | (.21) |

a adapted and extended from Mairesse and Sassenou (1991); Mairesse and Mohnen (1995) and Cincera (1998).

b MFP = multi factor productivity; VA = value-added; ID = inclusion of industry dummies; DC = correction for the double counting of R&D; I2Def = Industry 2 digit level deflators

c SPPI = sector-level producer price index; F.D. = first differences; L.D. = long diff.

d Standard Error, * (**) = statistically significant at the 5% (10%) level

**Estimates of the elasticity of R&D: Level dimension estimates**

The studies reported in Table 6.4 assessed the output elasticity of R&D stock on the basis of a level specification of the production function. One interesting question is, whether the R&D-productivity relationship has changed over **time**. In the first study (*Schankerman*, 1981), the estimates are performed for different industry sectors in 1963. The estimates that are statistically significant range from .034 (Electric equipment) to .292 (Aircraft industry). His estimated elasticity of .104 for chemicals is very close to the one obtained in *Minasian* (1969) for firms operating in the same industry sector during the 1950´s (11%). *Hall* - *Mairesse* (1995) obtain an estimate of .18 for the R&D elasticity of French firms during the 1980's. This result is again very close to the one reported by *Cunéo* - *Mairesse* (1984) for the 1970s (.203). On the other hand, in *Griliches* (1980), the estimated elasticity of R&D in 1963 is. 07, which is less than the corresponding result of .12 for 1972 in his 1986 study. *Cincera* (1998) finds increasing elasticities in the cross sectional dimension and at the same time a sharp decline in the temporal estimates, and concludes that there may be a mismatch between business cycles and R&D patterns over time, which could not be accounted for in the simple Cobb-Douglas model at hand.

According to *Schankerman* (1981), it is important to correct traditional inputs, i.e. labour and physical capital, for the **double counting** of R&D inputs (see Section 6.2.2). When such a correction is not made, downward biases are likely to arise since a part of the traditional inputs is used to increase the stock of R&D capital and not to produce the current output. Indeed, his results indicate that such a bias is present and quite important for some industries such as aircraft (800%) and electrical equipment (600%). For other industries, such as chemicals and oil and motor vehicles, the downward bias is still present, but is less important: 50% and 30% respectively. It is interesting to note that the highest estimated elasticities of R&D have been found for the two most R&D intensive industries, which are aircraft (R&D elasticity of .292) and electric equipment (.232). Moreover, these industries also present the largest downward biases arising from the double counting issue.

The results of Schankerman (1981) concerning the double counting issue have been confirmed by the results of *Cunéo* - *Mairesse* (1984), *Hall* - *Mairesse* (1995), *Mairesse* - *Hall* (1996) and *Bartelsman et al.* (1996). *Cunéo* - *Mairesse* and *Mairesse* - *Hall* observe a downward bias to the order of about 80% for French firms. In *Bartelsman et al.* correction for double counting leads to an increase of the R&D elasticity from .01 to .05 for the period 1985-1989 and from .04 to .10 for the 1989-1993 period.

## Table 6.4: Firm level econometric estimates of the elasticity of R&D, level dimensions[a]

| Study | Country | Time period covered | Number of firms, industries | Specification[b] | Econometric model | Elasticity | s.e.[c] |
|---|---|---|---|---|---|---|---|
| Shankerman (1981) | USA | 1963 | 110 firms, Chemicals and Oil | VA | Cross-section | .104 | (.036)* |
| " | " | " | " | VA-DC | " | .159 | (.035)* |
| " | " | " | 187 firms, Metals & Machinery | VA | " | .018 | (.022) |
| " | " | " | " | VA-DC | " | .099 | (.021)* |
| " | " | " | 101 firms, Electric. Equipment | VA | " | .034 | (.020)** |
| " | " | " | " | VA-DC | " | .232 | (.029)* |
| " | " | " | 34 firms, Motor vehicles | VA | " | .069 | (.047)* |
| " | " | " | " | VA-DC | " | .09 | (.046)* |
| " | " | " | 31 firms, Aircraft | VA | " | .032 | (.033)* |
| " | " | " | " | VA-DC | " | .292 | (.048)* |
| " | " | " | 419 firms, Miscellaneous | VA | " | .043 | (.011)* |
| " | " | " | " | VA-DC | " | .065 | (.011)* |
| Griliches (1980) | USA | 1963 | 883 firms | VA | Cross-section | .069 | (.009)* |
| Griliches (1986) | USA | 1972 | 491 firms | VA | Cross-section | .115 | (.018)* |
| " | " | " | " | VA-ID | " | .089 | (.017)* |
| Sassenou (1988) | Japan | 1976 | 394 firms | VA | Cross-section | .10 | (.01)* |
| " | " | " | 112 firms, Scientific | " | " | .16 | (.03)* |
| " | " | " | " | ID | " | .07 | (.02)* |
| Minasian (1969) | USA | 1948-1957 | 17 firms | VA | Total | .113 | (.015)* |
| Griliches-Mairesse (1984) | USA | 1966-1977 | 133 firms | Sales | Total | .054 | (.011)* |
| " | " | " | 77 firms, Scientific | " | " | .185 | (.013)* |
| Cuneo-Mairesse (1984) | France | 1972-1977 | 182 firms | VA | Total | .203 | (.007)* |
| " | " | " | 98 firms, Scientific | VA | " | .114 | (.010)* |
| " | " | " | " | VA-DC | " | .206 | (.014)* |
| " | " | " | " | Sales | " | .176 | (.019)* |
| Harhoff (1994) | Germany | 1977-1989 | 443 firms | Sales | Total | .15 | |
| Hall-Mairesse (1995) | France | 1980-1987 | 197 firms | VA | Total | .18 | (.009)* |
| " | " | " | " | VA-DC | " | .252 | (.008)* |
| Mairesse - Hall (1996) | USA | 1981-1989 | 1073 firms | Sales-I1Def | Total | .035 | (.005)* |
| " | " | " | " | Sales | " | .246 | (.012)* |
| " | France | 1981-1989 | 1232 firms | Sales-I1Def | " | .09 | (.006)* |
| " | " | " | " | Sales | " | .093 | (.006)* |
| " | " | " | " | VA | " | .092 | (.004)* |
| " | " | " | " | VA-DC | " | .165 | (.004)* |
| Bartelsman & al. (1996) | Netherlands | 1985-1989 | 209 firms | VA | Total | .008 | (.016)* |
| " | " | " | " | VA-DC | " | .046 | (.015)* |
| " | Netherlands | 1989-1993 | 159 firms | VA | " | .043 | (.023)* |
| " | " | " | " | VA-DC | " | .165 | (.004)* |
| Cincera (1998) | World | 1987-1994 | 625 firms | Sales | Total | .11 | (.006)* |
| " | " | " | " | Sales-ID | " | .19 | (.008)* |
| " | " | " | " | Sales-GD | " | .08 | (.006)* |
| " | " | 1987-1990 | " | Sales | " | .09 | (.009)* |
| " | " | 1991-1994 | " | " | " | .12 | (.008)* |
| " | Europe | 1987-1994 | 101 firms | Sales | " | .10 | (.012)* |
| " | Japan | " | 133 firms | " | " | .02 | (.013)* |
| " | USA | " | 378 firms | " | " | .09 | (.007)* |
| " | World | 1980-1994 | 2445 firms (unbalanced) | " | " | .13 | (.004)* |
| O´Mahoney - Vecchi (2000) | Europe, USA | 1988-1997 | 783 firms | Sales | Total | .027 | (.014)* |

a adapted and extended from Mairesse and Sassenou (1991); Mairesse and Mohnen (1995) and Cincera (1998).

b VA = value-added; DC = correction for double counting of R&D; ID = inclusion of industry dummies; GD = inclusion of country dummies;

I1Def = single manufacturing sector deflator (Sales is usually deflated by 2- or 3-digit industry deflators)

c Standard Error, * (**) = statistically significant at the 5% (10%) level

*Griliches* (1986) reports estimates with **industry dummies** as additional explanatory variables of the production function. In this case, the estimated R&D elasticity is .03 lower (.09 compared to .12 without industry dummies). *Sassenou* (1988) reaches a similar conclusion in his analysis of Japanese firms. Indeed, the elasticities of R&D reported in his study are lower when industry dummies are included.[137]

*Griliches - Mairesse* (1984) investigate 133 US firms, and find an elasticity of R&D with respect to sales of .05. However, the estimated R&D elasticity for **scientific firms** is .19, which is higher than the findings reported for other firms in their sample. This result is confirmed by the results obtained by *Sassenou* (1988), who reports a somewhat larger elasticity of R&D for scientific firms (16%) compared to other firms (.10). However, the R&D elasticity reported by *Cunéo - Mairesse* (1984) is lower for scientific French firms (elasticity of .11) than for other ones (.20). One possible explanation of this result may arise from the fact that both US and Japanese firms in the scientific sector are much less reliant on government funding than is the case for French firms. Since publicly-funded R&D is in general more fundamentally based, it is likely that its contribution to the productivity performance of private firms is less important than the returns on privately financed R&D.

Comparing the estimates of the studies by Griliches (1980) and Sassenou (1988), it follows that the contribution of R&D is quite similar for US and Japanese firms. The value of .15 reported in the analysis by Harhoff (1994) for a sample of 443 German firms is quite comparable to similar results obtained for French firms. On the other hand, his result appears to be higher than the findings for US and to some extent for Japanese firms. Bartelsman et al. (1996) provide estimates of the contribution of R&D for Dutch manufacturing firms. On the whole, the estimated coefficients reported in their analysis are lower than the corresponding ones obtained in other **countries**. Cincera (1998) investigates R&D elasticities for 625 firms in different countries between 1987 and 1994. He finds comparable estimates for US firms (.09) and European firms (.10). However, in the case of Japan, the estimate is much lower (.02).

*Cunéo - Mairesse* (1984) experiment with value added and sales as the output variables. Considering sales instead of value added as the dependent variable leads to a higher elasticity of R&D capital (.18 for sales versus .11 for value added). The study by *Mairesse - Hall* (1996) uses two datasets for the USA and France to investigate the R&D-productivity relationship in both countries and to examine to what extent this relationship is similar in France and the US.

[137] However, the interpretation of these sectorial dummies is ambiguous. Quoting Mairesse - Mohnen (1995: p. 37), `On the one hand, the indicators may correct the estimates for the bias resulting from the erroneous omission from the production function of structural variables strongly correlated to the sectorial characteristics. On the other hand, their presence may itself be a source of distortion to the extent that they reflect in part the return to research resulting from technological opportunities. The latter are probably essential to explain the greater tendency to carry out research in certain sectors. Thus, scientific sectors benefit from a more solid and broader knowledge base, on which it may be easier to devise a research program and achieve profitable innovations.

The authors explore two alternative price indexes used to deflate the dependent variable. The first one consists of the manufacturing sales deflators as a whole, while the second one is defined as the sales deflator at the two digit industry level. Using the latter deflator tends to increase the R&D elasticity in France slightly and in the USA dramatically (about 500%). In the opinion of the authors, the reason for this difference stems from the way the US deflator is constructed. Actually, this deflator is based on a hedonic price index for computers and, as a consequence, while computers became much more powerful and much less expensive during the 1980s, the price index for this industry declined by about 80% during this period. Since this industry has become increasingly important in manufacturing, the effects of this price decline, combined with growing R&D budget and output productivity, play a substantial role in explaining the observed differences in terms of the R&D elasticity.

**Estimates of the elasticity of R&D: Time series estimates**

The series of studies reported in Table 6.5 uses the time series dimension of the data. Some studies are based on the growth rates of the variables (total or between first difference estimates or long difference estimates), while others rest on deviations from the means of the variables (within transformation). As a whole, it can be observed that estimates of R&D elasticity in the time series dimension provide more controversial results than estimates of R&D elasticity in the level dimension of the data. In fact, in a large number of studies, the estimated coefficients do not appear to be statistically significant.[138]

According to *Mairesse* (1990), it is an open question, as to whether we should give preference to the time series estimates or the level estimates. However, in some respects, the results from Table 6.5 confirm those in the level dimension. Corrections for double counting lead to higher estimates (*Cuneo-Mairesse* 1984); the impact of R&D on productivity seems to be higher for US firms than for European firms, which in turn, surpasses Japanese firms (*Cincera* 1998, within) and, there is no clear indication, whether scientific firms show larger elasticities of R&D than other firms (*Griliches-Mairesse* 1984*; Cuneo-Mairesse* 1984).

[138] Quoting Mairesse - Mohnen (1995: p. 37), "The fact that the estimates are lower and more fragile in the temporal dimension can be explained in a number of ways. A simple but important reason relates to the collinearity between the physical capital and research capital variables and the time trend reflecting autonomous technical change. Another reason is that measurement errors tend to have a much more serious impact on growth rates than on the levels of the variables. A further factor is no doubt the omission of cyclical variables in the production function, such as the duration of work, the rate of utilization of physical capital, and more generally, the difficulties of providing a satisfactory specification of the lags and the dynamic evolution of the variables."

## Table 6.5: Firm level econometric estimates of the elasticity of R&D, temporal dimensions[a]

| Study | Country | Time period covered | Number of firms, industries | Specification[b] | Econometric model[c] | Elasticity | s.e.[d] |
|---|---|---|---|---|---|---|---|
| Griliches (1980) | USA | 1957-1965 | 883 firms | PFP-ID | Between | .076 | (.013)* |
| " | " | " | 110 firms, Chemicals & Petroleum | PFP | " | .093 | (.038)* |
| " | " | " | 187 firms, Metals & Machinery | " | " | .102 | (.022)* |
| " | " | " | 101 firms, Electric. Equipment | " | " | .106 | (.030)* |
| " | " | " | 34 firms, Motor vehicles | " | " | .126 | (.070)* |
| " | " | " | 31 firms, Aircraft | " | " | .107 | (.077)* |
| " | " | " | 419 firms, Miscellaneous | " | " | .052 | (.015)* |
| Griliches - Mairesse (1983) | USA, Japan | 1973-1978 | 343 + 185 firms | Sales | Between | .02 | (.03) |
| Sassenou (1988) | Japan | 1973-1981 | 394 firms | VA | Between | .04 | (.04) |
| Cincera (1998) | World | 1987-1994 | 625 firms | Sales | Between | .10 | (.006)* |
| Mairesse - Hall (1996) | France | 1981-1989 | 1232 firms | Sales-I1Def | Total, F.D. | -.003 | (.003) |
| " | " | " | " | Sales | " | -.003 | (.003) |
| " | " | " | " | VA | " | -.005 | (.003)** |
| " | USA | 1981-1989 | 1073 firms | Sales-I1Def | " | .01 | (.024) |
| " | " | " | " | Sales | " | .092 | (.026)* |
| Cincera (1998) | World | 1987-1994 | 625 firms | Sales | Total, F.D. | .33 | (.042)* |
| " | " | 1987-1990 | " | " | " | .38 | (.069)* |
| " | " | 1991-1994 | " | " | " | .26 | (.046)* |
| " | Europe | 1987-1994 | 101 firms | " | " | .27 | (.100)* |
| " | Japan | " | 133 firms | " | " | .29 | (.114)* |
| " | USA | " | 378 firms | " | " | .29 | (.039)* |
| " | World | 1980-1994 | 2445 firms (unbalanced) | " | " | .28 | (.022)* |
| O´Mahoney - Vecchi (2000) | Europe, USA | 1988-1997 | 783 firms | Sales | Total, F.D. | .328 | (.050)* |
| " | " | " | 157 firms, Chemicals | " | " | .354 | (.067)* |
| " | " | 1993-1997 | 362 firms, Machinery | " | " | .191 | (.038)* |
| " | USA | " | 151 firms, Machinery | " | " | .297 | (.056)* |
| " | Japan | " | 107 firms, Machinery | " | " | .107 | (.083) |
| " | Europe | " | 104 firms, Machinery | " | " | .069 | (.083) |
| Cincera (1998) | World | 1987-1994 | 625 firms | Sales | L.D. | .21 | (.094)* |
| Mairesse - Cuneo (1985) | Japan | 1974; 1979 | 390 firms | | L.D. | .02 | (.10) |
| Bartelsman & al. (1996) | Netherlands | 1985-1989 | 209 firms | VA-DC | L.D. | .247 | (.083)* |
| " | " | 1989-1993 | 159 firms | " | " | .185 | (.080) |
| Minasian (1969) | USA | 1948 - 1957 | 17 firms | VA | Within | .084 | (.068) |
| Griliches - Mairesse (1984) | USA | 1966 - 1977 | 133 firms | Sales | Within | .091 | (.022)* |
| " | " | " | 77 firms, Scientific | " | " | .021 | (.026) |
| Cuneo-Mairesse (1984) | France | 1972-1977 | 182 firms | VA | Within | .05 | (.039) |
| " | " | " | 98 firms, Scientific | VA | " | .144 | (.054)* |
| " | " | " | " | VA-DC | " | .17 | (.052)* |
| " | " | " | " | Sales | " | .028 | (.043)* |
| Sassenou (1988) | Japan | 1973 - 1981 | 394 firms | VA | Within | -.01 | (.01) |
| Hall-Mairesse (1995) | France | 1980-1987 | 197 firms | VA | Within | -.001 | (.036) |
| " | " | " | " | VA-DC | " | .069 | (.035)* |
| Mairesse - Hall (1996) | USA | 1981-1989 | 1073 firms | Sales-I1Def | Within | .041 | (.011)* |
| " | " | " | " | Sales | " | .17 | (.014)* |
| " | France | 1981-1989 | 1232 firms | Sales-I1Def | " | .008 | (.011) |
| " | " | " | " | Sales | " | .013 | (.011) |
| " | " | " | " | VA | " | -.016 | (.013) |
| Cincera (1998) | World | 1987-1994 | 625 firms | Sales | Within | .24 | (.041)* |
| " | " | 1987-1990 | " | " | " | .29 | (.069)* |
| " | " | 1991-1994 | " | " | " | .24 | (.054)* |
| " | Europe | 1987-1994 | 101 firms | " | " | .10 | (.043)* |
| " | Japan | " | 133 firms | " | " | .07 | (.039)* |
| " | USA | " | 378 firms | " | " | .19 | (.026)* |
| " | World | 1980-1994 | 2445 firms (unbalanced) | " | " | .21 | (.010)* |

a adapted and extended from Mairesse and Sassenou (1991); Mairesse and Mohnen (1995) and Cincera (1998).

b VA = value-added; DC = correction for double counting of R&D; ID = inclusion of industry dummies; GD = inclusion of country dummies;

I1Def = single manufacturing sector deflator (Sales is usually deflated by 2- or 3-digit industry deflators)

c F.D. = first differences; L.D. = long diff.

c Standard Error, * (**) = statistically significant at the 5% (10%) level

**A short meta-analysis of the estimated returns to R&D**

This section presents the results of a meta-analysis of the studies on the R&D-productivity relationship reported in Tables 6.3 to 6.5. We would like to have more consistent answers to the following questions: (1) Has the relationship between R&D and productivity changed over time? (2) Can we observe differences in the contribution of R&D to productivity in different countries? (3) Are there industries in which R&D contributes more to productivity than in others?

To this end, we collect the different outcomes (rate of return on R&D, elasticity of R&D) found in the various studies, and their associated standard errors. In order to explain the variations in results across the sample of studies, we estimate an equation as follows:

$$Y_j = \beta_0 + \sum_{k=1}^{K} \beta_k Z_{jk} + e_j \qquad j=1,2,.....,N$$

where $Y_j$ is the reported estimate of the returns on R&D (rate of return; elasticity) in study j from a total of N studies, and $Z_{jk}$ are meta-independent variables which proxy characteristics of the empirical studies in the sample. The variables of interest in Z are the time periods covered, the countries and the industries. Additionally, we control for differences in specifications and the econometric model. That is, we utilise all information in Tables 6.3 to 6.5. The results of the meta regressions are reported in Table 6.6.[139]

Column (1) shows the results of the reported estimates of the rate of return on R&D. The regression is based on 50 observations (i.e. 50 regressions) from the 17 studies in Table 6.3. US manufacturing firms in the 1970s comprise the reference category (basis), so that the coefficients of the other variables measure the extent to which they differ from the basis. The results suggest that there are neither country specific effects nor time period or sector specific effects, i.e. there is no (statistically significant) variation across time periods, countries and industry groups in the estimated rates of return on R&D.

[139] To deal with the heteroscedasticity problem, we employ a weighted least squares (WLS) estimation with standard errors of the estimates (the $Y_j$s) as analytical weights.

