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research:

First issue - pilot

**The ANNUAL DIGEST
of Industrial R&D**

Directorate General Joint Research Centre
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The Annual Digest of Industrial R&D seeks to highlight recent findings on industrial R&D based on a review of publicly-available sources, including official reports and relevant professional and academic literature¹. The information published here is intended to complement other Industrial Research Investment Monitoring (IRIM) activities², jointly carried out by the European Commission's Directorates-General Joint Research Centre (DG JRC) and Research (DG RTD).

The Annual Digest is primarily intended for people involved in policy-making at the EU level. Furthermore, it aims to be of interest to users in research and innovation policy-making generally as well as academics, researchers, policy analysts and people working in industry. A publication such as the Annual Digest helps base policy-making on evidence, not anecdote. Currently there is no other product that systematically reviews the literature and summarises recent findings relevant to industrial R&D.

This document was developed from a first draft produced by DG JRC's Institute for Prospective Technological Studies (IPTS), which was based on a limited amount of information drawn from publicly-available sources. Subsequent reviews of that draft identified the need for additional information from a wider range of sources. The European Techno-Economic Policy Support Network (ETEPS), a consortium of research institutions, assisted DG JRC-IPTS in the task of reviewing more sources and complementing the initial information. Overall monitoring and guidance was provided by DG RTD.

This is the first, pilot issue of the Annual Digest. Comments, feedback and other input are welcome and can be sent by email to: JRC-IPTS-IRI@cec.eu.int.

1 Industrial R&D refers here to R&D undertaken in the private sector.

2 Such as the *EU Industrial R&D Investment Scoreboard* and the *EU Survey on Business Trends in R&D Investment*.

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- BERD:** Business Expenditure on Research and Development
- EIRMA:** European Industrial Research Management Association
- EU:** European Union
- GDP:** Gross Domestic Product
- GERD:** Gross Expenditure on R&D
- FDI:** Foreign Direct Investment
- MER:** Market Exchange Rates
- MNC:** Multinational Company
- MNE:** Multinational Enterprise
- NA:** Not Available
- NEC:** Not Elsewhere Classified
- PPP:** Purchasing Power Parity
- PER:** Preferred Exchange Rates
- R&D:** Research and Development
- ROI:** Return on Investment
- RTA:** Revealed Technological Advantage
- TBP:** Technology Balance of Payments

Research and development (R&D) is important for economic progress and the well-being of society. It also plays an increasingly vital role in the knowledge-based economy. Although the private sector's main rationale for undertaking R&D is to improve the efficiency and competitiveness of the businesses that fund it, it also has downstream and spillover effects on other businesses and industries, as well as on consumers and citizens and on employment. Industrial R&D is related to business needs and plays a key role in developing the products, processes, services and industries that will help to propel Europe towards a sustainable and competitive knowledge-based economy.

The Annual Digest of Industrial R&D has been developed with the aim of gathering, structuring, and analysing patterns and trends in industrial R&D through a systematic review of a wide variety of recent reports, studies and other publicly available information on industrial R&D. There is a need for such an activity because policy-makers seek clear and reliable evidence to monitor and analyse Europe's efforts in R&D and innovation.

This pilot document is divided into four chapters.

Chapter 1: The impact of industrial R&D

There are various reasons why the impact of industrial R&D merits discussion. Firstly, industrial R&D activity is linked to innovation and economic growth (observed at the national, regional and firm levels). However, over time these links have become more complex and difficult to elucidate as they have grown more competition-driven, market-oriented and globally dispersed. Secondly, industrial R&D generates new and improved products, processes and services, and develops firms' strategic capabilities. And thirdly, industrial R&D helps improve the well being of society, by offering solutions to social and environmental problems, and supporting the transition towards a knowledge-based society.

Chapter 2: Growth in industrial R&D investment

Chapter 2 provides a summary of trends in industrial R&D investment. The backcloth is that world business (industrial) R&D expenditure in real terms has more than doubled over the past few decades. It discusses differences in BERD growth across countries and sectors of economic activity. It also examines structural differences between the EU and other economies in an attempt to identify possible explanations for the business R&D deficit between them. Finally, it looks at funding sources of industrial R&D.

Chapter 3: Factors affecting R&D investment

Chapter 3 presents an overview of changes in R&D management methods and attitudes over three decades. This longer-term perspective is important in order to understand and discuss how management teams might think differently about R&D investments in the future. It is a subject that needs mainly to be assembled from micro studies (usually done to try to advise management on improved methods for decision making). These are inevitably context specific, as the strategic management of R&D depends on the sector in which a firm operates and, more specifically, on the position of the company within its sector. Differences between high-tech, low-tech, and large, medium or small firms, need to be considered, as do differences between industry sectors and factors such as firms' positions in value chains.

Chapter 4: Internationalisation of industrial R&D

The process of internationalisation of industrial R&D is determining the location of R&D activities in Europe and the location of European industrial R&D in other locations worldwide, notably China, India and the USA. This phenomenon is not just an isolated contemporary feature of the R&D landscape. It is intertwined with the shift of manufacturing operations to China and other countries, with the emphasis of management attention and stakeholder pressure on business financial performance, with the availability of creative workers and graduates, and their career aspirations, with the reputation of European research and higher education institutions, and how they are concentrated and coordinated within European research and innovation systems, as well as with access to large emerging markets.

1. The Impact of Industrial R&D

Investing more in industrial R&D is a political priority in the European Union. But why should we be concerned about the level of R&D activity? Why is R&D seen as being so important to the development and well-being of the EU? There are three reasons:

- 1) The first relates to the link between R&D, growth and economic performance that can be seen on a variety of scales (macro, meso and micro).
- 2) Secondly, R&D is important not only to firms and organisations in the direct sense of in-house R&D generating new and improved products and processes, but also in a more indirect way in terms of supporting innovation by being associated with the ability to absorb, adapt and diffuse technology acquired outside the firm. R&D is therefore important in helping firms exploit technologies more fully.
- 3) Thirdly, for the above reasons, R&D makes an important contribution to economic development. It also plays a role both in creating and alleviating economic and social inequalities within Europe. Thus, neo-Schumpeterian interpretations of economic growth have emerged which suggest that not all countries or regions will be equally placed to generate and benefit from innovations and there will be strong tendencies for cumulativeness. R&D and innovation will, therefore, be a strong disequilibrating factor in the processes of economic growth, giving rise to the pervasive differential growth rates between geographical areas (Verspagen, 1997).

At the same time the research environment and how it links to innovation and economic growth has become more complex and uncertain. This is evident in a number of ways:

- Firstly, the internationalisation of R&D has brought about new R&D management strategies at the level of national governments and business entities. R&D is performed by firms in the potentially best local conditions. The location of the R&D performance and the exploitation of its outputs now diverge more than ever before.
- Secondly, the 'European paradox' (namely that the EU's scientific performance is excellent but its ability to transform the results of research into competitive advantages is weak) needs to