## Table 6.6: R&D and productivity: Results of Meta-Regression [a]

| | Rate of return | | Elasticity | | | | | |
|---|---|---|---|---|---|---|---|---|
| | (1) | | (2) | | (3) | | (4) | |
| | | | levels | | time series | | levels & time s. | |
| Independent Dummy Variable | est. | s.e. | est. | s.e. | est. | s.e. | est. | s.e. |
| USA | b | | b | | b | | b | |
| Japan | .11 | (.131) | -.07 | (.061) | -.05 | (.042) | -.05 | (.031)** |
| Europe | -.12 | (.335) | -.08 | (.052) | -.06 | (.046) | -.07 | (.034)* |
| World (mixed) | -.21 | (.387) | -.06 | (.065) | .11 | (.037)* | .08 | (.028)* |
| 1950s | .01 | (.539) | .05 | (.090) | -.01 | (.070) | .00 | (.055) |
| 1960s | -.11 | (.261) | -.12 | (.070)** | .16 | (.073)* | .04 | (.047) |
| 1970s | b | | b | | b | | b | |
| 1980s | .10 | (.192) | .08 | (.071) | .06 | (.049) | .07 | (.036)** |
| 1990s | .31 | (.389) | -.01 | (.079) | .06 | (.048 | .05 | (.036) |
| manufacturing (mixed) | b | | b | | b | | b | |
| scientific only | -.06 | (.221) | .04 | (.051) | -.04 | (.041) | -.02 | (.029) |
| others | -.34 | (.221) | .01 | (.057) | -.11 | (.034)* | -.09 | (.028)* |
| TFP-VA (Total Factor productivity - value added) | b | | | | | | | |
| TFP-VA-Industry Dummies | -.24 | (.303) | | | | | | |
| TFP-Sales (Total Factor Productivity - Sales) | -.52 | (.240)* | | | | | | |
| TFP-Sales-Industry Dummies | -.38 | (.586) | | | | | | |
| VA (value added) | -.38 | (.274) | b | | b | | b | |
| VA-Double Counting | -.36 | (.272) | .10 | (.026)* | .08 | (.051) | .08 | (.027)* |
| VA-Industry Dummies | -.63 | (.426) | -.07 | (.059) | | | .03 | (.077) |
| Sales | -.21 | (.170) | .09 | (.039)* | .04 | (.045) | .05 | (.031) |
| Sales-Industry Dummies | -.29 | (.226) | | | | | | |
| Sales-I1Def (single sector deflator) | | | -.02 | (.100) | -.03 | (.061) | -.02 | (.046) |
| Cross section | | | b | | | | .00 | (.031) |
| Totals | | | -.12 | (.076) | | | -.02 | (.051) |
| Between | | | | | b | | b | |
| Totals, F.D. (First differences) | | | | | .16 | (.069)* | .08 | (.052) |
| L.D. (Long differences) | | | | | .10 | (.065) | .04 | (.049) |
| Within | | | | | .05 | (.065) | -.04 | (.048) |
| constant | .29 | (.267) | .18 | (.063)* | .05 | (.070) | .12 | (.049)* |
| Num. of obs. | | 50 | | 45 | | 52 | | 97 |
| F | | 1.65 | | 1.91 | | 6.48 | | 7.16 |
| $R^2$adj. | | .19 | | .24 | | .63 | | .55 |

a Weighted Least Squares Regression with standard errors as analytical weights

Note: b = reference category (Basis)

* (**) = statistically significant at the 5% (10%) level

Columns (2) to (4) show the meta-regressions for the estimated elasticities in levels specifications and time series specifications, and combined. Contrary to what has been the case in the rate of return regression, we now observe significant country and time effects, as well as industry effects. In the combined regression (4), the estimated elasticities are significantly lower for Japan and Europe. Also, the estimated elasticities were significantly higher in the 1980s compared to the 1970s, and there are industries (machinery, motor vehicles and miscellaneous) which obtain significantly lower returns on R&D compared to manufacturing as a whole.

Many researchers have focused their attention on possible changes in the productivity of R&D over time, and some of them have documented the collapse of what had been a relatively strong R&D effect (see the discussion above). However, the higher elasticities reported in Table 6.6 for the 1980s (and probably in the 1990s as well), compared to the 1970s, suggest that R&D opportunities are not exhausted at all and might well be promising in the future.

The significantly lower elasticity estimates in Japan and Europe compared to the USA can be interpreted in different ways. First, it might be the case that US firms on average spend more of their money on R&D, relative to their sales, than Japanese and European firms do. That is, R&D intensity in the USA is higher. Secondly, R&D use in US firms might be more efficient. Third, both might be the case. Which policy conclusions emerge from this fact depends on the interpretation. In the first case, political measures should be directed towards stimulating the R&D activities of European firms. In the second case, measures should encourage organisational incentives.

Overall, the results from the meta regressions confirm that R&D continues to be an important driver of productivity growth at the firm level, and there are differences between countries and industries which leave room for political discussions.

### 6.3.2 Spillovers

So far we have explored the empirical relationship between R&D and productivity at the firm level. We have not taken possible spillover effects into account, i.e. the distinction between private and social returns on R&D. Although the contribution of R&D spillovers to productivity growth has long since been acknowledged, it is only recently that the empirical measurement of the magnitude and direction of such effects has become a major point on the research agenda for the economics of innovation. Indeed, the measurement and assessment of the impact of R&D spillovers within and between industry sectors, not to mention among different countries, should help governments to better identify the scientific and technological policies necessary for the enhancement of innovative activities at the firm level and of overall competitiveness.

Table 6.7 summarises the findings reported in some selected studies which have focused on the measurement of technological spillovers on the economic performances of firms. Only a small number of studies have estimated the impact of spillovers at the firm level. Some of these studies have based their investigations on the impact of spillovers on production costs, rather than on productivity gains (multi factor productivity growth). Another important point that differentiates these studies is the proximity measure considered in the establishment of the spillover pool. Among the studies reported in Table 6.7, two main approaches for modelling these proximities must be distinguished. The first one attaches the same weight to the R&D of all firms and the second one locates firms into a patent space.[140]

All the studies reported in Table 6.7, except the last two, examine the impact of technological spillovers on productivity growth. Furthermore, all studies, with the exception of *Branstetter* (1996), which takes Japanese and US firms into consideration, and *Cincera* (1998), which considers European firms as well, are based on samples of firms operating in a single country. The first three and the last two studies use an unweighted sum of the R&D of all other firms. The other studies implement *Jaffe´s* framework (1986, 1988, 1989), in which the technological proximity between firms is characterised by their relative position in a patent space. Besides these differences, some studies distinguish between local (LS) and external (ES) or domestic (NS) and foreign (IS) components of the spillover pool. The local stock is defined as the pool of spillovers generated by firms which are specialised in similar technological activities, whereas the external stock comprises spillovers from firms in technologically different activities.

In most cases, the estimated elasticities and/or rates of returns of R&D spillovers are significant and positive. *Jaffe* (1988) finds a positive effect of spillovers generated by firms which are technologically close in his sample of US firms in the 1970s. *Cincera* (1998), who applied a similar approach to a sample of US firms during the period 1987 to 1994, found estimates which are remarkably close to the ones reported by Jaffe. The only important difference concerns the local spillover component, which is somewhat higher in Cincera´s study.

*Bernstein* (1988) provides econometric evidence on the private and social returns on R&D in Canada, and distinguishes between intra-industry and inter-industry spillovers. He identifies the relative and absolute importance of spillovers according to the fact that social rates of return on R&D investments are substantially higher than private rates of return. In fact, inter-industry spillovers are relatively small for all of the sample industries (2%). Conversely, intra-industry spillovers are relatively large, particularly in industries that have a relatively high propensity to spend on R&D (up to 24%).[141] In a related study, *Bernstein-Nadiri* (1989) find significantly positive intra-industry spillovers in four US industries (9%-16%).

[140] See *Griliches* (1992) and *Mohnen* (1996) for reviews.
[141] The inter-industry variable is defined as the sum of the R&D capital stocks for all other industries, lagged one period. The intra-industry variable for any firm in the sample industry is defined as the sum of the R&D capital stocks of all rival firms in the same industry, lagged one period.

# Table 6.7: Firm level econometric studies assessing the impacts of spillovers[a]

| Study | Country | Time period covered | Number of firms, industries | Specification | weighting matrix | spillover variable[b] | elasticity or rate of return (%) |
|---|---|---|---|---|---|---|---|
| production function appr. | | | | | | | |
| Raut (1995) | India | 1975-86 | 192 firms | Cobb-Douglas | Unweighted sum | ΔNS | .06%* to .36%* |
| Antonelli (1994) | Italy | 1984-85 | 92 firms | Cobb-Douglas, F.D. | Unweighted sum | ΔNS | insignificant |
| Klette (1994) | Norway | 1989-90 | 804 plants, 3 industries | non parametric productivity analysis | Unweighted sum of R&D in plants: within same business line within same group | D | significant% |
| " | " | " | " | | across lines of business within same firm | D | insignificant% |
| " | " | " | " | | across lines of business within same group | D | significant% |
| Fecher (1990) | Belgium | 1981-83 | 292 firms | Cobb-Douglas L.D. | I/O flows | K/S | 2%* |
| " | | " | " | " | " | NS/S | .5%* |
| " | | " | " | " | " | IS/S | -1% |
| Harhoff (1994) | Germany | | 443 firms | | Position (of firm) in R&D space | | .03* |
| Jaffe (1988) | USA | 1972-77 | 434 firms | Cobb-Douglas L.D. | Position (of firm) in patent space | K/S | 1.3%*-15%* |
| " | | " | " | " | | Δln(LS) | .10%-.25%* |
| " | | " | " | " | | Δ(ES/LS) | .00035 |
| Jaffe (1989) | USA | 1972-77 | 434 firms | Cobb-Douglas L.D. | " | ΔK | .03* |
| " | " | " | " | " | " | ΔNS | .13* |
| " | " | " | " | " | " | ΔK+ΔNS | .01 |
| " | " | " | low tech firms | " | " | ΔNS | .13* |
| " | " | " | medium tech firms | " | " | ΔNS | .15* |
| " | " | " | hi-tech firms | " | " | ΔNS | .17* |
| Branstetter (1996) | USA | 1983-89 | 209 firms | Cobb-Douglas L.D. | Position (of firm) in patent space | ΔK | .36* |
| " | " | " | " | " | " | ΔNS | .83** |
| " | " | " | " | " | " | ΔIS | -.48 |
| " | Japan | 1983-89 | 205 firms | " | " | ΔK | .01 |
| " | " | " | " | " | " | ΔNS | .70* |
| " | " | " | " | " | " | ΔIS | .38 |
| Los & Verspagen (1996) | USA | 1974-93 | 485 fims | Cobb-Douglas Within | Position (of industry) in patent space | K | .02* |
| " | | " | | " | Position (of industry) in patent space | TS | .51* |
| " | | " | | " | Unweighted sum | TS | .53* |
| Cincera (1998) | World | 1987-94 | 625 firms | Cobb-Douglas Within | Position (of firm) in patent space | Δln(TS) | 1.11* |
| " | " | " | " | " | " | Δln(LS) | .25* |
| " | " | " | " | " | " | Δln(ES) | .59* |
| " | " | " | " | " | " | Δln(NS) | -.31* |
| " | " | " | " | " | " | Δln(IS) | 1.03* |
| " | " | " | " | Cobb-Douglas F.D. | " | Δln(TS) | .94* |
| " | " | " | " | " | " | Δln(LS) | .24* |
| " | " | " | " | " | " | Δln(ES) | .60* |
| " | " | " | " | " | " | Δln(NS) | -.19* |
| " | " | " | " | " | " | Δln(IS) | .65* |
| " | Europe | 1987-94 | 101 firms | Cobb-Douglas Within | " | Δln(NS) | .13 |
| " | " | " | " | " | " | Δln(IS) | .32 |
| " | " | " | " | Dobb-Douglas F.D. | " | Δln(NS) | .13 |
| " | " | " | " | " | " | Δln(IS) | .06 |
| " | Japan | 1987-94 | 133 firms | Cobb-Douglas Within | " | Δln(NS) | -.17 |
| " | " | " | " | " | " | Δln(IS) | .91* |
| " | " | " | " | Dobb-Douglas F.D. | " | Δln(NS) | -.23 |
| " | " | " | " | " | " | Δln(IS) | 1.46* |
| " | USA | 1987-94 | 378 firms | Cobb-Douglas Within | " | Δln(NS) | .69* |
| " | " | " | " | " | " | Δln(IS) | -.02 |
| " | " | " | " | Dobb-Douglas F.D. | " | Δln(NS) | .59* |
| " | " | " | " | " | " | Δln(IS) | -.43 |
| Cost function appr. | | | | | | | |
| Bernstein (1988) | Canada | 1978-88 | 680 firms, 7 industries | Translog Pool | Unweighted sum | IntraS | 17%* to 24%* |
| " | " | " | " | | | InterS | 2%* |
| Bernstein & Nadiri (1989) | USA | 1965-78 | 48 firms, 4 industries | Translog Pool | Unweighted sum | IntraS | 9* to 16* |

a adapted from Mohnen (1996) and Cincera (1998)

b NS=national stock; IS=international stock; LS=local stock; ES=external stock; TS=total stock

Note: By local stocks, we mean spillovers generated by firms which are specialised in similar technological activities, whereas, by external stocks, we meann spillovers generated by firms which operate in different technological spaces

*Griliches* (1992) summarises the results of econometric studies of rates of return on privately and publicly funded R&D in the United States. In absolute terms, the excess of the social over the private rates of return (spillovers) tends to cluster in the range of 18% to 20%. In relative terms, spillovers seem to create a gap between the private and social returns that is equal to 50% to 100% of the private rate of return. He concludes `R&D spillovers are present, their magnitude may be quite large, and social rates of return remain significantly above private rates´ (p. 42). Additionally, he highlights the fact that there is no differential return between federal versus private R&D dollars at the firm level, although differences are evident at the industry level. It is suggested that the latter result reflects the differential rates of government R&D funding across industries.

*Branstetter´s* results (1996) suggest that spillover effects are more national than international in scope. This is confirmed by the results of *Cincera* (1998) for the USA, but not for Japan. Unable to find consistent effects for Europe, he concludes that `the sensitivity of firms to spillovers differs significantly among the three geographic areas. Indeed, the United States, Japan and Europe seem to adopt very different behaviours. While US firms are mainly concerned with their national spillover stock, Japanese firms are more receptive to the international stock and European firms do not seem to particularly benefit from either sources of spillovers.´

In a recent paper, *Branstetter* (2001) provides estimates of the relative impact of intranational and international knowledge spillovers on innovation and productivity at the firm level, using panel data from the USA and Japan. He again concludes that `there is a strong evidence of intranational knowledge spillovers. There is limited evidence that Japanese companies benefit positively from research undertaken by American firms (......). There is no evidence that American companies benefit positively from research undertaken by Japanese firms. In fact, where the effect is statistically distinguishable from zero, it is negative.´ (p. 75).

The *Australian Industry Commission* (1995) has summarised several studies at the industry level, which assess the returns on R&D. First, from the studies in Table 6.8, the mean ratio of national (that is, private plus total spillover returns) to industry (that is, private plus intra-industry spillovers) returns on R&D is approximately 2.5 (90/37). That is, the social return on R&D is on average at least twice as high as the private return. Second, although it is not possible to directly compare intra- with inter-industry spillovers at the industry level, the latter appear to be more significant than the former. The mean inter-industry return amounts to 73%, compared to the returns of 37% at the industry level. Hence, if private rates of return (from which the firm profits) are positive, inter-industry spillovers must on average be more important than intra-industry spillovers.

### Table 6.8: Industry level econometric studies assessing the impacts of spillovers[a]

| Study | Country | Time period covered | Rate of return to[b] Industry[c] | Firms in other industries | National[d] |
|---|---|---|---|---|---|
| Bernstein - Nadiri (1989) | USA | 1958 - 81 | 19 to 37 | 2 to 145 | 21 to 172 |
| Bernstein - Nadiri (1991) | USA | 1957 - 86 | 25 to 39 | 0 to 113 | 28 to 142 |
| Griliches - Lichtenberg (1984) | USA | 1959 - 78 | 11 to 31 | 69 to 90 | 41 - 62 |
| Scherer (1982) | USA | 1948 - 78 | 19 to 43 | 64 to 147 | 103 |
| Scherer (1984) | USA | 1973 - 78 | 29 | 74 to 104 | 103 |
| Sveikauskas (1981) | USA | 1959 - 69 | 7 to 25 | 50 | 57 to 75 |
| Terleckyj (1974) | USA | 1948 - 66 | 12 to 37 | 45 to 187 | 73 to 107 |
| Terleckyj (1980) | USA | 1948 - 66 | 25 to 27 | 82 to 183 | 107 to 110 |
| Wolff - Nadiri (1987) | USA | 1947 - 72 | 11 to 19 | 10 to 90 | 21 to 109 |
| Bernstein (1989) | Canada | 1963 - 83 | 34 to 57 | 0 to 70 | 39 to 104 |
| Hanel (1988) | Canada | 1971 - 82 | 50 | 100 | 150 |
| Mohnen - Lepine (1988) | Canada | 1975 - 83 | 15 to 284 | 2 to 90 | 21 to 329 |
| Goto - Suzuki (1989) | Japan | 1978 - 83 | 26 | 80 | 106 |
| Sterelacchini (1989) | UK | 1954 - 84 | 2 to 33 | 7 to 32 | 18 to 56 |
| Unweighted mean | | | 37 | 73 | 90 |
| Standard deviation | | | 53 | 55 | 67 |

a adapted from Australian Industry Commission (1995)

b gross rates of return (in some cases net rates of return have been converted to a gross rate of return assuming a depreciation rate of 10%; see AIC(1995))

c Industry return includes both The firm undertaking R&D and Other firms within the same industry returns

d National returns includes both the Industry and Ohter firms in other industries returns. As those industries wioth the lowest (highest) rate of return to the industry may not be those with the lowest (highest) rate of return to Firms in other industries, the National total may not represent the sum of the ranges.

## 6.4 R&D and Productivity Growth: Evidence for European and US firms in the 1990s

This section uses a sample of large, quoted firms to show that firms which report R&D are growing faster and have higher productivity. The econometric approach has to deal with the problem that the reporting behaviour may depend on structural characteristics and performance differences of the firms. The main result is that the impact of research on production is significant and robust, the rate of return on R&D is estimated at approximately 12%.[142]

[142] For the purpose of the following descriptive analysis, we make no distinction 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 our data, and we account for this in the econometric model.

### 6.4.1 Data and variables

*The data*

The company accounts database employed in the analysis, Global Vantage, includes consolidated information on company accounts for approximately 12,000 companies world-wide, covering the 10 year period between 1989 to 1998. From this we have extracted information on the United States and twelve countries in the European Union.[143] Companies are sampled from a wide range of manufacturing sectors.

We started with information on 2681 (EU 1482; US: 1199) manufacturing firms over the period 1990-1998. Due to the omission of certain observations concerning employment, and questionable data on other variables, we first had to limit the sample to 2649 (EU 1481; USA 1168), and then, in response to merger and acquisition problems (outliers), to restrict it further to 2167 firms (EU 1365; USA 833). The cleaning procedure is based on the following criteria:

- Any observation for which the growth rate of net sales, capital stock, and employment is less than minus 80% or greater than 100% has been removed.
- Any observation for which R&D intensity is greater than 50% has been removed.
- Any observation for which net sales per worker (productivity), capital stock per worker and R&D capital per worker is above or below three times the interdecile range of the median has been removed.

The resulting samples and the corresponding sub-samples of firms reporting R&D are presented in Table 6.9. Just over 48% 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 European countries.

**Construction of variables**

Several variables have been constructed for the purpose of the subsequent empirical analysis. These variables are the firm´s R&D intensity and the R&D spillover stock available to the firm. Furthermore, in order to proxy industry and geographic specific effects, several sets of dummy variables have also been constructed. Finally, in order to allow for a comparison of all these variables across industries, countries and over time, several deflators have been taken into

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[143] There is no information on R&D expenditures for firms in Spain, Luxembourg and Portugal.

consideration and all nominal variables have been converted into 1995 constant dollars. Table 6.10 lists all the constructed variables.

**Table 6.9: Number of firms included in the sample (1990-98)[a]**

| | All firms | | R&D firmsb | | Non R&D firms | |
|---|---|---|---|---|---|---|
| | absolute | *% of sample* | absolute | *% of sub-sample* | absolute | *% of sub-sample* |
| Total | 2198 | *100.0* | 1034 | *100.0* | 1164 | *100.0* |
| 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* |
| Irland | 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* |
| US | 833 | *37.9* | 581 | *56.2* | 252 | *21.6* |
| EU-12 | 1365 | *62.1* | 453 | *43.8* | 912 | *78.4* |

a The sample excludes firms with large jumps in the data, generally caused by mergers

b All firms that reported nonzero R&D expenditures in one or more years in the 1990-98 period

The model we consider in the econometric section can be thought of as a modified version of the Cobb-Douglas production function framework in its growth rate form, with output growth being a function of physical capital, labour and R&D capital. Unfortunately, we do not have enough information in our data to construct the R&D capital stock at the firm level.[144] Because of this, an alternative approach, suggested by *Griliches* (1973) and *Terleckyj* (1974) is used, in which the R&D intensity from the beginning of the period is substituted for the unavailable R&D capital variable. This approach directly estimates the rate of return on R&D instead of its elasticity (see Section 6.2). The firm´s ***R&D intensity*** is measured as the ratio between the level of R&D expenditures and the firm´s output, i.e. net sales.

The measure of ***physical capital stock*** corresponds to the net property, plant and equipment of firms. „Net" means that accumulated reserves for depreciation, depletion and amortisation are not included. Information on annual capital expenditures is available as well. Hence, it may be possible to construct a capital stock according to the perpetual inventory method. However, this approach requires knowledge of the rates of depreciation of physical capital, which vary across firms and over time. Since this information is unavailable, and capital expenditures are missing for some firms and years, we did not choose this approach.

## Table 6.10: List of variables

| Variable | Description | Source |
|---|---|---|
| aggregated variables | | |
| D1 | GDP deflator | OECD |
| D2 | Industry value added deflators (NACE-3 digits) | Wifo, OECD |
| DC | Physical capital (Investment) deflator | OECD |
| variables at the firm level | | |
| *Nominal values* | | |
| S | Net sales | GV |
| L | Number of employees | GV |
| C | Net property, plant & equipment (gross depreciation) | GV |
| RD | Annual R&D expenditures | GV |
| RD/S | R&D intensity | GV |
| *Real values* [a] | | |
| Sd | Net sales deflated by D2 | GV |
| Cd | physical capital deflated by DC | GV |
| RDd/Sd | R&D intensity deflated by D1 | GV |
| *control variables (selection bias; Heckman procedure)* | | |
| CFL | Cash Flow | GV |
| S | Net Sales (Size) | GV |
| *Dummies* | | |
| G1 | Country dummies | |
| GD | Geographic dummies | |
| MD | Industry dummies | |
| *Spillovers* | | |
| *IRD/S* | Intra Industry R&D spillovers (R&D by firms within the same industry) | OECD-ANBERD |
| CRD/S | Total R&D spillovers (R&D by firms in other industries; at country level) | OECD-ANBERD |

[a] all variables in constant 1995 US$

In order to pick up unobserved market factors or ***industry specific effects,*** as well as ***geographic effects***, two sets of dummy variables were constructed by assigning each firm to its main industrial sector and the geographic area in which the firm is domiciled. As far as the industry dummies are concerned, the industry sectors corresponding to these variables were chosen so as

[144] We have only a very short history of research expenditures for most European firms. Over the period 1990-1998, US firms report R&D expenditures an average of 8 times, whereas European firms report 4 times on average.

to allow for a concordance between the SIC (industrial classification retained in the Global Vantage database) and the NACE (industrial classification retained in the EU databases).

Several approaches have been developed in the literature for the measurement of the potential pool of ***R&D spillovers*** (see Sections 6.2 and 6.3). In our present work, we rely on a rather simple approach. The spillover variable is constructed as the manufacturing sector-based amount of R&D reported in the ANBERD database less the firm´s own R&D investment. This approach assigns an identical weight to the R&D of all other firms operating in the same industry sector and only considers intra-sector spillovers. In a similar manner, many more aggregated R&D spillover stocks can be constructed: the intra-industry national stocks, the intra-industry international stock, the inter-industry national stocks, and, finally, the inter-industry international stock.

R&D expenditures were deflated using the GDP ***deflators*** of the respective countries, while the deflator of physical capital was used for the capital stock. Regarding net sales, value added deflators had to be estimated for all countries and industries (NACE-3 digit), respectively. A substantial number of firms in the sample might have more than one product line at the SIC two digit level, and might be multinational, that is, a substantial part of its activities is performed outside the domestic market. Therefore, the use of domestic output price indexes for each country may not seem to be a relevant approach for deflating sales. Unfortunately, shares of sales performed in the home country and abroad are not available, and a more general price index could not be computed. Results based on real values should therefore be interpreted with caution.

### 6.4.2 Structural and performance differences between firms reporting R&D and other firms

*Differences in levels*

Table 6.11 shows 1994/95 levels of average employment, sales, gross physical capital, R&D expenditures and R&D intensities for the European and US firms in the sample. We also include the lower quartile, the median and the upper quartile for these variables.

First, the European firms in the full sample are, on average, only (slightly) smaller than the US firms. This is true in terms of average employment, average sales and average physical capital stock as well.

Secondly, the European firms which report R&D expenditures are much larger than the US firms reporting R&D. European R&D firms have, on average, 25,600 employees, whereas US R&D firms have, on average, 14,600 employees. Furthermore, European R&D firms are more than twice as large as non R&D firms, whereas in the US sample R&D firms and firms that do not report R&D expenditures are approximately similar in size. Additionally, average R&D expenditures of European R&D firms are considerably higher than those of US R&D firms. These three observations suggest that small European firms active in innovation are not adequately represented in the subsample of R&D reporting firms.

## Table 6.11: Sample characteristics: 1994/95[a] levels of major variables

| | EU-12 | | | USA | | |
|---|---|---|---|---|---|---|
| Variable | 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 |
| Average employment[b], in thousands | 12.3 | 25.6 | 5.9 | 12.5 | 14.6 | 7.8 |
| Q1 | 0.8 | 1.1 | 0.7 | 1.0 | 10.0 | 1.2 |
| Me | 2.2 | 5.2 | 1.9 | 3.1 | 3.3 | 2.8 |
| Q3 | 8.7 | 21.8 | 6.5 | 10.0 | 12.0 | 6.9 |
| Average sales in millions of dollars | 2,160 | 4,570 | 1,050 | 2,274 | 2,766 | 1,210 |
| Q1 | 103 | 156 | 106 | 152 | 146 | 157 |
| Me | 307 | 728 | 278 | 473 | 501 | 414 |
| Q3 | 1,324 | 3,605 | 1,011 | 1,539 | 1,870 | 909 |
| Average phys. Cap.[c] in millions of dollars | 821 | 1,747 | 402 | 853 | 1,035 | 436 |
| Q1 | 26 | 40 | 28 | 34 | 33 | 39 |
| Me | 89 | 206 | 83 | 128 | 142 | 112 |
| Q3 | 398 | | 328 | 512 | 623 | 328 |
| Average R&D[d] in millions of dollars | | 199 | | | 119 | |
| Q1 | | 3 | | | 4 | |
| Me | | 13 | | | 14 | |
| Q3 | | 71 | | | 45 | |
| Average R&D/sales ratio | | 3.6 | | | 4.8 | |
| Q1 | | 1.0 | | | 1.2 | |
| Me | | 2.2 | | | 2.8 | |
| Q3 | | 4.7 | | | 6.4 | |

a average 1994/95

b average number of employees

c property, plant and equipment (gross depreciation)

d research and development expense

Q1: lower quartile, Me: median, Q3: upper quartile

Third, average R&D intensity (R&D/sales) is much higher in the USA (4.8% compared to 3.6% in Europe). However, if the disclosure decision depends positively on the importance of R&D

activities to the firm (measured by the R&D-to-sales ratio)[145], then the `true´ average R&D intensity of European firms might be even smaller.

Fourth, the size distributions in both samples are highly skewed. In most cases the means are above the third quartile. Hence, even after outlier corrections the samples are heavily dominated by large firms in both countries.

*Differences in growth rates*

Bearing in mind the limitations of our R&D data (domination of large firms; under-representation of small European R&D firms), we look now at the performance records of the firms for both countries during the 1990s. Table 6.12 shows median growth rates for major variables of R&D firms and firms which do not report R&D, in the European countries, as well as in the US. If we compare the performances of R&D firms to other firms in both countries, we observe that the former reveal higher labour productivity growth, as well as more capital deepening compared to non-R&D firms in both countries. While the physical capital stock grew significantly faster in R&D firms, there was no statistically significant difference in employment growth.[146] This suggests that part of the higher productivity growth of R&D firms is due to more capital deepening. Alternatively, it could be the case that R&D firms are subject to more pronounced (international) competition, which forces them to rationalise faster.

Another important observation evident in Table 6.12 is that R&D firms in the USA exhibited more rapid growth in all variables compared to European R&D firms, during all the periods under investigation. Growth in R&D expenditures by US firms was almost twice as high compared to European firms, and labour productivity increased by 1.6% per year faster in the USA [147]

[145] This is one of the conclusions reached in *Gaeremynck – Veugelers* (2000).
[146] We applied a non parametric test (Mann-Whitney U) on the significance of observable differences in the growth rates of the variables. The *Mann-Whitney U* test statistic is based on the mean ranks of different samples.
[147] 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.

**Table 6.12: Median growth rates (per year) - Non parametric tests for significant differences in growth rates**

| | EU-12 | | USA | |
|---|---|---|---|---|
| Variable | 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. |
| phys. capital | 3.2 | 4.6 | 5.8 | 7.0 |
| US vs. EU | * | * | * | * |
| Non R&D vs. R&D | * | * | * | * |
| sales/employee | 1.1 | 2.7 | 3.3 | 4.3 |
| US vs. EU | * | * | * | * |
| Non R&D vs. R&D | * | * | * | * |
| phys. cap./empl. | 1.1 | 2.7 | 3.4 | 4.0 |
| US vs. EU | * | * | * | * |
| Non R&D vs. R&D | * | * | * | * |

* = statistically significant at the 5% level; n.s. = not significant

### 6.4.3 R&D Intensity and output growth: Econometric analysis

In order to assess the contribution of R&D to output growth, we consider in this section the R&D intensity version of the Cobb Douglas production function (equation 6.5 in Box 6.1) with output growth being a function of the growth rates of physical capital and labour, as well as the R&D intensity at the beginning of the period. Our measure of output is `net sales or revenue´, physical capital is `net property, plant and equipment´, employment is `average number of employees´ and R&D intensity is `research and development expenses divided by sales´.

*The selection problem*

One important econometric problem in estimating the relationship between R&D and productivity is related to the selectivity bias. If data on R&D expenditures by firms are not missing at random, OLS estimates may be biased. Unfortunately, our dataset is particularly prone to a selectivity bias. The large number of European firms that do not report R&D expenditures raises the likelihood that, at least in the European sample, some kind of sample selection might be at work. One reason is that European firms are in most cases not forced to disclose their R&D activities in their official accounts.[148] Another reason might be that firms which do not report R&D expenditures are actually those firms which have very low values anyway. If we do not acknowledge these observations, we lose valuable information that may explain part of the relationship between R&D and productivity in our sample.

The usual approach to accounting for the selection bias is to add an explicit selection equation to the model of interest. In the first step, a probit function (selection equation) is estimated for the overall sample to obtain the probability of a firm reporting R&D expenditures. This function depends on observed variables which help identify the selection rule.[149] In addition to capital and labour, we include the following factors as determinants of the observability of R&D expenditures: firm size, cash flow, industry dummies and geographic dummies.[150] Based on the probit estimates, the inverse Mills ratio is calculated, which is used as an additional regressor in the subsequent OLS regression (Heckit method).

We do not report the results of the probit estimation for all the specifications which follow. It serves to mention that the probability of reporting R&D expenditures depends negatively on employment growth and positively on the size of firms. Additionally, we attain significant positive results for industry dummies in the case of research intensive industries and significant negative results for European country group dummies. There is no dependency on the firm´s cash flows. To summarise, disclosure of R&D is more likely for large, slowly growing R&D intensive firms from the US. Stated otherwise, what is noticeably missing from our data are small, fast growing European firms with above average productivity, given the level of R&D intensity.

### *Econometric results*

Table 6.13a documents the basic results at the firm level regarding the contributions of R&D capital to output growth. In the Basic Specification 1, the estimates are all statistically

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[148] Compared to the EU, the reporting rules for R&D expenses are less liberal in the US. The US Securities and Exchange Commission (SEC) requires reporting of `material´ R&D expenditures in the interim and annual financial statements in Forms 10-Q and 10-K.

[149] The set of explanatory variables in the model equation must be a strict subset of the observed variables in the selection equation. The error term of the selection equation is assumed to be independent of the observed variables (and therefore of the explanatory variables in the model equation). The correlation of the error terms of the two equations causes a sample selection problem. See Wooldridge (2000, Ch. 17) and Box 6.4 for a treatment of the selection bias in OLS using the Heckman method.

[150] Unfortunately, there is nothing else available in our data which could be used as `identifying´ information. *Gaeremynck – Veugelers* (2000), using a more comprehensive and informative dataset on 200 Beglian firms, discuss factors which determine the reporting behaviour of firms with respect to R&D. They conclude that in their sample *`disclosure is more likely for big, R&D intensive firms with external R&D sourcing strategies operating in highly concentrated industries with turbulent performance and high speed of technological change´*.

significant at the 5% level and reveal important effects on total net sales, which is the variable on the left hand side of the growth model. The estimated rate of return of R&D (RD/S) is 12%, which is within the limits determined by former studies (see Section 6.3).

Specification 2 includes industry dummies (ID) (nace 2 digit) as additional explanatory variables, in order to assess the importance of industry specific effects. As *Griliches - Lichtenberg* (1984) and *Jaffe* (1988) underlined, it can be expected that, in a perfect world, multi factor productivity is not explained by factors specific to industries. However, in the present context, there are at least two good reasons to take the market factors into account. First, as long as the inputs are not corrected by the utilisation rate of the maximal production capacity, variations in these inputs affect the measurement of productivity. Second, omitting materials when sales are used to proxy the output may lead to some biases. Although the share of materials in output may vary significantly across firms, these variations should mainly be observed across industries. If R&D expenditures are correlated with these sectoral effects, then omitting these effects will lead to biased estimates of the rate of return on R&D. However, the results in Specification 2 lead to the conclusion that the introduction of industry dummies does not influence the estimates.

Specifications 3 and 4 include variables measuring different spillover pools. In Specification 3, the spillover variable is constructed as the industry based amount of R&D reported in the ANBERD database in percent of the industry’s production value. This industry wide R&D Intensity (IRD/S) should capture intra-industry spillovers in our model. In Specification 4, these industry wide R&D intensities are aggregated for the individual countries (CRD/S) to measure inter-industry spillovers. However, as the results show, we could not detect any spillover benefits in these two specifications.

One interesting question concerns the relative impact of R&D activities carried out by firms in the different countries. As is evident in Table 6.9, we have little information on the R&D activities of firms in some of the smaller European countries and on firms in Italy, for example. We therefore only explore the difference between the USA and the European countries as a whole. We tried to account for country specific effects by introducing an interactive dummy for the European firms in the sample (EU*RD/S). Although the estimated rate of return on R&D seems to be lower for European firms (8% compared to 14% in the US), this coefficient is not statistically significant at the usual levels.

*Robustness*

Table 6.13b and Tables 6.14a and 6.14b present robustness checks, first for real values with Heckit and than with OLS. 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, respectively. Furthermore, no single specification reveals significant country effects. However, the OLS results point to high and significant spillover benefits if output growth is measured in nominal values. Indeed, if measured in real values, inter-industry spillovers are still significant, but their magnitude is negligible.

## 6.5 Conclusions

In this chapter, we have analysed the contribution of R&D to the growth performance of firms by reviewing the main empirical findings in the literature. The quantitative assessment of the R&D contribution to economic performance shows that R&D activities are an important factor in the explanation of growth. The main empirical findings may be summarised as follows:

- First, R&D and growth are clearly positively related. The estimated magnitudes of the returns on R&D vary considerably, depending on the type of data used and the method of estimation employed. The results, however, suggest a strong relationship between R&D and growth in productivity and output. The reported private rates of return, if significant, are in a range of 7% to 69% and the elasticities are in a range of .02 to .38. The associated median (mean) rate of return is 27% (29%), and the median (mean) elasticity is .11 (.15).

- Second, the studies confirm that R&D leads to the accruement of spillover benefits by other firms. The estimated elasticities and/or rates of return of R&D spillover variables are in most cases significant and positive. The spillover benefits observed in industry studies are on average two times higher than the private rates of return, yielding mean social rates of return (i.e. private return plus spillovers) on R&D to the order of 90% to 100%. Furthermore, most studies indicate that spillovers between industries are more important than those within industries.

- Third, the studies indicate that the rates of return often vary between industries, sometimes significantly, but there is little consensus in the literature as to which industries generate higher returns and by how much these returns exceed those of other industries. The results of a meta-analysis suggest that there are some industries which exhibit below average elasticities of R&D compared to manufacturing as a whole. On the other hand, we could not confirm that the returns earned by scientific firms are consistently higher than the average.

- Fourth, there is no clear picture as to whether the returns on R&D have changed over time. Several studies have found that the productivity of R&D has declined. However, there are also numerous studies which do not find any evidence of a decline over time. The meta-results indicate a significantly higher elasticity in the 1980s and consistently higher estimates for the 1990s, as compared to the 1970s. This suggests that R&D opportunities are not exhausted at all, and might well be promising in the future.

- Fifth, most researchers conclude that the rates of return on R&D are of comparable magnitudes in different countries. This is confirmed by our meta-analysis. However, the elasticities are significantly lower in Europe and Japan, as compared to the US. Whether this is due to a higher R&D capital coefficient or a more efficient use of R&D capital in the USA or both is not clear. If R&D intensity in Europe is too low, political measures should be directed towards increasing the number of R&D activities initiated by European firms. If, however, R&D is less efficiently implemented by European firms, traditional measures (i.e. subsidisation or special forms of taxation for R&D) will not be effective. In this case, measures directed towards organisational and structural change within firms and industries might be more appropriate.

- Finally, our own empirical work confirms the positive and significant contribution of R&D to productivity growth, for both the USA and the European firms in our sample. The estimated rate of return is about 12%, which is at the lower end of previously reported estimates. Although the estimate for the European firms seems to be lower (8%), the difference is not statistically significant at the usual levels. Despite the fact that the dataset used is problematic (unbalanced panel, selection bias), different specifications and methods lead to very robust findings with regard to the estimated rate of return on R&D.

## Table 6.13a: Output growth and R&D intensity (nominal): heckit results (robust)[z]

| | | | Coefficients and (Standard Errors) independent Variables[a] | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Specification | Classification | Description | c | l | RD/S[b] | IRD/S[c] | CRD/S[d] | U*RD/S[e] | EU | nv. Mills ratio | Chi² - Test[g] |
| 1 | Basis | pooled | .26<br>(.052)* | .61<br>(.049)* | .12<br>(.048)* | | | | | -.02<br>(.016) | 2.47<br>(.116) |
| 2 | Industry Effects | pooled, ID | .26<br>(.052)* | .60<br>(.053)* | .12<br>(.052)* | | | | | -.01<br>(.004)* | 8.94<br>(.003) |
| 3 | Intra-Industry Spillov | pooled, IRD/ | .26<br>(.050)* | .61<br>(.053)* | .11<br>(.048)* | .02<br>(.060) | | | | -.01<br>(.004)* | 8.10<br>(.004) |
| 4 | Inter-Industry Spillov | pooled, CRD | .26<br>(.062)* | .60<br>(.071)* | .12<br>.061)** | | .14<br>(1.195) | | | -.02<br>(.054) | .17<br>(.680) |
| 5 | Country Effects | EU*RD/S | 0.27<br>(.024)* | .60<br>(.027)* | .14<br>(.041)* | | | -.06<br>(.105) | -.00<br>(.007) | -.01<br>(.011) | 1.01<br>(.313) |

* (**) statistically significant at the 5% (10%) level.
z Heckman full maximum-likelihood estimation with Huber/White/sandwich estimator of the variance
a c and l = mean logarithmic growth rates over the period 1991-1998 of phys. Capital and Employment
b Average R&D to Sales ratio: R&D averaged over the years 1991-93, divided by average sales 1991 through 1998.
c IRD/S = industry R&D outlays/nominal production (NACE-2 digit) at industry level; average 1990-98; from OECD-ANBERD
d CRD/S = industry R&D outlays/nominal production (NACE-2 digit) at country level; average 1990-98; from OECD-ANBERD
e EU*RD/S = interactive EU-Dummy, representing R&D from EU firms in the sample
f The inverse Mills ratio is an additional regressor (in essence, an omitted variable).
A significant coefficient implies sample selection (see Wooldridge (1999), Ch. 17).
g The likelihood ratio test is an equivlaent test for sample selection.

## Table 6.13b: Output growth and R&D intensity (real): heckit results (robust)[z]

| | | | Coefficients and (Standard Errors) independent Variables[a] | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Specification | Classification | Description | c | l | RD/S[b] | IRD/S[c] | CRD/S[d] | U*RD/S[e] | EU | nv. Mills ratio | Chi² - Test[g] |
| 1 | Basis | pooled | .28<br>(.057)* | .57<br>(.060)* | .10<br>(.049)* | | | | | -.03<br>(.013)* | 6.07<br>(.014) |
| 2 | Industry Effects | pooled, ID | .30<br>(.057)* | .55<br>(.059)* | .12<br>(.055)* | | | | | -.03<br>(.014)* | 4.83<br>(.028) |
| 3 | Intra-Industry Spillov | pooled, IRD/ | .29<br>(.058)* | .57<br>(.062)* | .12<br>(.050)* | -.00<br>(.001) | | | | -.03<br>(.015)* | 5.22<br>(.022) |
| 4 | Inter-Industry Spillov | pooled, CRD | .30<br>(.057)* | .55<br>(.061)* | .10<br>(.050)* | | .01<br>(.005) | | | -.02<br>(.018) | .92<br>(.337) |
| 5 | Country Effects | EU*RD/S | .29<br>(.029)* | .56<br>(.033)* | .10<br>(.051)* | | | .02<br>(.128) | -.01<br>(.011) | -.02<br>(.020) | 1.99<br>(.156) |

* (**) statistically significant at the 5% (10%) level.
z Heckman full maximum-likelihood estimation with Huber/White/sandwich estimator of the variance
a c and l = mean logarithmic growth rates over the period 1991-1998 of phys. Capital and Employment
b Average R&D to Sales ratio: R&D averaged over the years 1991-93, divided by average sales 1991 through 1998.
c IRD/S = industry R&D outlays/nominal production (NACE-2 digit) at industry level; average 1990-98; from OECD-ANBERD
d CRD/S = industry R&D outlays/nominal production (NACE-2 digit) at country level; average 1990-98; from OECD-ANBERD
e EU*RD/S = interactive EU-Dummy, representing R&D from EU firms in the sample
f The inverse Mills ratio is an additional regressor (in essence, an omitted variable).
A significant coefficient implies sample selection (see Wooldridge (1999), Ch. 17).
g The likelihood ratio test is an equivlaent test for sample selection.
g The likelihood ratio test is an equivlaent test for sample selection.

## Table 6.14a: Output growth and R&D intensity (nominal): OLS results

| Specification | Classification | Description | c | l | RD/S[b] | IRD/S[c] | CRD/S[d] | U*RD/S[e] | EU | $R^2$adj. | MSE |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | **Coefficients and (Standard Errors)** independent Variables[a] | | | | | | | | |
| 1 | Basis | pooled | .28 | .58 | .16 | | | | | .81 | .037 |
| | | | (.024)* | (.026)* | (.036)* | | | | | | |
| 2 | Industry Effects | pooled, ID | .29 | .58 | .14 | | | | | .81 | .037 |
| | | | (.024)* | (.026)* | (.042)* | | | | | | |
| 3 | Intra-Industry Spillovers | pooled, IRD/S | .28 | .58 | .12 | .10 | | | | .81 | .038 |
| | | | (.024)* | (.027)* | (.041)* | (.043)* | | | | | |
| 4 | Inter-Industry Spillovers | pooled, CRD/S | .28 | .58 | .14 | | .60 | | | .81 | .037 |
| | | | (.0.24) | (.026)* | (.037)* | | (.209)* | | | | |
| 5 | Country Effects | EU*RD/S | .27 | .59 | .15 | | | -.06 | .03 | .81 | .037 |
| | | | (.024)* | (.026)* | (.039)* | | | (.105) | (.002)* | | |

* (**) statistically significant at the 5% (10%) level.
a c and l = mean logarithmic growth rates over the period 1991-1998 of phys. Capital and Employment
b Average R&D to Sales ratio: R&D averaged over the years 1991-93, divided by average sales 1991 through 1998.
c IRD/S = industry R&D outlays/nominal production (NACE-2 digit) at industry level; average 1990-98; from OECD-ANBERD
d CRD/S = industry R&D outlays/nominal production (NACE-2 digit) at country level; average 1990-98; from OECD-ANBERD
e EU*RD/S = interactive EU-Dummy, representing R&D from EU firms in the sample

## Table 6.14b: Output growth and R&D intensity (real): OLS results

| Specification | Classification | Description | c | l | RD/S[b] | IRD/S[c] | CRD/S[d] | U*RD/S[e] | EU | $R^2$adj. | MSE |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | **Coefficients and (Standard Errors)** independent Variables[a] | | | | | | | | |
| 1 | Basis | pooled | .31 | .54 | .15 | | | | | .74 | .044 |
| | | | (.027)* | (.030)* | (.044)* | | | | | | |
| 2 | Industry Effects | pooled, ID | .32 | .53 | .13 | | | | | .76 | .043 |
| | | | (.027)* | (.030)* | (.050)* | | | | | | |
| 3 | Intra-Industry Spillovers | pooled, IRD/S | .32 | .53 | .13 | .00 | | | | .75 | .044 |
| | | | (.028)* | (.030)* | (.048)* | (.001) | | | | | |
| 4 | Inter-Industry Spillovers | pooled, CRD/S | .31 | .54 | .12 | | .01 | | | .75 | .044 |
| | | | (.027)* | (.030)* | (.043)* | | (.002)* | | | | |
| 5 | Country Effects | EU*RD/S | .30 | .55 | .13 | | | .04 | -.02 | .75 | .043 |
| | | | (.027)* | (.030)* | (.047)* | | | (.128) | (.005)* | | |

* (**) statistically significant at the 5% (10%) level.
a c and l = mean logarithmic growth rates over the period 1991-1998 of phys. Capital and Employment
b Average R&D to Sales ratio: R&D averaged over the years 1991-93, divided by average sales 1991 through 1998.
c IRD/S = industry R&D outlays/nominal production (NACE-2 digit) at industry level; average 1990-98; from OECD-ANBERD
d CRD/S = industry R&D outlays/nominal production (NACE-2 digit) at country level; average 1990-98; from OECD-ANBERD
e EU*RD/S = interactive EU-Dummy, representing R&D from EU firms in the sample

## Box 6.1: The production function and productivity framework

Most of the econometric studies that have assessed the contribution of R&D to productivity adopt a general version of the Cobb-Douglas production function. In addition to the traditional inputs, this function includes knowledge capital at the firm level, and one or more terms representing specific pools of R&D that the industry or economy may draw upon:

$$Q_{it} = Ae^{\lambda t} C_{it}^{\alpha} L_{it}^{\beta} K_{it}^{\gamma} X_{it}^{\eta} e^{\varepsilon_{it}} \qquad (6.1)$$

where: Q is output (production, value added or net sales), L is a measure of labour (often the number of employees); C is physical (or tangible) capital; K is research capital; X measures external stocks of R&D available (spillover pool); A is a constant; i and t denote firms and time periods (years); $\lambda$ is the rate of disembodied or autonomous technical change; $\varepsilon$ is a multiplicative error term, reflecting the effects of unknown factors, approximations and other disturbances; $\alpha$, $\beta$, $\gamma$ are the parameters of interest, i.e. the elasticities of output with respect to each of the inputs.

Usually, equation (6.1) is taken in logarithms to enable the estimation of $\alpha$, $\beta$, $\gamma$ and $\eta$. This leads to the following linear regression models:

$$q_{it} = a + \lambda t + \alpha c_{it} + \beta l_{it} + \gamma k_{it} + \eta x_{it} + \varepsilon_{it} \qquad \text{levels} \quad (6.2)$$

$$\Delta q_{it} = \lambda + \alpha \Delta c_{it} + \beta \Delta l_{it} + \gamma \Delta k_{it} + \eta \Delta x_{it} + \Delta \varepsilon_{it} \qquad \text{first differences} \quad (6.2)$$

where lower case letters denote logarithms of variables.

In the way equation (6.2) is specified, returns to scale with respect to the three inputs can or cannot be assumed as constant. There are constant returns to scale if the sum of factor elasticities is equal to one. In order to measure this assumption explicitly, equation (6.2) is re-written by subtracting labour from both sides:

$$(q_{it} - l_{it}) = \lambda + (\mu - 1) l_{it} + \beta (c_{it} - l_{it}) + \gamma (k_{it} - l_{it}) + \eta (x_{it} - l_{it}) + \varepsilon_{it} \qquad (6.3)$$

where: $\mu=\alpha+\beta+\gamma+\eta$ represents the coefficient of returns to scale.

In order to circumvent the issues associated with the construction of the R&D stock of knowledge, an alternative specification of equation (6.2´) is sometimes used. This approach, suggested by *Griliches* (1973) and *Terleckyj* (1974), directly estimates the rate of return on R&D instead of its elasticity. From equation (6.1) we obtain:

$$\gamma = \frac{\partial Q_{it}}{\partial K_{it}} \frac{K_{it}}{Q_{it}} = \rho_1 \frac{K_{it}}{Q_{it}} \qquad (6.4)$$

where $\rho$ is the rate of return on (or marginal productivity of) R&D.

By disregarding the depreciation of R&D, i.e. $\Delta k = \Delta K / K = RD / K$, and applying the same transformations to the R&D spillover-stock X, we can re-write equation (6.2´):

$$\Delta q_{it} = \lambda + \alpha \Delta c_{it} + \beta \Delta l_{it} + \eta \Delta x_{it} + \rho_1 (RD/Q)_{it} + \rho_2 (XD/Q)_{it} + \theta_{it} \qquad (6.5)$$

This equation can be simplified further by re-writing it in terms of growth in labour productivity and growth in physical capital per employee and by assuming constant returns to scale in the production function ($\alpha+\beta=1$):

$$\Delta(q-l)_{it} = \lambda + \alpha \Delta(c-l)_{it} + \eta \Delta(x-l)_{it} + \rho_1 (RD/Q)_{it} + \rho_2 (XD/Q)_{it} + \theta_{it} \quad (6.6)$$

We can go even further by relying on a prior measurement of multi factor productivity, that is

$$\Delta \pi_{it} = \Delta q_{it} - \overline{\alpha} \Delta c_{it} - \overline{\beta} \Delta l_{it} = \Delta(q-l)_{it} - \alpha \Delta(c-l)_{it}$$

where the elasticity of labour $\overline{\beta}(=1-\overline{\alpha})$ is estimated by the share of labour costs (wages and related charges) in value-added. We could then just estimate the simple regression

$$\Delta \pi_{it} = \lambda + \rho_1 (RD/Q)_{it} + \rho_2 (XD/Q)_{it} + \theta_{it} \qquad (6.7)$$

## Box 6.2: Calculating data on R&D capital stocks (perpetual inventory method (PIM))

In an appendix to their paper, *Coe - Helpman* (1995) provide the most detailed explanation of any study as to how their stocks of R&D capital were derived. The four key steps in calculating the R&D capital stock figures are:

(1) establishing the rate of depreciation or obsolescence of knowledge;

(2) establishing the average annual growth rate of real R&D expenditures over the period for which the data are available

(3) calculating the initial capital stock figure; and

(4) calculating the remaining capital stock figures from the initial capital stock figure and the expenditure figures.

(5) Under the perpetual inventory method (PIM), the R&D capital stock in the previous period is a function of:

(5) the value of the R&D capital stock in the previous period, net of any depreciation that has occurred; and

(5) the level of R&D expenditure in the previous period

(6) $K_t = (1-\delta)K_{t-1} + SD_{t-1}$ (B6.2)

where

$K_t$ is the stock of R&D capital at the beginning of period t (in constant prices)

$K_{t-1}$ is the stock of R&D capital at the beginning of period t-1 (in constant prices)

$SD_{t-1}$ is the expenditure on R&D during period t-1 (in constant prices); and

is the depreciation or obsolescence rate of knowledge.

Through equation B6.2, the R&D capital stock in one period can be related to that in any other. However, equation B6.2 does not tell us how the initial, or benchmark, stock of R&D capital is calculated.

Calculating the initial stock of R&D capital

*Coe - Helpman* (1995) state that their benchmark R&D capital stock was calculated according to the following procedure suggested by Griliches (1980):

$$K_0 = \frac{SD_0}{(g+\delta)}$$

where

$K_0$ is the stock of R&D capital at the beginning of the first year for which R&D expenditure data (in constant prices) is available;

$SD_0$ is the expenditure on R&D (in constant prices) during the first year for which it is available;

g is the average annual logarithmic growth of R&D expenditures (in constant prices) over the period for which published R&D data were available; and

δ is the depreciation or obsolescence rate of knowledge.

## Box 6.3: Econometric estimation methods

A useful way of introducing alternative methods of modelling, is to have a closer look at the structure of the error term of equation (6.2) (See Box 6.1). More specifically, this error term can be decomposed as follows:

$$\varepsilon_{it} = \alpha_i + u_{it} \qquad (6.8)$$

where $\alpha_i$ is the cross sectional unit or firm specific (unobserved) effect which is assumed to be constant (fixed) over time, e.g. managerial ability; and $u_{it}$ summarises the effects of idiosyncratic or time-varying errors representing unobserved factors that change over time.

The less restrictive model is the one that assumes the $\alpha_i$ to be constant across all units. In this case, the estimates are based on the pooling of the cross-section and time-series observations composing the panel dataset. The estimates obtained from this model are usually referred to as the (level-) ***total estimates***. Alternatively, a regression of equation (6.2) can be run for each time-period separately ((level-) ***cross section estimates***). If we average the observations of each cross-sectional unit over all time-periods and then run a cross-sectional regression, we obtain ***between estimates***. This last model is equivalent to the removal of the last term in equation (6.8). The ***first-differences*** (total) ***estimates*** are based on annual growth rates of the variables, while taking deviations from individual means of equation (6.2) results in the ***within estimates***. The within transformation is equivalent to the introduction of individual dummies in the first model, i.e. total estimates. These parameters are sometimes referred to as the specific unobserved ***fixed effects*** of firms.

Another aspect of the modelling problem is that these specific effects of firms may not be fixed but randomly distributed across cross-sectional units. In such a setting, we speak about ***random effects***. One advantage of random effects over fixed ones, is the higher efficiency of the former estimates. However, the consistency of the random estimates relies on the assumption that the individual effects and the regressors are not correlated. However, such an assumption is rarely verified in the context of the R&D-productivity relationship.[151]

If some important explanatory variables are not included in the productivity equation, and to the extent that these omitted variables are correlated with the ones at hand, then omission biases are likely to be present in the estimates based on cross sectional models. In order to circumvent this problem, we can assume that these unobserved variables are picked up by the specific effects of firms, which in turn can be removed by applying the first difference or the within transformations. However, these models require predetermination or even strong exogenous regressors for the within estimates to be satisfied. Moreover, various issues, in particular random measurement errors in the variables, may exacerbate the omitted variable bias by deteriorating the estimates we can attain by applying these transformations.

The strong exogeneity of the regressors is related to the ***simultaneity*** of the decision process regarding employment or R&D and production. This last issue is a another main cause of the high disparities between the cross-sectional and time-series estimates, often found in the studies. It refers to the question of whether R&D, for instance, depends on past, current or future values of output, i.e. expectations of the dependent variables, or conversely, if the case is the other way round. Among the different solutions proposed to circumvent this simultaneity problem, semi-reduced forms of equation 6.2 can be estimated (*Griliches - Mairesse*, 1984). *Maireisse - Hall* (1995) consider beginning of year's capital stocks rather than end of year's to attenuate the possible simultaneity biases. *Griliches - Hall - Pakes* (1991) 'enrich' the R&D-productivity model by considering additional information on the investment policy adopted by the firm, the number of patents it has received or its stock market value. An alternative approach that allows for all these issues to be present, i.e. correlated fixed effects, measurement errors and simultaneity, relies on a General Method of Moments (GMM) estimator.[152]

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[151] A statistical test allows one to accept or to reject the null hypothesis that the individual effects are uncorrelated with the regressors (*Hausman*, 1978).
[152] See *Mairesse - Hall* (1996) for a general description of this methodology (which is based on that of *Arellano - Bond* (1991)).

## Box 6.4: Selectivity bias and Heckman correction

One important econometric problem in panel data estimation is related to the ***selectivity bias*** (*Heckman*, 1976). Included in the estimation are those companies which perform and record R&D investments. Companies that either do not perform or do not record them are not in the sample. If they are not randomly missing, that is, if the selection rule is non-ignorable, an inference based on the resulting panel may be misleading because it is no longer representative of the population. One has to take into account the mechanism that causes the missing observations in order to obtain consistent estimates of the parameters of interest. In cross-sectional data *Heckman´s* (1979) selectivity bias correction can be employed to obtain consistent estimates.

Our dataset used in the empirical analysis in Section 6.4 is particularly prone to the selectivity bias. Selectivity concerns the presence of some characteristics of firms that is both associated with the reporting of R&D expenditures and associated with the productivity performance, so as to lead to a false attribution of causality regarding the relationship between R&D and productivity. If R&D reporting behaviour is not random, OLS estimates may be `contaminated´ by the selectivity bias.

Heckman´s (1976) insight was that it is sometimes possible to control for this in a simple way. He proposed a two – step method of dealing with the selectivity problem. Specifically, the Heckman selection model assumes that there exists an underlying regression relationship.

$$q_i = \mathbf{x}_i \beta + \varepsilon_{1i} \qquad \text{regression equation}$$

It is argued, however, that the sample of individuals involved is not a random sample, and that this selectivity may bias the coefficients. Alternatively, one might say that the dependent variable is not always observed. Rather, the dependent variable for observation i is observed if

$$\mathbf{z}_i \varphi + \varepsilon_{2i} > 0 \qquad \text{selection equation}$$

where $\varepsilon_1 \sim N(0,\sigma)$, $\varepsilon_2 \sim N(0,1)$, and $corr(\varepsilon_1, \varepsilon_2) = \rho$.

**z** includes variables that predict whether or not individuals participate. Individuals participate if $\mathbf{z}_i \varphi > -\varepsilon_{2i}$, or, equivalently, if $-\mathbf{z}_i \varphi > \varepsilon_{2i}$. When $\rho \neq 0$, OLS applied to the first equation yields inconsistent results.

Principally, **x** should be a (strict) subset of **z**, i.e. any element that appears as an explanatory variable in the regression equation should also be an explanatory variable in the selection equation. Excluding variables can lead to inconsistency if they are incorrectly excluded (see *Johnston-DiNardo* 1997). In our case, **z** includes variables that predict whether or not firms report R&D expenditures. As R&D intensity is not the dependent variable in the regression equation, but it is our variable of interest in this context, we should not include it in the selection equation. All other variables are included. Additionally, we need (identifying) variables that effect selection but do not have a partial effect on productivity. Actually, we chose to include firm size (average revenue over the period), cash flow, industry and country dummies.

As *Johnston - DiNardo* (1997, p. 450) note, however, even with sufficient identifying information in **z**, the parameters of the model appear to be sensitive to the presence of heteroscedasticity, or departures from normality. We used a maximum likelihood estimation with the Huber/White/sandwich estimator of variance to obtain robust standard errors for our productivity model.

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# Chapter 7: Summary of the main findings

**KARL AIGINGER**

### The main results in a nutshell are:

(A) Innovation is important to growth, productivity and competitiveness. Research and development raises sales at the firm level; research intensive sectors increase productivity faster; technology driven industries are at the heart of the acceleration in productivity which took place during the nineties. Country performance is related to research, knowledge and the use of modern technologies. The link between research and growth may be more direct in the USA: here R&D expenditures are still higher relative to GDP than in Europe, and the USA is particularly strong in many industries at the frontier of technology, university industry links are closer, technology start ups more important. For Europe, capabilities at the firm level and the National Innovation Systems at the macro level prove to be very important, as are gradual innovation, the diffusion of technologies, and the use of skills for quality upgrading. The links between innovation and growth seem to become closer in Europe too, as the industries leading in productivity become more similar in the late nineties.

(B) European growth was behind US growth in the nineties; this holds for output, productivity and employment. Indicators predicted by growth theory to be important for long run growth – called in this study "drivers of growth" – underline that this was no chance occurrence. The USA had higher levels of inputs and – where measurable – also higher outputs for many indicators of innovation, knowledge, and the diffusion of technologies. In addition, its shares of technology driven industries was larger. The drivers of growth are related to output growth and productivity in the European countries. However, the attempts of governments to reduce unemployment and budgetary deficits, the implementation of various strategies, differing speeds of liberalisation, currency and financial crises, and other shocks, often conceal the relationship between productivity and growth determinants.

(C) Some European countries – notably Sweden, Finland and Denmark – are performing excellently according to the drivers of growth, contesting the leading position of the USA in research, education and ICT. Four countries – Ireland, Finland, Austria and Sweden- managed to increase productivity faster in the nineties than the US. The countries lagging in productivity level and in drivers of economic growth are catching up, although at a different, and in general, slow speed. The large European countries did not focus specifically on factors important to long run growth. Therefore, the figures for the European Union do not reveal a consistent and broad pattern of narrowing the gap in productivity and growth drivers. This assessment may prove to be too pessimistic, since some of the growth drivers are also favoured by the cyclical situation. Nevertheless, accelerating the growth of productivity and output in Europe will remain a great challenge; waiting for a shift in the cyclical tide will not be enough.

## The evidence provided:

*Innovation is important; it is part of a complex Innovation System*

(1) Countries exhibiting rapid growth have in general high levels of research, they invest in human capital, and make use of new technologies. Specifically during the late nineties, productivity rose fast in technology driven industries and in industries with high research intensities. Firms investing in R&D have higher productivity and output growth. Increases in productivity, as well as the complementary quality upgrading of products (on which the last Competitiveness Report focused) are defining the competitive edge of high wage countries in general. They are specifically important to the European Union, as it passes through a period of integration with low wage countries.

(2) However, innovation is a complex process in many respects. Innovation expenditures are not only a source of growth, they also are fed and accelerated by growth. Furthermore, innovation and growth are influenced jointly by a third group of factors, such as legal regulations, institutions, knowledge, capabilities, standards, and ecological and social goals. Innovation is accelerated by competition and openness; hindered by the barriers and imperfections in the product and input markets, by transaction costs between firms and universities, and by the preferences of governments for traditional or local suppliers. The objective to lower unemployment, to cut budget deficits, and to build up the credibility central banks as they fight inflation, all influence measured productivity and weaken the direct link between innovation and productivity.

(3) Production and productivity growth are not enhanced solely by innovation. The enlargement of the working population, physical investment, and improvements in the quality of human capital and other intangibles can all stimulate growth. These factors may be the result of changing structures, the liberalisation of markets, integration, or

globalisation. Sound fiscal and monetary management, innovations which promote industrial relations, and a business-friendly environment all influence growth. On the other hand, productivity growth may not always need to be based on a country's own research, but can also be achieved via the purchase of inputs and capital goods (embodied technology), as has been illustrated for printing and for textiles. Growth may also result from the transfer of technologies, e.g. by multinational firms, as has been the case in Spain and Ireland. On the other hand, growth may be passively forced upon an industry by increasing competitive pressure, as has been reflected in the high productivity increases in capital intensive sectors, or in those parts of the textile industries which survived the pressure from low wage industries. Growth may temporarily increase due to pressure on the government to stop losses, to privatise and to liberalise. Financial markets force firms to regain profitability, by means of restructuring, takeovers, and mergers. The closing of plants, the permission exit, and the outsourcing of uncompetitive channels of production also increase productivity, but are reflective of "passive changes", rather than "active changes", which are driven by a progressive attitude towards the creation of new processes or products.

*The concepts of innovation and productivity*

(4) Productivity enhances competitiveness and increases factor incomes, such as per capita wages and profits. However, productivity is neither the only nor the ultimate goal of economic policy, and it is not always given top priority. In periods when resources (specifically labour) are under-utilised, governments intentionally try to spread production among more persons, thus decreasing productivity per employee. During periods of disequilibrium and in the aftermath of economic shocks – as were abundant in the nineties - growth in output and growth in productivity are less closely related than is otherwise predicted by the growth models, which refer to steady state growth, in which all variables move along their equilibrium path.

(5) The concept of productivity relates the quantity of output to the quantity of one or more inputs. If output is related to all inputs, we speak of multi factor productivity; in many parts of this study, output is related to labour only (labour productivity). In all cases, output is measured in real terms, which becomes a complicated concept when changes in quality or output arise. Last year's report focussed on quality, illustrating that, as incomes rise, countries "climb up the quality ladder", by constantly upgrading the quality of outputs within industries and by moving into industries which are less price elastic. Europe is enjoying a quality premium, insofar as its exports are of higher quality than its

imports. And, with respect to quality rather than productivity, the European position has been assessed as more favourable than that of the USA. In this sense, the focus of this report is complementary to that of the last. A full assessment of competitiveness must incorporate quantity and quality.

(6) The term "innovation" is very broadly defined in this study. Innovation is the "renewal and enlargement of the range of products and services, and the associated market; the establishment of new methods of production, supply and distribution; the introduction of changes in management, work organisation, the working conditions and skills of workers". The relationship between innovation and knowledge is interactive: first, knowledge is an input in the generation of innovation; secondly, innovations are contributing to the existing stock of knowledge. The knowledge based society builds on a broad range of skills, knowledge and capabilities, and ICT is its backbone. It encompasses hardware, software, and telecommunications; it influences production and sales logistics in many industries. A set of indicators is available for the measurement of production and diffusion, and there is a state of the art method of measuring its quantitative impact on growth and productivity. We begin this report with an examination of the theoretical links, as defined by stylised growth models, as well as by evolutionary models, which include human capital, innovation, absorptive capacities and firm capabilities. We then discuss the broad concept of knowledge, illustrating the progress made by Europe and the impact on market shares. Later, we concentrate on ICT, taking a look at the differences in production and expenditures, and its impact on growth. In our explanation of the differences in manufacturing growth across countries, we use a broad set of "growth drivers"; these are the variables which theoretically will determine the long run growth of economies. It follows that, if we study the performances of sectors and firms, data restrictions will then force us to narrow down the concept of innovation to expenditures on research and development.

*Growth models and evolutionary models each explain parts of real world behaviour*

(7) In the macroeconomic growth models, we find a highly stylised picture of innovation. In the neo-classical model, technological progress is all important, but unexplained. Since the returns on physical capital are diminishing over time, only the unexplained "residual", which sets the pace of technical progress, enables long term growth. Modern growth theory emphasises the role of human capital and research, and describes how research expenditures are chosen deliberately by firms, as a profit-maximising activity. Continued growth and the prevention of diminishing returns are enabled by economies of scale, as

well as by spillovers and externalities, which spread the fruits of innovation to firms not directly engaged in the process. A specifically important objective of innovation can be the development of new product variants. Growth in factor productivity is then a function of the degree of product differentiation. Equilibrium growth – inter alia - is a function of the rate of innovation. More generally, in this group of models, the factors decisive to growth are: the starting position, the rate of physical and intangible investment, spillovers, and the ability to absorb existing technologies. Furthermore, the openness of trade, integration, and foreign direct investment influence the steady state growth rate. A race between innovative countries and imitators can be modelled, whereby countries and firms steadily climb up the quality ladder by means of innovation and imitation. The policy consequences of new growth models are much broader than those of the neo-classical models; they do not rely solely on taxes in the elimination of the under-research bias, but rather hint at the importance of trade policy, integration, foreign investment policy, and intellectual property rights.

(8) Evolutionary growth models stress that innovation intrinsically takes place during periods of disequilibrium and in an environment of uncertainty. Secondly, innovation depends on a broad range of capabilities at the firm level: social capabilities, such as the ability and willingness to co-operate; marketing skills; individual and collective learning capabilities, communication with customers, networking and alliances, and the ability to meet specific demands. Thirdly, innovation is embodied in a set of interrelated institutions: universities, firms, the government, intermediate agents, and laws. These institutions, together with firms and their entrepreneurial attitudes, define the National Innovation System, which is very different across countries and co-determines the differences in productivity and growth.

(9) The innovation process results in new products and new techniques. To a certain extent, some of these results are public goods. This means that not all of the innovation output can be appropriated exclusively by the innovator. If users are non rival (implementation by one user does not reduce the utility of others), it is socially optimal to permit the proliferation of "ideas". However, the innovator does lose incentive to innovate. Therefore, most models and consequently most economists strongly support the subsidisation of research and legally defined, but not overly restrictive rules for patenting.

*The concept of a Knowledge Based Economy*

(10) The concept of a knowledge based Economy imparts the message that knowledge defines the competitive edge. The Knowledge Based Economy is an extended version of the concept of the information society or the digital economy, which focuses on information and ICT. Knowledge is broader than information in general, and could be defined as codified information. Knowledge is cumulative and interactive, created by combining past knowledge. The concept of the Knowledge Based Economy is broader than that of ICT, or that of a digital economy, since skills, competencies, and capabilities are put into focus. We distinguish between three bodies or elements of knowledge: science-base, skills, and technologies (of which ICT is one specifically important one). Rather than presenting a full scoreboard on the indicators of the Knowledge Based Economy, we show that the share of people with secondary and tertiary educations is increasing and that the number of research related jobs is rising. Patenting is an output indicator which reflects how research is combined with knowledge. It is a signal of country performance according to different technologies. Furthermore, patent data reveal that biotech and ICT are among the fastest growing fields of inventive activity. The share of electrical patents (in which ICT is classified) now outnumbers chemical patents and is challenging the lead of mechanical inventions. It can be demonstrated that relative positions in patenting and increases in market shares correlated in the nineties.

(11) The upshot of this is that Europe is making progress towards becoming an economy which is more oriented towards innovation and knowledge. Country differences are declining, while lagging countries are catching up – with the exception of the share of tertiary education, where some leading countries have increased their shares significantly. The quality of human capital is increasing, research outlays are on the rise, and output from the innovation process is being shared more and more often. Many countries have schemes for vocational training; long term contracts favour on-the-job training; firms are investing in education and life long learning; and policies to reduce gaps in skill levels are working positively in the same direction. The European Union has formulated its intention at the Nice summit in 2000, to challenge the USA by making Europe the most competitive, knowledge based economic area.

(12) Policies promoting the Knowledge Based Economy support education, improve innovative capabilities and activities, and the diffusion of technologies. The major difference to traditional approaches is the underlying systemic view:

The following main areas of policy measures can be distinguished:

- Increasing human skills; e.g. by fostering polytechnics, bachelor’s degrees, and life long learning
- Enhancing the capabilities of firms; e.g. changes in the tax treatment of R&D
- Special provisions for small and medium sized firms; e.g. by fostering technology start ups
- Strengthening regional competencies; e.g. by encouraging clusters and networks, and science policy links
- Securing world class research in science; e.g. increasing the mobility of human resources
- Encouraging start-ups and technology based firms

Most of these policy lines are not new. However, the design and implementation of these measures reflect that the perspective has changed. Innovation is understood as an interactive process based on knowledge and the innovative capabilities which individuals, firms and regions have attained.

*The size and impact of ICT*

(13) Information and Communication Technology is currently exerting significant influence on the growth of output and technology. The USA has a considerable lead in this form of technology. The share of ICT expenditures in US GDP is one third larger than that of Europe. There is no clear tendency indicating that the gap would become smaller if we compare the USA with the European Union.

- The absolute difference in expenditure shares between the EU and the USA is remaining approximately constant; the relative difference, which accounts for higher shares in later years, is declining.
- Europe's shares in production, investment and in the world market are less dynamic than those of the USA.
- Europe is leading in mobile phones, creating an opportunity for a competitive advantage in mobile devices in general. The second lead – that in expenditures on telecommunication - is, as any cost indicator either a signal for excellent infrastructure or an indicator for high costs
- The Scandinavian countries, the Netherlands and to a certain extent the UK and Denmark, are matching the USA in several indicators. However, the larger countries (France, Germany, Spain, and Italy) are far behind the leading European countries, and are not catching up with the USA in ICT expenditures relative to GDP.

- The differences between the USA and Europe in the use of PCs and internet is narrowing; nevertheless, the gap in expenditures on information technology proper is widening.

(14) The impact of ICT on growth and productivity has been estimated according to the growth accounting approach. This is a difficult exercise, since it involves the estimation of capital stocks, of real prices, and the elimination of the cyclical component. The method to calculate the growth impact is rather mechanical, as the share of ICT in investment together with its growth define the impact. Despite all these problems, the mainstream results are very close and instructive. In the USA, ICT investment contributed 0.8 % – 1.0 % of output growth in the second half of the nineties, in comparison to 0.4 % – 0.5 % during the first half. Parallel to the lower ICT expenditures in Europe, the impact of ICT on output has been estimated at 0.5 % to 0.6 % for the second half of the nineties, following 0.3 % – 0.4 % during the first half. This results in a "forgone growth premium" of about one third of a percentage point for the late nineties. Again, parallel to expenditure levels, Sweden, Finland, and the UK are enjoying a growth contribution of ICT, which is within the range estimated for the USA.

(15) The productivity enhancing effect of ICT consists of three components. At first place, ICT investment has enlarged the capital stock, thereby increasing labour productivity (capital deepening). Secondly, productivity in the sectors producing ICT increased, contribution to growth of multi factor productivity. Productivity jumped upwards in the electronic and computer industries, specifically when output is measured in real terms (according to a method which holds the characteristics of ICT goods, such as capacity or speed, constant). Thirdly, spillovers from the sectors producing ICT to the sectors using ICT, has increased multi factor productivity in the latter. Spillovers are difficult to measure, as is productivity in the service sectors, and cyclical effects also intervene. But a growing number of studies confirm that ICT also contributes significantly to productivity growth in the sectors using ICT, which is seen as the factor critical for the upcoming of a "New Economy" and for the continued impact of ICT on growth.

(16) Sceptics maintain that the impact of ICT may be overestimated, specifically since the adjustment costs necessary to realise its potential and the organisational costs involved in implementing the technology may be high. Advocates of an even greater impact of ICT hint at the fact that the increase in value for the consumer ("consumer surplus"), enabled by the wider range of choices provided (independence of location, sudden increases in information, etc.), are not adequately reflected in the data. This may be specifically the

case in financial sectors, in which measured productivity does not increase, while choices, options, convenience and the independence of time have increased dramatically. However large the exact magnitude of the new technology is, the upshot of the available results is that ICT makes an important contribution to the growth of output and productivity and that this impact is smaller by about one third in Europe as compared to the USA.

*ICT accounts for one third of business sector investment in Finland and the USA*

(17) There has been a fundamental change in the nature of investment, as it has moved away from traditional physical investments in plant and equipment towards ICT. In the USA, 32 % of business investment is now directed towards ICT. ICT investment includes hardware, software and infrastructure. It is much higher in the USA than in the large European countries, where it also increased strongly, and is now estimated at 16 % in total investment. Finland excels with an ICT share of 36 % of business investment. Dividing ICT investment into its components reveals that in the USA, half is software, while IT and communication equipment each account for one quarter. In the European countries, communication equipment is the largest component, followed by software and IT equipment.

*Growth differences across countries increase for the total economy and industry*

(18) Differences in macroeconomic growth across countries became more clearly visible during the nineties. This observation is independent of whether actual growth is taken into consideration, or whether hypothetical growth after eliminating cyclical differences is estimated ("trend growth"), or whether growth of manufacturing is measured . Average growth over the decade was 3.3 % for the USA, but amounted to only 1.9 % in Europe. European growth was stronger in the second half of the decade than in the first, but the difference widened relative to the excellent 4.3 % rate of the USA in the second half. Of the European countries, only Ireland was able to grow faster than the USA, although Finland joined Ireland during the second half of the decade. For manufacturing, the picture is about the same, with the exceptions that (i) the growth difference narrowed during the second half of the decade and (ii) there are four countries which were able to match US growth in the nineties, namely Ireland, Finland, Austria and Sweden.

(19) In contrast to growth, differences in labour productivity did not widen during the nineties. As a high growth country in Europe, Ireland (like the USA) had a large pool of unemployed who were willing to enter the workforce. Several low growth countries had to maintain or regain competitiveness by shedding labour. The higher growth in the USA

was strong enough to increase (accelerate) productivity for the total economy by one percentage point and for manufacturing by two percentage points (in the second half of the decade vs. the first). Growth was too slow in Europe to accelerate macro productivity growth; on the contrary GDP growth per employee decreased, partly due to policy efforts to decrease unemployment. For manufacturing, productivity upheld a growth rate of about 3 % in Europe. An acceleration in manufacturing productivity took place in nine countries, and in Finland was even stronger than in the USA.

(20) Multi factor productivity, which relates GDP to all its inputs, not just labour, accelerated in the USA and decelerated in Europe during the nineties. Within Europe, it accelerated in Finland, Sweden, and Denmark, and maintained its extraordinary growth in Ireland. All the countries in which it accelerated enjoyed high growth in output and labour productivity. While the acceleration in the USA and the overall deceleration in the European Union are robust in many estimates, the difference in MFP growth is very small, since the USA started from a lower growth in the eighties. And, as for the impact of ICT reported above, we cannot definitely rule out the possibility that the trends are influenced by differences in the length and dynamics of the business cycle. Nevertheless, in light of the trends on sectors and drivers, the evidence increases that there are systematic forces behind the different trends.

*Factors likely to explain long term growth (growth drivers) are related to performance differences*

(21) The growth of manufacturing in the EU countries is shown to be related to those factors suggested as relevant by economic theories ("growth drivers"): research, human capital, knowledge, capabilities and the ability to use modern technologies (specifically ICT ). However, the competitive pressure has increased productivity in slow growth countries, as well as in countries with high shares of mature, capital intensive industries. The nineties were also a period of severe external shocks, including the currency crisis during the first half, and the Asian crisis during the second. European integration went an important step beyond the Single Market, into the Monetary Union. And, specifically important to country differences in productivity, the individual countries pursued different strategies in their efforts to decrease high unemployment. The sizes of the budget deficits which had to be cut in order to fulfil the entry criteria for the Monetary Union also varied noticeably. These factors make it difficult to carve out the exact influence of innovation on growth in output and productivity, since productivity growth depends (1) pro-actively on innovation, (2) passively on productivity increases and labour

shedding to regain competitiveness and (3) on policies to spread employment and to cut deficits.

(22) Production growth and - to a lesser extent - productivity increases in manufacturing across countries is closely related to indicators of firm capabilities, such as innovation expenses, shares of co-operative research, and the continuity of research It is also related to innovation expenses, which include expenses for licences, marketing, training, thus incorporating – additional to research expenditures- outlays necessary to absorb knowledge which is in principle available but not used by all firms (hinting at competitive or strategic advantages of firms). Country growth in manufacturing relates to indicators of human capital, ICT use, and structural change between industries. The last indicator, the speed of change of industrial structures, could proxy policy forces to either promote change or to weaken its effects. We use the notion "relate to", since many intervening variables are left out when we demonstrate the connection, and since correlations do not inform us about the direction of causality. More than the statistical numbers, it is the relation of the indicators chosen to the factors proposed by the theoretical consideration, which builds our confidence regarding the underlying forces.

*European countries are converging, however very slowly*

(23) Indicators of the forces behind country performance reveal a distinct, although not really fast convergence within the European countries. This convergence is mainly driven by the improved performances of the lagging countries. The bottom five – defined per indicator according to the individual position of each country in the early nineties – have improved their positions in 16 of 20 indicators. The speed of catching up has been considerable for the indicators reflecting the use of information technology, indicators of secondary education, and the majority of research indicators. In expenditures on telecommunication equipment, the countries which were lagging in the early nineties are now partly above average, reflecting heavy infrastructure investment. Catching up is evident for the share of working population with tertiary education, in skill intensive industries and in patents. For some of the more demanding growth drivers (resources in science and technology) the convergence within Europe has not been established.

*Small countries take leading positions for several growth drivers*

(24) Sweden has been enjoying a rather persistent lead according to many indicators; Finland, Denmark, and the Netherlands are pushing upwards from the middle ranks. The top five countries – chosen individually according to their positions within a specific growth

driver - are increasing their leads in patents, education, the research intensity of manufacturing, as well as in technology driven industries and in expenditures on information technology, reflecting the strong positions of Finland and Sweden in research and ICT. In PC and internet use, and in secondary education, the relative lead decreased, reflecting increasing market saturation in the leading European countries and the catching up of the followers. In general, there is however a strong persistence in the leading countries. Sweden, which was among the leaders for sixteen indicators at the beginning of the nineties, was ranked in the top 5 for all but one indicator at the end of the nineties. Finland increased its top positions from twelve to fifteen, Denmark from ten to eleven. The larger countries are losing ranks: Germany lost five of its thirteen top 5 positions, the UK seven out of fourteen, and France also lost on average in rank. The Netherlands are well placed according to the drivers for growth .

*According to many indicators, the USA is holding on to its foremost position; cyclical forces may have fostered its lead*

(25) The USA is better placed according to 14 of 16 drivers of growth, for which comparable data are available. According to the most recent data, Europe is leading only in mobile phones and expenditures on telecommunications. Europe is catching up with the USA in secondary education (the indicator of which measures the share of secondary education in an older age group vs. a younger one) and in the use of internet and PCs. The gap with respect to US figures widened in IT-expenditures and in the share of ICT industries in production. Europe is not catching up in shares of technology driven industries and in shares of patents per resident.

(26) One of the reasons behind Europe's failure to catch up significantly has to do with the insufficient performances of large countries. Germany, France, and the United Kingdom all decreased their research efforts by one tenth relative to GDP, and are not excelling in information technology. Although the large countries are maintaining their positions as centres of research in absolute amounts and relative to GDP, they are being overtaken in relative figures by smaller countries. The gap in research inputs between Germany, France and the United Kingdom on the one hand, and the USA on the other, is growing in absolute and relative figures.

*The leading European countries are catching up, reaching par and even forging ahead*

(27) The picture is definitely better for the leading European countries. The top 5 European countries have improved their positions relative to the USA in 12 of 16 indicators. They

surpassed the USA in patents, internet use and the share of skill intensive sectors (in addition to mobile phones and telecom expenditures, where Europe as a whole is ahead). The areas where the top 5 European countries are not improving their relative positions is patents, the share of IT expenditures and the share of ICT industries in production. Taking a look at the average performances of Sweden, Finland and Denmark, reveals that these top countries improved their positions and are successfully contesting the USA lead for several industries.

(28) As far as convergence is concerned, the overall results indicate that it is given for the leading European countries, but not for Europe as a whole. There are some signs that this may simply be a question of time. Productivity in sectors producing ICT increased late in the USA, and is now growing fast; during recent years, Europe has also been enjoying this trend. The diffusion of technologies in Europe was hindered by national barriers and high transaction costs, but should now accelerate. Some of the indicators used are dependent themselves on profits and on the cyclical position. The USA enjoyed a stable period of growth and was able to invest in research and ICT continuously, while Europe suffered two downturns during the nineties. If Europe grows faster during the upcoming US recession, the trend may reverse. However, waiting for the realisation of this scenario is not enough; leading positions often feed further investment and establish a "path dependency" of growth and productivity, whereby past growth feeds future growth.

*Productivity increased most strongly in technology driven industries, capital intensive sectors restructured*

(29) The strongest increase in productivity occurred in technology driven industries. In these, research intensity, as well as innovation outlays in general, are particularly high, thus establishing a correlation between innovation and growth across sectors and industries. However, specifically in Europe and in the first half of the nineties, productivity also climbed rapidly in capital intensive industries. And labour intensive industries managed in some countries to remain competitive by increasing productivity and quality, as did mainstream industries in which Europe is specifically strong. Nevertheless, the acceleration in productivity between the first and the second halves of the nineties was mainly driven by the technology intensive sector. The smallest increase was in sheltered sectors, as for example the food industries or construction materials.

*Productivity and research intensity are related significantly for the EU and the USA*

(30) Productivity growth and research intensity are related across sectors. Research drives productivity growth at the EU level. Electronic equipment, instruments and computers are sectors with high research intensities and high increases in productivity. Additionally, chemicals and motor vehicles are ranked in the upper third of sectors, with respect to research intensity and productivity growth. On the other hand, leather and apparel, as well as the food industry have low levels of research intensity and low productivity growth. Textiles combines low research and low production growth, and although productivity is about average, competitive pressure is leading to decreasing employment

*Technology impact seems to be stronger in the US*

(31) In the USA, manufacturing excelled in several respects during the nineties. Growth was higher, and productivity increased more strongly, accelerating faster than in Europe, specifically if we extend the data up to the very recent past. The impact of technology seems to be stronger or at least more direct than in Europe: the share of technology driven industries has been higher historically, the productivity lead - however difficult to measure – has also been the highest. Furthermore, these industries are dominant in the hierarchy of productivity growth. In the USA, many high tech industries, and the group of technology driven industries as such, enjoyed double digit annual growth rates in labour productivity during the second half of the nineties.

*Growth pattern is increasingly similar*

(32) The industry patterns of growth for the USA and Europe are similar but not completely the same. This is also true for individual European countries. We have drawn country profiles, illustrating in which industries countries are specialised, how they perform according to indicators relevant to future growth, what contribution is made by innovative activities, and how policy tries to increase growth and competitiveness. Once all the differences across countries have been revealed, we can venture to the tentative conclusion that policies and performance seem to converge to a certain extent, although at a very slow speed and with many trials, experiments and errors.

*Research efforts pay off at the firm level*

(33) The impact of innovation on the growth of output and productivity has been illustrated at the country level, for manufacturing and its sectors. However, decisions regarding innovation are made at the firm level. Using a data set for 2,167 large European and US

firms reveals a significant impact of research and development on output. More specifically, the rate of return on R&D is estimated at 12 %, implying that one Euro spent on research and development increases output by 12 cents (permanently). The impact on output seems to be larger in the US, and although this result is not significant from a statistical point of view, the impact seems to increase over time (again, more strongly in the USA). Spillovers are evident in some specifications, while in other specifications, corrections for the structural differences of firms which report, and those which do not report spillovers, are not significant. This could be due to the elimination not only of the structural characteristics but also the impact of spillovers.

(34) These results alone would not suffice for sound evidence, since the data set has, as usual, been collected for investors and not for studies on the impact of research. However, they lie within the range of a large number of studies available for different data sets, for different countries, using different approaches. Summing up 50 studies on the rates of return, the median is 20 % for all studies and 27 % for all with significant results. Our results are therefore slightly on the lower bound, enabling a cautious assessment of the impact of research and development. In a mega framework, we compile 50 comparable regressions for different countries, using various approaches to determine on what the rate of return depends. The results are surprisingly robust: the impact of research on output and productivity seems to be lower in Europe than in the USA, but this is significant only for research elasticities, not for the rate of return to research. Deducting labor and capital inputs to the research input from total capital and labour input (i.e. eliminating the double counting bias) increases the measured impact of research.

(35) The panel used is comprised of 1,365 European firms, of which 453 report research expenditures. Figures on reported research are much more complete for US firms, as 581 of 833 firms supply figures; the provision of this information is demanded by law in the USA. The European firms which report figures, have a research intensity of 3.6 %, while US firms spend 4.8 % of sales on research. Research expenditures grew by 4.1 % in Europe and by 7.8 % in the USA, - the largest difference in recent years.

## Towards policy conclusions

(A) Europe needs high growth, if it is to achieve its long run objectives. Lowering unemployment, regaining fiscal stability, keeping down inflation, and securing the pension system would all be easier with a higher long term growth path. Closing the gap to the USA in growth and productivity and moving closer to the technology frontier will be important to long run competitiveness and will increase Europe's ability to shape cutting edge technologies according to economic needs and the goals of society.

(B) Europe will be able to close the gap relative to the USA only if it at the same time (i) increases its efforts in activities which determine the technological lead, (ii) increases the diffusion of technologies and (iii) builds upon its existing strengths in innovation, capabilities, skills, and mainstream industries. Part of the higher growth and acceleration of productivity in the USA during the nineties may be due to cyclical effects, shocks which had a heavier impact on Europe, lagging liberalisation in Europe, and the use of ICT. However, this is not comforting, since the leader can hold onto lasting advantages. A fast growing country can reinvest profits, stimulating growth drivers anew, and consequently stabilise high growth rates.

(C) The first part of the strategy demands increases in research and expenditures. Despite all the attempts to foster links between universities and firms, to increase applied research and providing capabilities which businesses demand, the importance of basic research and high levels of education should not be underestimated. The USA has taken and maintained its lead in ICT and in the life sciences partly through its strong position in and supply of top universities and the financing of basic research, often promoted by government programs. These programs are necessary in Europe at the national and community levels. Open tenders, benchmarking and first class evaluations should enable the competitive allocation of funds for basic research. Mission-oriented programs (health, biotech, ICT, and the environment) may help to close the research gap, to create spillovers from universities to firms, and at the same time enable the fulfilment of social goals at low costs and with a large variety of choices.

(D) Increasing the speed of technology transfer and the use of spillovers is the second part of such a strategy. It would help to increase growth even for only a given level of basic research. Increasing education; making labour, firms, and management more mobile; accelerating liberalisation and the implementation of single market initiatives; and internationalising research and finance would all be helpful along this line.

(E) The USA lead may be overestimated, since cutting edge technologies, formal research, and high levels of education all play specifically important roles in the USA. On the other hand, in Europe, mainstream industries, skills, on-the-job training, and technology embodied in machines and inputs, and incremental innovation are more important. Europe is well positioned in the higher quality segment in many industries – as was demonstrated in last years' report. The importance of capabilities in explaining growth is another hint. Building on existing strengths - as the third element of the strategy- includes the vigorous introduction of additional educational programmes, specifically: vocational training, increasing skills in ICT, bachelor’s degrees, polytechnical training, and raising the quality standards of life long learning. Policies which promote the knowledge based society have been addressed above; programmes supporting skill upgrades are reported in Annex 1, policy measures proposed in the OECD-Growth Project in Annex 2.

(F) National innovation systems are different, and so are policy measures. Despite their similarities and the co-ordination of European policy, European countries chose different strategies. Sweden and Finland succeeded to shift attention towards research and telecom in very difficult economic situations. This was done not only with the help of excellent firms, but also by consistently implementing the tools of the information society. They increased the science base in government, institutions, and regions, while at the same time cutting high budget deficits. Denmark and the Netherlands spread employment to reduce unemployment, made work more flexible, and simultaneously stimulated technology and research (double strategy). Such successful strategies seemed not to have been feasible in larger economies, where fighting unemployment and budget deficits could not be combined with strategies to increase R&D and attain excellence in ICT production and diffusion. The lagging countries were partly successful in attracting foreign capital and in increasing their own skill bases. Productivity and growth in less open industries was insufficient, as were the growth rates of small, indigenous firms clustering around the subsidiaries.

(G) As some smaller European countries, like Sweden, Finland and Denmark show, efforts to boost the "drivers of growth" succeed in increasing growth and competitiveness. Part of these success stories reflects the determination to specify demanding goals and to follow them by means of a set of initiatives. These are constantly monitored and implemented through a consensus of firms, employees and policymakers. Learning from the best European examples is as good a stimulus for increased efforts, as is the evidence that differences in performance can be explained by growth drivers and that the USA has a persistent lead in many of them.

# Annex 1: European skills shortage in ICT and policy responses

**HANNES LEO[153]**

## A1.1 Why has demand for ICT skills increased in the past?

The shortage of ICT (information and communication technology) skills is the direct product of the development and diffusion of new digital technologies. Two intermingled but still separable trends have to be taken into consideration when analysing the impact of new technologies on the demand for highly skilled people: first, the long-term trend towards a greater share of university and college graduates in the economy which is most pronounced in sectors that are among the first users of digital technologies (computers, etc.); second, the more recent increase in demand for ICT skills which is related to the expansion of telecommunications, Internet and new media.

The long-term trend of a steadily growing share of university and college graduates in the economy can be observed at least since the Second World War. Higher shares of "skilled" workers within industries are apparent in most OECD countries (see *Berman – Bound – Machin*, 1998) and are widely associated with skill-biased technological change and the globalisation of the economy. Econometric and case studies suggest that the relative utilisation of more skilled workers is positively correlated with capital intensity and the implementation of new technologies both across industries and across plants within industries (*Autor – Katz – Krüger*, 1998).

The recent spread of computers and computer-based technologies has further accelerated this trend. Autor – Katz – Krüger (1998) find evidence for the USA 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 has resulted – at least in the USA – in increasing wage inequality and growing educational wage differentials. It is important not to simplify the relationship between the introduction of computers and demand for "skilled" workers. Several authors (e.g. *DiNardo – Pischke*, 1997, *Haisken-DeNew – Schmidt*, 1999) stress that the causal relationship between computer use and demand for "skilled" workers is not straightforward but rather entangled in

[153] I would like to thank Karin Städtner for helpful research assistance.

complex innovation processes which involve increased computer usage as well as, and more importantly, changes in organisation, production processes, etc.

The relationship between skills upgrading and the introduction of new technologies is supported by studies which analyse the employment impact of innovative activities. Innovations tend to increase overall demand for labour but simultaneously lower demand for unskilled labour (see *Leo – Steiner*, 1994, *Leo, et. al.*, forthcoming).

However, indicators of the use of new technologies (e.g. PCs), innovations and schooling attainment as a proxy for skills and competences may not capture some of the fundamental changes behind the skills upgrade in the economy. Howell and Wolff 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". Therefore the presumption that educational attainment is synonymous with skills requirements in the workplace does not hold.

In their analysis of the situation in the United States, they "attempt 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 skills 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, in which mechanisation is found to be linked to the deskilling of production workers and to the growing share of managers and supervisors. "With the transition to production methods based on information technologies, it is perhaps increasingly true that it is technical change, not mechanisation *per se* that increases the demand for cognitive skills" (*Howell – Wolff,* 1992).

This line of argument is supported by research on the impact of investment in ICT (*Bresnahan – Brynjolfsson – Hitt*, 1998 and 1999). Firm-level data suggest that ICT use is correlated with increases in the demand for various indicators of human capital and workforce skills. ICT use is also correlated with a pattern of work organisation involving more decentralised decision-making and greater use of teams. Increases in firms' ICT capital stock are associated with the greatest increases in output, which also have high levels of human capital or decentralised work organisation, or both. These empirical results are emphasised by a survey of managers which found that ICT is skill-increasing, and this tendency is particularly pronounced in high human capital, ICT-intensive, and decentralised firms. Bresnahan, Brynjolfsson and Hitt 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 long-term increase in the share of highly skilled professionals and the recent shortage of IT-skilled workers are of course intermingled with technology change as a driving force behind these developments. The long-term trend was matched by a constant increase of output from the educational system. In contrast, the short-term surge in ICT investment in the 1990s led to a constant widening of the ICT skills gap which was broadest in the first half of 2000 and was not accompanied by an increase in the output of the educational system.

The increasing use of ICT goods and services is motivated by high returns on investments which are generated either by technology itself or by changes in the (regulatory) environment. The key causes for the huge increase in ICT investment can be best illustrated by evidence from the ICT sector itself. In the past two decades, five broad developments shaped the demand for ICT investments and consequently for labour and skills in the ICT sector:

1. Digitisation: The number of employees of public telecommunications operators (PTOs) has been falling since the beginning of the 1980s (–8.5 percent between 1982 and 1995). This development is especially apparent in countries which were early in liberalising their markets (New Zealand[154], Japan, and the UK) but also affected countries where liberalisation is in progress (Ireland and Greece). The early onset of this downward trend in employment, and the sizable employment losses in countries with a slower pace of market liberalisation in the telecommunications sector show that it is digitisation of telephony rather than competition which leads to job loss. Liberalisation does play a role, however: it creates incentives – reinforced by outsourcing and privatisation – to invest in new technologies and to develop new organisational structures in order to save resources. In due course, lower skilled personnel which had been necessary for the operation and rollout of an analogue network were set free. Furthermore the skills mixture of former monopolists

[154] A large part of the decrease in employment in Telecom New Zealand (TCNZ) took the form of shifting operations to newly established enterprises, steps that had been taken by other providers in earlier reform phases. The total decrease in jobs is thus lower than the numbers suggest. This development is important in other respects as well. TCNZ's process of restructuring was aimed at catching up with other PTOs. In 1994, the number of mainlines per employee was equal to the OECD average of 1992.

changed dramatically: not only marketing skills but also skills necessary to handle digital equipment were in huge demand. Although the overall employment performance of former monopolists in the telecommunications sector is negative, these companies still recruited a large number of highly skilled persons.

2. Liberalisation: The steps towards liberalisation taken so far have sought to create a market for terminal equipment, and telecommunications services, to separate regulatory and commercial activities, to facilitate free access to networks and services, and to create competition in the mobile telecommunications and infrastructure market. Liberalisation in the European telecommunications sectors started on its final phase on January 1, 1998 when the voice communication monopoly disappeared and competing telecommunications infrastructure and service providers entered the market. Since then liberalisation has not only forced former monopolist to introduce cost-saving innovations and new services but has also created a huge number of new competitors: In the European Union alone, 1237 firms have since launched public telecommunications networks. This strong start-up activity has of course intensified demand for skilled labour (*EC*, 2000).

3. Year 2000 hype: The Y2K problems created huge demand for software firms as businesses feared that their IT systems would stop working at the turn of the year 2000. Though the change of date turned out to be no major problem – perhaps because of the general awareness and large investments made before the event – it certainly created demand for specialised software firms and strengthened competition for skilled labour in this area.

4. Internet revolution: The Internet inspired a huge number of start-up activities. Europe has seen a strong upward trend in early-stage investment in high-tech companies over the past five years, and the trend continues unabated. The amount of early-stage investment rose to €3 billion in 1999, more than ten times the amount invested five years ago. In 1999, investment in the technology sectors increased by 94%, and capital committed to start-up ventures rose by 89%. Though this is still behind US levels, the trend toward venture capital remains strong. The increase was fuelled by the huge optimism in Internet start-ups which continued until April 2000. Although venture capitalists are nowadays more risk-conscious, the amount of available capital is still rising. The firms created by this investment of course were all scheduled for rapid growth and consequently hired a large number of skilled personnel.

5. The spread of the Internet and new media was not limited to a small number of highly specialised firms but affected the whole economy. Firms have been investing in their

Internet presence, B2B and B2C activities and thus created additional demand for ICT-skilled labour. It is generally assumed that three quarters of ICT experts work in the ICT sector itself and one quarter in the rest of the economy. If this proportion continues to hold, then demand from the non-ICT sectors of the economy is not dramatic but adds to the existing shortage of ICT skills at a critical point in time.

All five trends cumulated between 1998 and mid 2000. Digitisation, liberalisation and the Internet revolution created strong demand for ICT skills, emanating from a rather small segment of the economy but increasingly spreading throughout the economy.

As supply from the educational system is virtually fixed in the short run, the shortage of qualified IT experts was significantly inhibiting expansion of this sector. Yet there is a positive side to the skills shortage: firms which were not able to recruit desired personnel had to invest in productivity-enhancing management and technology strategies, thus making firms more efficient and less vulnerable to supply shortages on the labour market.

In April 2000 industry dynamics underwent a fundamental change. Technology and Internet stocks suffered massive devaluation on the stock markets as expectations for future profits were substantially lowered. Internet start-ups had to scrutinise their business models and efficiency of operation to secure further funding. Some of them even went bankrupt.

The overall downswing of this market not only shattered the “constant growth without business cycle” myth of the “new economy” but also led to significant layoffs in the ICT sector paired with low recruitment activity. Though not supported by surveys, industry reports of the past months create the impression that the skills shortage has almost vanished. Given the still positive long-term perspectives of the sector, this seems to be only a temporary relief of the problem, i.e. the shortage will be back once the business cycle turns the other way as there seems to be no oversupply of ICT skills but – at best – a balance between demand and supply.

## A1.2 Estimates of IT skills shortages in Europe

The ICT skills shortage is felt in all European countries, the USA and Japan. Studies to quantify the number of missing ICT qualifications are usually conducted at country level. Currently there are only two studies which focus on the ICT skills shortage and are comparable among European countries. Both were done by IDC, the earlier one (*IDC*, 2000) on behalf of Microsoft, the second for EITO (*EITO*, 2001). Both studies present very detailed estimates of the gap between ICT skills demand and supply even at rather disaggregated levels. Their major drawback is that the methodology applied to estimate the ICT skills gap is not described in sufficient detail to allow identifying the variables which drive demand for and supply of ICT skills.

Before going into details, some of the possible problems associated with estimates of the ICT skills gap need to be discussed:

1. ICT skills shortages can be measured in different ways, e.g. the number of vacant jobs in the economy, the number of jobs created in the past or in the future, the number of people with specific qualifications demanded. The outcome of the estimates depends significantly on the variable which is measured in the study, as does its relevance for policy makers.

2. The size of the skills gap depends on the scope of the study, e.g. the part of the economy which is analysed. Several studies concentrate on the ICT branches of the industry as these were the first to feel the skills shortage. Of course, the shortage has since spread throughout the economy which renders it increasingly difficult and more tedious to come up with an estimation of the skills gap for the whole economy.

3. The supply of people with the required skills is not easy to measure. First of all, statistics on the output of the educational system have to be analysed at a very disaggregated level. This task demands detailed knowledge of the educational system. It is even more complex to measure the output of re-education or training activities as the market for these services is highly segmented and heterogeneous.

4. Any estimate of future skills demand is highly risky as the overall business cycle and industry developments impact on labour demand. This is even more true for areas like ICT production and consumption where technological change is rapid and the organisation of commercial activities changes at a similarly fast pace. Businesses themselves have problems to forecast their demand for specific skills over a period of more than six months. Consequently, medium term-forecasts are prone to errors.

Given these problems attached to measuring ICT skills shortages, estimates discussed in this section should be viewed rather as broad indications of major trends in this area and not as accurate projections of shortages.

In the following section the results of both IDC studies will be discussed at some depth. The first study will be analysed in more detail as if offers data on all Western European countries. This information is lacking in the second study, or to be more precise, detailed information on the country level was supplied only for France, Germany, Italy, Spain and the UK. This change in the aggregation of country information renders the results obviously less relevant for countries not included.

A simple framework is applied in analysing the results of the IDC studies. First, information on demand, supply and shortage of ICT employment will be expressed as a share of total employment in all countries surveyed. This seems to be a better benchmark for indicating the magnitude of the skills problem in Western Europe. Second, a correlation analysis is performed to get indications of which variables impact on the demand, supply and shortage of ICT skills. Two sets of indicators are included in the correlation analysis: indicators on the use and production of ICT goods and services and indicators on the education system. The correlation analysis is done only for the first study, which has information available at country level.

The next chapter compares the results of the ICD studies with studies performed at country level. All problems related to an estimation of the skills gap outlined above similarly apply when trying to compare different studies. Therefore this chapter calls for a co-ordinated approach among EU member states rather than each member state following its own route. Finally, a number of possible actions to combat the skills gap is outlined. In addition to basic models to counteract the skills problem, some initiatives in member countries will be described for illustrative purposes. As information on policy responses to this problem is given in all countries at different levels and by different actors, it is almost impossible to present a complete survey.

### *A1.2.1 IDC estimates for Microsoft*

In the first study, IDC concentrated on people 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). IDC expects demand for IT skills to grow from approximately 9.47 million IT professionals in 1999 to 13.07 million in 2003, while supply is set to grow from 8.61 million in 1999 to 11.33 million in 2003. Consequently, the Western European skills shortage is estimated to reach 1.7 million IT professionals by 2003 (13% of demand).

Demand for ICT professionals is rather heterogeneous among European countries. This is obvious when demand is expressed as a percentage of total employment, which can be interpreted as a measure of the magnitude of the problem in each country (see Figure A1.1). Overall demand for ICT specialist amounts to 5.7% of employment in Western European countries but is almost at twice this level in the Netherlands, Belgium, Sweden and – though slightly lower – Austria and Switzerland. Somewhat surprisingly, demand is below this level in the UK, Finland, Ireland and Norway. The demand for skilled ICT personnel is not strongly related to ICT spending and the size of sectors producing and using ICT (see correlation analysis below). Consequently, Scandinavian countries – with the exception of Sweden – which are among the big investors in ICT are obviously not confronted with above-average demand for these qualifications.

### Box A1.1: IDC's Methodology to Determine the IT Skills Shortage

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 needed 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 investments, is analysed by company size band for each country, generating a picture of demand for skills over the years.

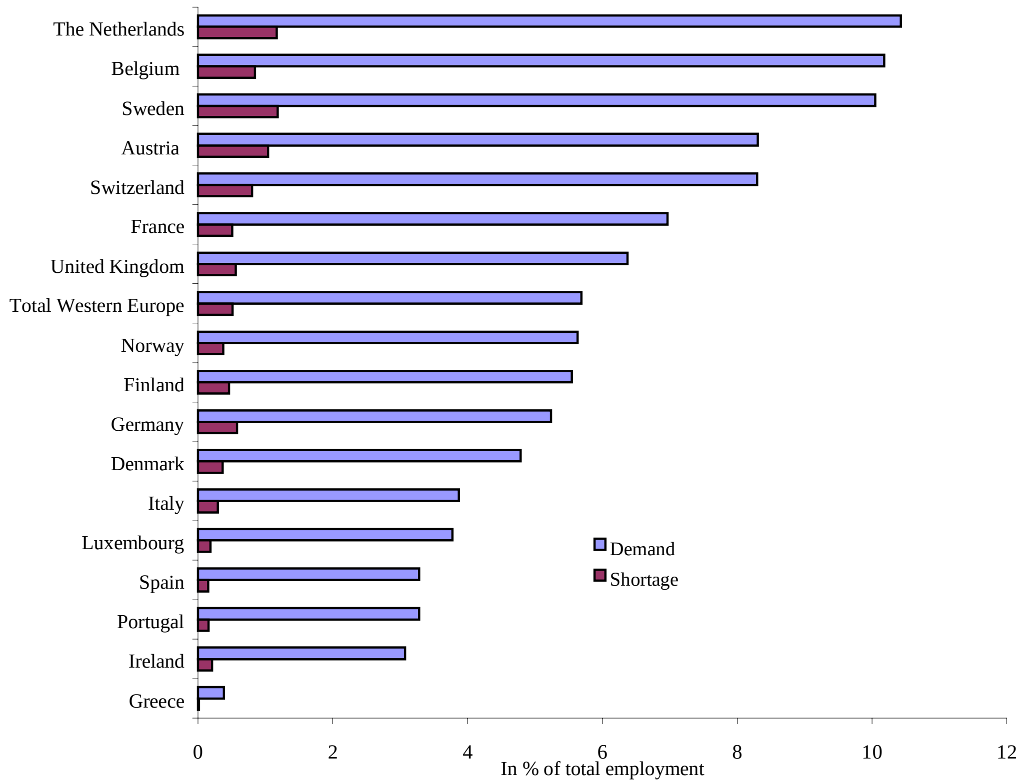
Validation of this demand profile is performed by investigating trends among "intermediaries", typically recruitment agencies. IDC estimates that 40–70% of vacancies (depending on the country) are filled by these intermediaries, and trends in their activities provide valuable validation of the demand 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 with administrators with insights on intake trends, evolution of courses and the subsequent employment tracks of graduating students. This data has been used to compile baseline trends in the supply of fresh 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 reskilling of workers from other industries, for example the defence and manufacturing sectors.

*Source*: IDC 2000.

The shortage – when expressed as percentage of total employment – is not as alarming as the estimates in absolute numbers. In Western European countries it ranges from Greece, where supply and demand are balanced, to the Netherlands, where it is set at 1.2% of total employment. The magnitude of the skills shortage is closely linked to the level of demand and supply for ICT-skilled personnel expressed as a percentage of total employment. From Figure A1.1 it follows that the skills shortage should be most severe in the Netherlands and Sweden, followed by Austria, Belgium, Germany, UK, Finland, France, Denmark, Italy, Ireland, Luxembourg, Portugal, Spain and Greece.

**Figure A1.1: Demand for and shortage of ICT skills as percentage of total employment, 1999**

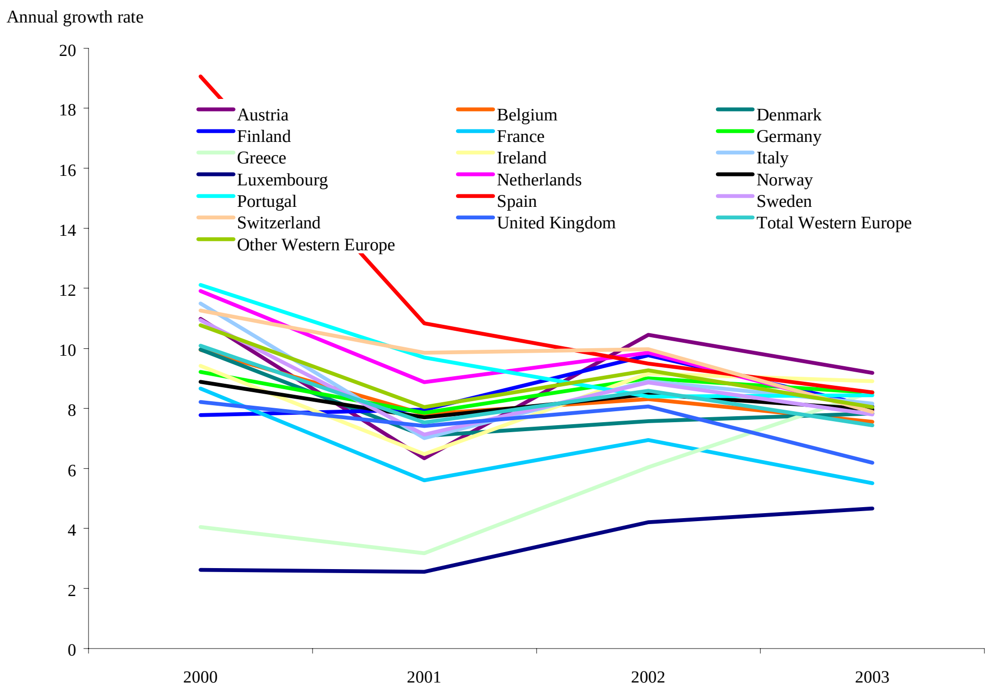



*Source*: WIFO calculations using IDC, 2000; European Commission, 2001.

The evolution of demand up to 2003 more or less complies with the same pattern in all countries included (see Figure A1.2). Growth rates of demand are highest in the 1999/2000 and 2001/2002 periods. Over the 1999 to 2003 period, growth rates of demand remain high and – given the increased absolute level of demand – no substantial decline in demand is forecast. Only Spain, which has significantly higher growth rates for the 1999–2000 period, as well as Luxembourg and Greece, which reveal lower than average growth rates, deviate from this pattern.

In order to obtain some indication of the factors impacting on demand and supply of ICT skills, we conducted a correlation analysis with two different sets of variables (see Table A1.1). In the first set of variables, demand, supply and shortage expressed as percentage of total employment are correlated with variables for the production and use of ICT at country level: The second set of variables correlates ICT demand, supply and shortage with variables measuring the output and investment of the education sector.

## Figure A1.2: Annual growth rate of demand for ICT skills




*Source*: WIFO calculations using IDC 2000.

The correlation analysis with variables for ICT production shows that demand, supply and shortage of ICT qualifications are strongly correlated with each other. This relationship indicates that countries with a high level of demand (expressed as percentage of total employment) also exhibit high levels of supply but at the same time a high level of missing ICT-skilled labour. The fact that correlation between these variables is almost perfect might point to a common factor which drives the level of those indicators. Given the poor documentation of the methodology applied to estimate demand and supply, it cannot be ruled out that this result is due to methodological shortcomings.

The latter interpretation is supported by the lack of significant correlations with variables describing demand for ICT skills: the rather high and positive correlation with ICT spending and ICT employment is not significant. The missing significance level for ICT spending and employment may be due to the high aggregation level of the data. GDP growth is negatively correlated – although again insignificantly – with demand, supply and shortage of ICT skills. It is far rather difficult to find an explanation for the negative correlation between demand for ICT qualifications and GDP growth.

## Table A1.1: Correlation between IDC estimate for demand, supply, shortage and variables on ICT and education

| | IDC in % of total employment | | | Average ICT expenditure | Share of ICT producers in business sector | | Average GDP growth | Higher education | Public expenditure on education | Schools linked to internet | Number of pupils |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | demand | supply | shortage | in % of GDP | Employment | Value added | | per GDP | per GDP | in % | per PC |
| IDC in % of total employment demand | 1.00 | | | | | | | | | | |
| IDC in % of total employment supply | 1.00 * | 1.00 | | | | | | | | | |
| IDC in% of total employment shortage | 0.95 * | 0.93 * | 1.00 | | | | | | | | |
| Average ICT expenditure in % of GDP | 0.46 | 0.46 | 0.45 | 1.00 | | | | | | | |
| Share of ICT producers in business sector - employment | 0.36 | 0.35 | 0.39 | 0.33 | 1.00 | | | | | | |
| Share of ICT producers in business sector - value added | 0.12 | 0.11 | 0.22 | 0.38 | 0.77 * | 1.00 | | | | | |
| Average GDP growth | -0.36 | -0.37 | -0.31 | 0.10 | -0.22 | -0.21 | 1.00 | | | | |
| Higher education per GDP | 0.82 * | 0.80 * | 0.89 * | 0.60 * | 0.63 * | 0.52 | -0.35 | 1.00 | | | |
| Public expenditure on education per GDP | 0.23 | 0.22 | 0.25 | 0.34 | 0.70 * | 0.64 * | -0.18 | 0.63 * | 1.00 | | |
| Schools linked to internet in % | -0.38 | -0.37 | -0.41 | -0.10 | 0.30 | 0.06 | 0.48 | 0.32 | 0.62 * | 1.00 | |
| Number of pupils per PC | -0.32 | -0.31 | -0.34 | -0.50 | -0.73 * | -0.27 | 0.06 | -0.50 | -0.30 | -0.18 | 1.00 |

*Source*: WIFO calculations using European Commission, 2001; Daveri, 2001; OECD, 2000A.

There is a high, positive and significant relationship between expenditures for higher education (as percentage of GDP) and supply, demand and shortage of ICT skills but also with other variables measuring the size of the ICT producing sector and ICT diffusion. Public spending on education per GDP is also positively correlated with demand, supply and shortage of ICT skills, but the relationship between these variables is neither very strong nor significant. In contrast this variable is significantly correlated with employment and value added in the ICT producing sector.

Somewhat surprisingly, the number of schools (primary and secondary) linked to the Internet is negatively correlated with ICT skills indicators, which is somewhat difficult to interpret. First, the negative correlations with shortage and demand for ICT skills suggest that countries with high access of schools to the Internet do have lower demand and lower shortages. The interpretation, that investment in computer and Internet literacy in primary and secondary schools reduces the ICT skills shortages, is – given the time lag between primary and secondary education and its impact on the labour market – rather far-fetched and may only be relevant for low skilled ICT workers. On the other hand, the negative correlation with ICT skills supply indicates that high access to the Internet in schools decreases supply or the other way round. These relationship holds also for the number of pupils with PCs.

Generally, this analysis of correlations does not reveal factors which impact separately on demand, supply and shortage of ICT qualifications as measured by IDC because these three indicators are highly and positively correlated with each other. Some of the difficulties in analysing these results may be caused by the methodology applied to estimate demand, supply and shortage of ICT and by measurement errors of the indicators itself.

### A1.2.2 IDC estimates for EITO

The second ICD study was made on behalf of EITO (see *EITO*, 2001). The IDC studies are, with some limitations, comparable, as different segmentations of the labour market for ICT-qualified personnel were used.

The study for EITO uses the following segmentation to study supply of and demand for ICT skills:

- ICT professionals who support and develop technology environments in the industries that use ICT (or service vendors selling their ICT professional resources time).
- E-business professionals focused on supporting business strategies related to the Internet.
- Call centre professionals providing sales and support activities in the emerging phone channels.

The first segment of this study, ICT professionals, roughly equals the narrower scope of the first ICT skills study.

According to IDC, between 1999 and 2003 the demand for ICT employment will grow by 7.4 million jobs in Western Europe. By 2003, demand for ICT in Western Europe will be over 21.9 million jobs, whereas supply will be at 18.1 million, creating a gap of 3.8 million (18% of demand – see Table A1.2). The greater skills gap stems mostly from the inclusion of e-business professionals and call centre professionals. The gap of ICT professionals reflects that of the previous study (1.686 million in the 2001 study vs. 1.740 million in the 1999 study).

## Table A1.2: Demand, supply and shortage of ICT skills in Western Europe

| | 1999 | 2000 | 2001 | 2002 | 2003 |
|---|---|---|---|---|---|
| | | | 1000 persons | | |
| **Demand** | | | | | |
| ICT skills | 9450 | 10397 | 11170 | 12127 | 13030 |
| E-business | 1812 | 2800 | 3914 | 5084 | 6327 |
| Call centre | 1000 | 1300 | 1690 | 2113 | 2577 |
| Total | 12262 | 14497 | 16774 | 19324 | 21935 |
| **Supply** | | | | | |
| ICT skills | 8613 | 9188 | 9815 | 10609 | 11344 |
| E-business | 1481 | 2255 | 3040 | 3761 | 4347 |
| Call centre | 900 | 1183 | 1546 | 1954 | 2397 |
| Total | 10994 | 12626 | 14401 | 16324 | 18088 |
| **Shortage** | | | | | |
| ICT skills | 837 | 1208 | 1355 | 1519 | 1686 |
| E-business | 331 | 546 | 874 | 1324 | 1980 |
| Call centre | 100 | 117 | 144 | 158 | 180 |
| Total | 1268 | 1871 | 2373 | 3001 | 3846 |
| **Shortage in % of demand** | | | | | |
| ICT skills | 8.9 | 11.6 | 12.1 | 12.5 | 12.9 |
| E-business | 18.3 | 19.5 | 22.3 | 26.0 | 31.3 |
| Call center | 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 | |
| Supply | 6.6 | 7.7 | 8.7 | 9.8 | |
| Shortage | 0.8 | 1.1 | 1.4 | 1.8 | |

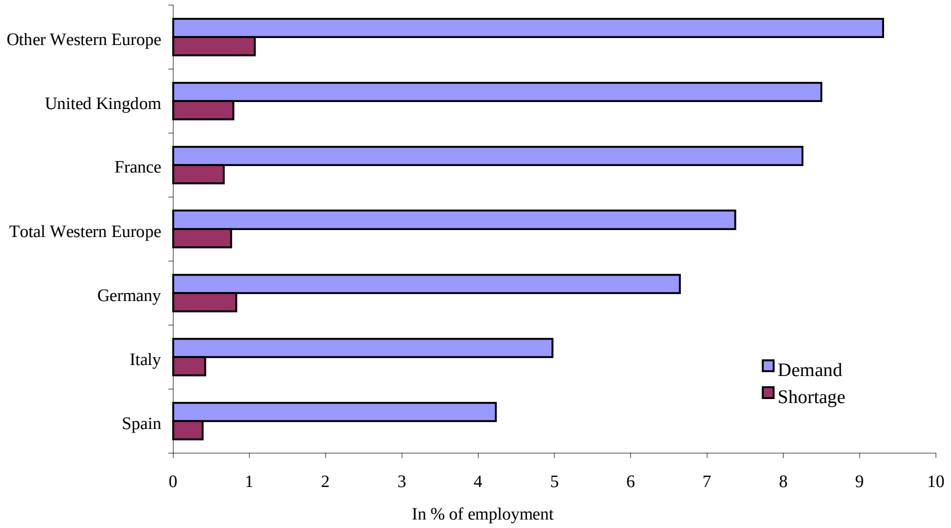
*Source*: WIFO calculations using EITO, 2001.

The shortage, expressed as a percentage of demand, will intensify for ICT skills and e-business skills until 2003. The growth of the ICT-skills gap will decelerate as of 2000. For e-business skills, ICD forecasts a constantly and sharply widening gap until the end of the period. Call centre skills will be also in demand but supply will increase faster than demand, which will result in a narrowing of the gap.

The ICT shortage is not distributed equally over the three analysed segments. The gap is highest for e-business skills at 31% of demand, 13% of demand in ICT skills and 7% of demand for call centre professionals. When we look at subcategories for ICT skills, we find that business are primarily looking for Internet specialists (where the shortage is 32% of demand).

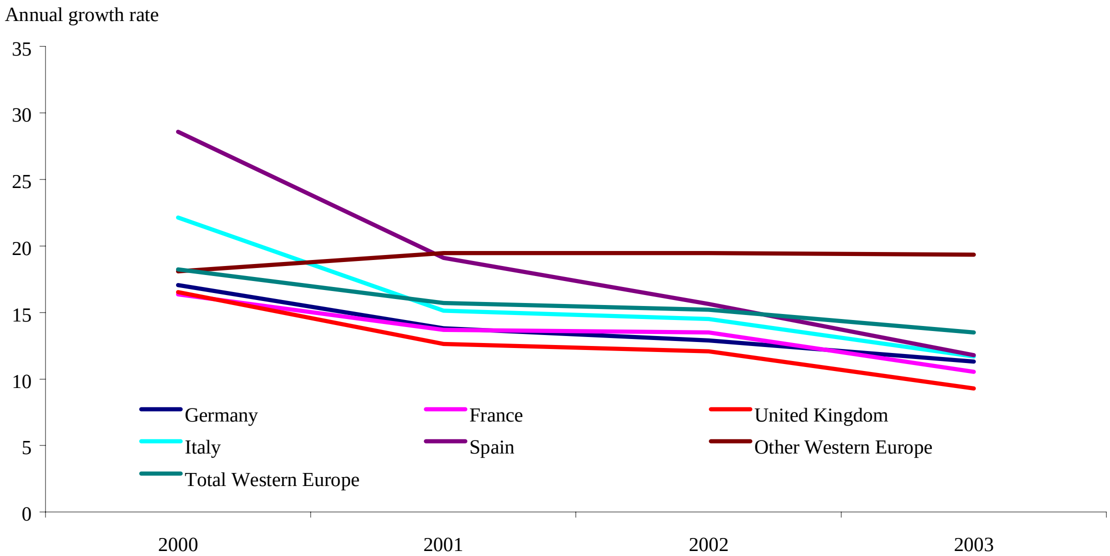
The overall demand for ICT skills amounts to 11.6% of total employment in 2002 (no estimates of total employment are available for 2003 – see Figure A1.3). Supply for these skills will increase strongly over that period, although not fast enough to narrow the gap. This results in a shortage of ICT skills of 1.8% of total employment in 2002, with a tendency to increase further.

**Figure A1.3: Demand for and shortage of ICT skills as percentage of total employment, 1999.**




*Source*: WIFO calculations using EITO, 2001; European Commission, 2001; OECD 2000.

**Figure A1.4: Annual growth rate of demand for ICT skills**




*Source*: WIFO calculations using EITO, 2001.

The growth pattern of demand is rather similar across the countries (see Figure A1.4). The highest annual growth rates are found at the beginning of the period surveyed. From 1999 to 2000, demand for ICT skills should have increased by around 20%. The annual growth rates are lower for the following years at around 15%. Germany has significantly stronger demand growth for the 1999 to 2000 period but later on converges towards the growth pattern of other countries. Other Western Europe reveals a different growth pattern: demand is generally developing fast and still increasing at about 20% annually for the countries included in this category.

Following the forecast of IDC, the shortages persists even as most governments and businesses are striving to narrow the gap thus indicating that the increased efforts to increase the skills base and to introduce productivity enhancing innovation are not paying off. Given the time of second estimate the downswing of the business cycle is not mirrored in the estimates which might be taken as evidence that these estimates mark the upper level of the skills demand

### *A1.2.3 Studies from member countries*

The ICT skills problem has surfaced in almost all member countries of the European Union, leading to a number of studies which analyse and measure the ICT skills gap at country level. The methodological approaches towards the problem are diverse and so are the results. Country estimates are usually not directly comparable but indicate the overall size of the problem. The scope of these studies ranges from a straightforward estimation of demand for or shortage of ICT skills to very detailed analyses of the causes and consequences of increased usage of ICT in firms.

We limit our analysis of these studies to the quantitative estimates of skills demand or shortages. This information is used to get an impression of the level of demand or shortage in the different countries and is then compared with the shortage estimates by IDC (see – Table A1.3).

Studies on this subject were obtained by searching the Internet. Consequently, we missed studies which are not found in the Internet, so that we can present only part of the overall picture.

## Table A1.3: Country level studies of the ICT skills gap

| Country | Authors | Period covered | Shortage Demand | Comments [155] | Sector |
|---|---|---|---|---|---|
| **Belgium** | IDC 2000 | 2003 | 72,932 | shortage | total economy |
| | INSEA | annually | 5,000 | shortage | software engineers |
| **Denmark** | IDC 2000 | 2003 | 24,679 | shortage | total economy |
| | SHAPIRO 1998 | 1998-2002 | 40,000 | demand | employees MA level computer skills |
| **Germany** | IDC 2000 | 2003 | 404,951 | shortage | total economy |
| | EITO 2001 | 2003 | 353,900 | shortage | total economy |
| | D21 | currently | 150,000 | shortage | total economy |
| | BMWI & bmb+f | currently | 75,000 | shortage | total economy |
| | BMWI & bmb+f | 1999-2002 | 350,000 | demand | total economy |
| | ZEW | 2000-2002 | 340,000 | demand | total economy |
| | BMWI | 2002 | 450,000 | demand | ICT & Multimedia |
| **Greece** | IDC 2000 | 2003 | 2,005 | shortage | total economy |
| **Spain** | IDC 2000 | 2003 | 101,011 | shortage | total economy |
| | EITO 2001 | 2003 | 107,100 | shortage | total economy |
| **France** | IDC 2000 | 2003 | 223,709 | shortage | total economy |
| | OECD 2000 | currently | 25,000 | shortage | total economy |
| **Ireland** | IDC 2000 | 1998-2003 | 9,881 | shortage | total economy |
| **Italy** | IDC 2000 | 2003 | 167,439 | shortage | total economy |
| | EITO 2001 | 2003 | 161,300 | shortage | total economy |
| | Ministry of | currently | 50,000 | shortage | total economy |
| **Luxembourg** | IDC 2000 | 2003 | 967 | shortage | total economy |
| **Netherlands** | IDC 2000 | 2003 | 118,882 | shortage | total economy |
| | FENIT | End of 2000 | 14,500 | demand | Telecom sector |
| | Dutch Ministry of Economic Affairs and Ministry of Education | 2000-2003 | 24,000 | shortage | total economy |

[155] The comparison and interpretation of these figure is rather difficult. In most cases demand is to be interpreted as “additional” to the already existing employment in the relevant part of the economy.

| Country | Authors | Period covered | Shortage/ Demand | Comments | Sector |
|---|---|---|---|---|---|
| **Austria** | IDC 2000 | 2003 | 85,013 | shortage | total economy |
| | Leo 2000 | 1997-2003 | 13,000 | demand | ICT |
| | Synthesis 2001 | 2002 | 7,400 | shortage | total economy |
| **Portugal** | IDC 2000 | 2003 | 21,913 | shortage | total economy |
| **Finland** | IDC 2000 | 2003 | 21,314 | shortage | total economy |
| | Ministry of Labour | 2002 | 8,000-12,000 | shortage | computer experts in the total economy |
| | Employers Confederation of Services Industry | 2001 | 2,500–3,000 | demand | IT service sector in member companies |
| **Sweden** | IDC 1999 | 2003 | 67,092 | shortage | Total economy |
| | Swedish National Labour Market Board | annually 2001-2011 | 10,500 | demand | total economy |
| **United Kingdom** | IDC 2000 | 2003 | 329,573 | shortage | total economy |
| | EITO 2001 | 2003 | 326,700 | shortage | total economy |
| | IER | 1997-2006 | 340,000 | demand | IT Service Industry |
| | Cambridge Econometrics | 2010 | 421,000 | demand | computer services |
| **Japan** | Ogura – Suzuki 1999 | 1996 | 9,000 | shortage | system engineers & programmers |
| **USA** | ITAA 2000 | 2001 | 846,000 | shortage | total economy |
| | ITAA 2001 | 2001 | 900,000<br>425,000 | demand<br>shortage | total economy |

A comparison of the studies cited above leads to some tentative conclusions:

1. Even estimates conducted at country level come up with diverging estimates of the skills shortage. This may be a result of differences in scope of studies, sector definition, time horizon, data gathering method, period of study, etc. All of these factors may have a significant impact on the results.

2. The country estimates of ICT skills shortage or demand are in most cases substantially lower than the IDC estimates, which leads to the conclusion that the ICD estimates either indicate the upper level of the skills problem or – in the worst-case scenario – grossly overstate the problem.

3. Recent studies – like those by ITAA in the USA – come up with a substantial decline in demand for ICT skills. In their view this is due to the recent downswing of the industry. Nonetheless even when taking the developments into consideration, the labour market is currently balanced at best, but the shortage will return once a new upswing sets in.

Generally speaking and without paying attention to methodological differences, country estimates of demand and shortage are in most cases substantially lower than ICD estimates. They are mostly at levels which seem to be achievable if action is taken with sufficient determination to allow swift changes.

The contraction currently affecting technology and Internet firms offers a break for politicians to prepare for a new upswing of the industry in the near future. This applies most of all to measures which impact on the supply of ICT skills in the short term (see below). Overall monitoring of supply and demand for skills – not restricted to the field of ICT skills – would be of advantage if carried out in a co-ordinated manner across all EU member states. Forecasts of demand for skills are always prone to error, and consequently making a wrong decision based on these estimates can be costly in terms of wasted potential for economic growth. Nevertheless, the cost of making no decision and of not trying to adapt the educational and training system to future demand seems to be even riskier.

### A1.3 Policy responses to the ICT skills gap

In the past years, measures to combat the shortage of ICT skills topped the agenda in European member states and in ICT firms. Both sides were active in designing strategies, occasionally by co-operative arrangements, to increase the supply of ICT-skilled labour. At European level, the Commission started the Initiative for New Employment, the eLearning Initiative and the European Computer Driving Licence. Member states have been trying hard to bring changes to their educational systems and to intensify training and requalification activities. Businesses have introduced new ways to recruit skilled people (most notably online recruiting) and to keep their employees "on board" by offering stock options. They have also invested in technology-focused alliances with partners, launched e-learning systems, virtual learning centres, etc. Some EU member countries have also tried to solve the ICT-skills problem by encouraging immigration, and some firms have established learning centres outside Europe or transferred part of their development and production units to non-EU member countries (for examples see *EITO*, 2001).

Coping with the ICT skills gap demands some analytical and strategic actions based on two dimensions: 1. What are the numbers required by the economy, and – more importantly – are they required either in the short or in the medium term? 2. What skills are requested, i.e. high-, medium- or low-skilled ICT personnel? If the problem is structured this way a simple matrix can be drawn up which integrates the different options to find solutions for the skills gap (see Table A1.4).

**Table A1.4: Actions against the ICT skills gap**

| | **Short-term demand** | **Long-term demand** |
|---|---|---|
| **High-skilled ICT personnel** | Immigration<br>Outsourcing to non-EU member states with highly qualified labour force | Increase output of tertiary education |
| **Medium-skilled ICT personnel** | Immigration<br>Outsourcing to non-EU member states with qualified labour force<br>E-learning<br>Training and retraining activities | Increase output of secondary education |
| **Low-skilled ICT personnel** | European computer driving licence<br>Training and requalification activities | Increase computer and Internet literacy in primary and secondary education |

The policy measures to solve the ICT skills problem depends crucially on the skill level demanded. 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 skill level. If highly skilled ICT personnel with ICT specific training of more than 3 years are demanded changes of the educational system may take to long to reduce the skills problem. Introducing new courses have lead times of 1 to 2 years as new curricula have to be developed and additional resources are needed. Altogether it may take time 5 to 7 years before additional highly skilled graduates leave the 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 time solutions. To a lesser degree the same conclusion applies to medium skill ICT personnel with ICT specific training of 1 to 3 years. In the latter case further measures – like elearning, training and retraining activities – might complement the measure to reduce the gap.

If low-skilled ICT personnel is short than all kind of activities which help people to acquire basic ICT skills are in demand. Training, retraining or requalification initiatives may help to diminish the skills problem and at the same time draw people onto the labour market again. To plan and execute these programmes in co-operation with firms helps to bring the measures in line with actual demand.

In all cases the severance of the skills problem is influenced by the timing of measures to increase the supply out of the educational and training system. Only few government and experts did predict the skills problem in advance and thus many government were surprised by the magnitude of the problem as felt in 1999 and 2000. In any case, shortages which are pressing at the moment might be no longer acute in the medium term, thus creating another skills mismatch. At the same time, as the demand for skills is changing over time, there are far greater risks involved when not taking action on the grounds that demand is changing and difficult to forecast. Consequently, more efforts to forecast future skills changes seem advisable even if it is obvious that correct quantitative estimates are rather the exception than the rule.

## A1.4 Conclusions

The shortage of ICT (information and communication technology) skills is the direct product of the development and diffusion of new digital technologies. Two intermingled but still separable trends have to be taken into consideration when analysing the impact of new technologies on the demand for highly skilled people: first, the long-term trend towards a greater share of university and college graduates in the economy which is most pronounced in sectors that are among the first users of digital technologies (computers, etc.); second, the more recent increase in demand for ICT skills which is related to digitisation and liberalisation in the telecommunication sector, the Y2K problem, the rapid expansion of Internet and new media and the corresponding massive start up activities.

Quantifying the ICT skills gap is not straightforward and associated with a number of problems. First, it is difficult to measure skills directly. Instead studies focus either on the number of vacant jobs in the economy, the number of jobs created in the past or in the future, the number of people with specific qualifications demanded. Second, the size of the skills gap depends on the scope of the study, e.g. the part of the economy which is analysed. Several studies concentrate on ICT branches of the economy as these were the first to feel the skills shortage. Of course, the shortage has since spread throughout the economy which renders it increasingly difficult and more tedious to come up with an estimation of the skills gap for the whole economy. Third, the supply of people with the required skills is not easy to measure. First of all, statistics on the output of the educational system have to be analysed at a very disaggregated level. It is even more complex to measure the output of re-education or training activities as the market for these services is highly segmented and heterogeneous. Fourth, any estimate of future skills demand is highly risky as the overall business cycle and industry developments impact on labour demand. This is even more true for areas like ICT production and consumption where technological change is rapid and the organisation of commercial activities changes at a similarly fast pace. Fifth, businesses themselves have problems to forecast their demand for specific skills over a period of more than six months. Consequently, medium term-forecasts are prone to errors.

Given these problems attached to measuring ICT skills shortages, estimates on the ICT skills gap should be viewed rather as broad indications of major trends in this area and not as accurate projections of shortages.

There are only two studies from IDC which measure the ICT skills gap across Europe. In the first study, IDC expects demand for IT skills to grow from approximately 9.47 million IT professionals in 1998 to 13.07 million in 2003, while supply is set to grow from 8.61 million in 1999 to 11.33 million in 2003. Consequently, the Western European skills shortage is estimated to reach 1.7 million IT professionals by 2003 (13% of demand). According to the second study, between 1999 and 2003 the demand for ICT employment will grow by 7.4 million jobs in Western Europe. By 2003, demand for ICT in Western Europe will be over 21.9 million jobs, whereas supply will be at 18.1 million, creating a gap of 3.8 million (18% of demand). The greater skills gap stems mostly from the inclusion of e-business professionals and call centre professionals which were not included in the first study.

There were a number of studies on the ICT skills gap on the country level. Even these estimates come up with sometimes substantially diverging estimates of the skills shortage. This may be a result of differences in scope of studies, sector definition, time horizon, data gathering method, period of study, time of conduct etc. All of these factors may have a significant impact on the results. The country estimates of ICT skills shortage or demand are in most cases substantially lower than the IDC estimates, which leads to the conclusion that the ICD estimates either indicate the upper level of the skills problem or overstate the problem.

Recent studies come up with a substantial decline in demand for ICT skills. In their view this is due to the recent downswing of the industry. Nonetheless even when taking the developments into consideration, the labour market is currently balanced at best, but the shortage will return once a new upswing sets in.

In the past years, measures to combat the shortage of ICT skills topped the agenda in European member states and in ICT firms. Both sides were active in designing strategies, occasionally by co-operative arrangements, to increase the supply of ICT-skilled labour. At European level, the Commission started the Initiative for New Employment, the eLearning Initiative and the European Computer Driving Licence. Member states have been trying hard to bring changes to their educational systems and to intensify training and requalification activities. Businesses have introduced new ways to recruit skilled people (most notably online recruiting) and to keep their employees "on board" by offering stock options. They have also invested in technology-focused alliances with partners, launched e-learning systems, virtual learning centres, etc. Some EU member countries have also tried to solve the ICT-skills problem by encouraging immigration, and some firms have established learning centres outside Europe or transferred part of their development and production units to non-EU member countries.

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# Annex 2: The OECD Growth project: focus and recommendations

**KARL AIGINGER**

## A2.1 The objective

The OECD Growth project (*OECD*, 2001) explores the causes of differences in growth performance in the OECD area, in particular the acceleration of trend growth in the United States and a few other OECD economies over the past decade. It asks how growth patterns has changed in recent years and examines the implications of those shifts for policymakers.

## A2.2 Divergence and factors behind

Three OECD countries - Australia, Ireland and the Netherlands - registered markedly stronger trend growth of GDP per capita over the past decade compared with the 1980s. Several other countries also experienced an improvement. These include the United States, where trend growth of GDP per capita accelerated strongly in the second half of the decade. In contrast, the growth in GDP per capita in many other OECD countries, including Japan and much of Europe, slowed. In several countries, e.g. Finland, Canada, Greece, Iceland and Sweden, trend growth picked up only in the second half of the 1990s.

The analysis showes 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 multi factor productivity*

## A2.3 Key policy recommendations of the OECD report

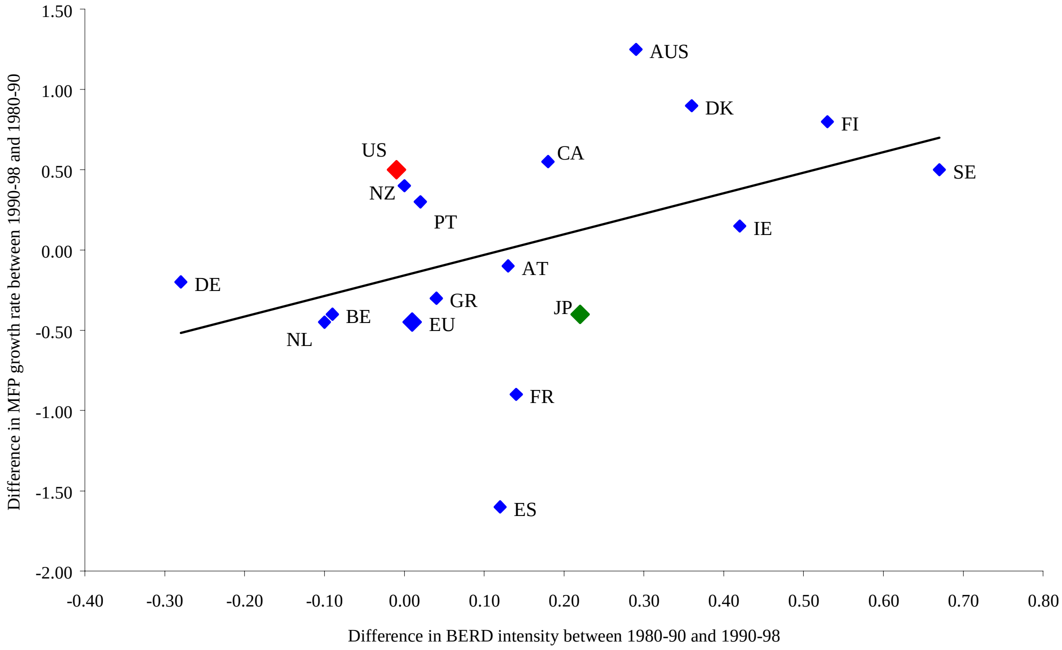
A comprehensive growth strategy should be based on a combination of actions in order to:

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 firm creation*, by improving access to high-risk finance, reducing burdensome administrative regulations and instilling positive attitudes towards entrepreneurship.

### Figure A2.1: Multi factor productivity and business R&D intensity

(acceleration 1990-98 minus 1980-90 vs. change in R&D intensity)




*Source*: Bassanini, Scarpetta, Visco, 2000; MFP = Multi factor productivity (hours adjusted version).

## Reference:

Bassanini, A., Scarpetta, St., Visco, I., Knowledge, technology and economic growth: recent evidence from OECD Countries, Eco Department Working Papers, No 259, OECD, Paris, 2000.

OECD, The new economy: beyond the hype, final report on the OECD Growth Project, OECD, Paris, 2001.

OECD, Growth Project, draft Ministerial paper, OECD, Paris, 2001.

# Annex 3: Research intensity and productivity growth for member countries

## Push in research intensity: Sweden and Finland

In **Finland,** research is concentrated in the high tech sectors. Electronics, electrical machinery, and instruments are all capable of transforming high research efforts into high productivity growth; for chemicals, high levels of research did not result in growing production and productivity, nor was this the case in office machinery. Finland succeeded in increasing productivity in its traditional areas of strength. Pulp and paper, wood and cork, and basic metals are all among the top five sectors in productivity growth. In these sectors, research intensity is lower than in other industries, but it is higher in Finland than in the EU. The contribution of research to production is highly significant in Finland; this relation is lower with respect to productivity, since the capital intensive industries boost productivity without their own research..

In **Sweden,** other transport and cars are specifically research intensive sectors. For motor vehicles, as well as for electronic equipment and for office machinery, high levels of research lead to high growth in productivity. Productivity growth in traditional strongholds is seen for basic metals, but not for pulp and paper and for wood. The overall correlation between research and growth in production and productivity is excellent, hinting at a systematic strategy to develop strength through research in promising fields.

## Research intensity drives growth: Belgium, France, the United Kingdom

In Belgium, 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 little research and low growth. A fast growing industry with low research is publishing and printing (however, inputs perhaps embody technology). Leather and footwear have high and increasing levels of research in Belgium – in contrast to other countries - but productivity growth performance did not improve. Belgium is one of the countries in which rank correlation between research intensity and growth is positive and significant.

Four of the five research intensive sectors in **France** are also high growth sectors and can boost productivity; the exception is office machinery, where research is high, and production is decreasing. Instruments, electrical equipment, other transport and chemicals are the sectors in which high research efforts specifically result in productivity growth. Food is a low research sector with small increases in productivity. Publishing and printing combines low research with about average production, but has below average productivity increases. The overall correlation between research intensity and growth of production, as well as productivity, is significant in France.

In the **United Kingdom** electronic equipment, chemicals, and instruments are sectors with high research intensities 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. Capital intensive industries, like oil, chemicals and food, have high levels of growth in productivity. The split between research and production seems to be specifically large in the United Kingdom, while the correlation between research intensity and productivity is insignificant.

### Specific factors dominate in other countries

In **Denmark,** instruments, chemicals (specifically, the pharmaceutical industry) and electronic equipment are research intensive and fast growing. Food and pulp and paper are low in both rankings. Office machinery and the other industries (incl. furniture) are research intensive, but have low growth. Wood, publications, and motor vehicles have high growth, but are not research intensive. These large differences in the ranks of the five industries last mentioned imply an overall weak correlation in Denmark, independent of whether research inputs are lagged or not.

The cross industry correlation between research intensity and production, as well as productivity growth, is practically zero for **Germany**. This may be due to the fact that restructuring more greatly effected productivity than research. Many firms began to outsource and went multinational. For all five industries which lead in research, production growth is not above average. Electronic equipment has high research and slow production growth; employment decreased sharply, so that productivity increased. Chemicals have a high research intensity, but slow growth in production and productivity. Vehicles, which place sixth in research intensity, increased production, but does not rank high in productivity growth. On the other hand, food and printing are growing fast – without research – and the productivity increase is low.

In the research intensive sectors in **Spain,** growth is high in office machinery (in real terms) and in electrical machinery. In chemicals, other transport and electronic equipment, neither production nor productivity grew fast. Food and apparel combine

low research with low productivity. In textiles and in basic metals, competitive pressure induced high productivity growth, despite low research. The overall correlation between research intensity and production, respectively productivity growth, is positive but not significant.

Three of the five leading research intensive sectors in **Italy** cannot transfer high research into productivity growth. Other transport has a specifically low level of productivity growth; motor vehicles are increasing production at a below average rate. Research activity and productivity are high in electronic equipment and in office machinery. The food industry and the textile industries rank low in both hierarchies, 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 is shown for wood, pulp and paper, and fabricated metal.

Office machinery has high levels of research and high growth in production and productivity in the **Netherlands**. High ranks in both hierarchies can also be seen in the car industry and in electronics. On the other hand, electrical machinery and chemicals cannot transfer research into production growth - in the latter case, perhaps due to the lower share of pharmaceuticals. Tobacco and pulp and paper are capital intensive industries with high productivity growth.

## Table A3.1: Industry profiles in research intensity and growth

| Sector | Number of EU countries in which industry is in a given combination of research intensity and growth | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Low R&D/ low production growth | Low R&D/ high production growth | High R&D/ low production growth | High R&D/ high production growth | Low R&D/ low productivity growth | Low R&D/ high productivity growth | High R&D/ low productivity growth | High R&D/ high productivity growth |
| Food products and beverages | 2 | 0 | 0 | 0 | 4 | 0 | 0 | 0 |
| Tobacco products | 3 | 1 | 0 | 0 | 2 | 1 | 0 | 0 |
| Textiles | 3 | 0 | 0 | 0 | 1 | 1 | 0 | 0 |
| Wearing apparel; dressing and dyeing of fur | 9 | 0 | 0 | 0 | 2 | 6 | 0 | 0 |
| Tanning and dressing of leather | 7 | 0 | 1 | 0 | 2 | 3 | 1 | 0 |
| Wood, products of wood and cork | 2 | 5 | 0 | 0 | 3 | 2 | 0 | 0 |
| Pulp, paper and paper products | 1 | 2 | 0 | 0 | 4 | 1 | 0 | 0 |
| Publishing, printing and reproduction | 1 | 4 | 0 | 0 | 6 | 1 | 0 | 0 |
| Coke, refined petroleum and nuclear fuel | 3 | 0 | 1 | 0 | 2 | 1 | 1 | 0 |
| Chemical and chemical products | 0 | 0 | 1 | 4 | 0 | 0 | 0 | 2 |
| Rubber and plastic products | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Other non-metallic mineral products | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Basic metals | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| Fabricated metal products | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Machinery and equipment n. e. c. | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 |
| Office machinery and computers | 0 | 0 | 6 | 2 | 0 | 0 | 5 | 2 |
| Electrical machinery and apparatus n. e. c. | 0 | 0 | 1 | 5 | 0 | 0 | 2 | 1 |
| Radio, TV and communication equipment | 0 | 0 | 3 | 7 | 0 | 0 | 0 | 10 |
| Medical, precision and optical instruments, watches | 0 | 0 | 1 | 5 | 0 | 0 | 1 | 5 |
| Motor vehicles, trailers and semi-trailers | 0 | 0 | 0 | 4 | 1 | 0 | 0 | 2 |
| Other transport equipment | 0 | 0 | 4 | 4 | 0 | 0 | 3 | 3 |
| Furniture; manufacturing n. e. c. | 0 | 2 | 0 | 0 | 4 | 1 | 0 | 0 |

*Source*: WIFO calculations using OECD (STAN, ANBERD).

# Annex 4: Sources for data used

| | Source |
|---|---|
| Use of computer for work (% of working population) | Eurobarometer 54.0, Autumn 2000 |
| Patents | U.S. Patent and Trademark Office (USPTO) |
| Total expenditure on R&D in % of GDP | OECD-MSTI, 2000/1 |
| Business enterprise expenditure on R&D (BERD) in % of GDP | OECD-MSTI, 2000/1 |
| R&D personell as a % of the labour force | SST Eurostat; European Commission (2001, p.61) |
| Research intensity in manufacturing | OECD, STAN |
| Publications per inhabitant | Institute for Scientific Information, NSIOD 1981-1999; ECO-DB |
| Patents per resident | OECD-MSTI, 2000/1 |
| Public expenditure on education | UNESCO/OECD/EUROSTAT |
| Percentage of the population that has attained at least upper secondary education by age group | OECD, Education at a glance (2000C) |
| Percentage of the population that has attained at least tertiary education, by age group | OECD, Education at a glance (2000C) |
| Human resources in science and technology by country (HRSTC) | SST Eurostat; European Commission (2001, p.130) |
| Working population with tertiary education - ISCED 5-7 | New Cronos |
| ICT expenditure in % of GDP | EITO/WITSA |
| Information technology (IT) expenditure in % of GDP | EITO/WITSA |
| Telecommunication (TLC) expenditure in % of GDP | EITO/WITSA |
| PC's per inhabitant | ITU-DB |
| Internet users per inhabitant | ITU-DB |
| Cellular mobile subscribers per 100 capita | OECD Communications Outlook 2001 |
| Share of technology driven industries in nominal value added | New Cronos, Peneder 1999 |
| Share of skill intensive industries in nominal value added | New Cronos, Peneder 2000 |
| Share of ICT industries in nominal value added | New Cronos, OECD definition |
| GDP per capita PPP | OECD, ECO |
| Openness (((exports+imports)/value added))*.5) | COMEXT, SBS |
| Export unit value (1998, ECU/kg) | Aiginger, 2000B (see chapter 5) |
| High quality exports (1998, share in high quality segment) | Aiginger, 2001 (see chapter 5) |
| Product market regulation (score) | OECD |
| Labour market regulation (score) | OECD |
| Open tenders (tenders published, in % of GDP) | EU, 2001/Appendix 2 |
| Life long learning (% of population, 25-64) | EU, 2001/Appendix 3 |
| Sectoral aid (1997-1999, in % of GDP) | EU, 2001/Appendix 4 |
| Venture capital (1994, in % of GDP) | EU, 2001/Appendix 5 |
| Market capitalisation (1999, New capital raised, in % of GDP) | EU, 2001/Appendix 6 |
| Growth of output, total economy (1991-2000) | EUROSTAT (New Cronos); Economic Forecasts |
| Labour productivity, total economy (1991-2000) | EUROSTAT (New Cronos); Economic Forecasts |
| Trend growth of GDP per capita (1991-1998) | Bassanini, Scarpetta, Visco, 2000 |
| Multi-Factor Productivity (1991-1998) | Bassanini, Scarpetta, Visco, 2000 |
| Growth of output, manufacturing (1991-2000) | EUROSTAT (New Cronos); Economic Forecasts |
| Labour productivity, manufacturing (1991-2000) | EUROSTAT (New Cronos); Economic Forecasts |
| Innovation expenditures in % of sales | Community Innovation Survey II |
| Share of new/improved products in % of sales | Community Innovation Survey II |
| Share of co-operations in % of R&D | Community Innovation Survey II |
| Share of firms with continuous research | Community Innovation Survey II |
| Structural change indicator (speed of change) | Aiginger, 2001 (see chapter 5) |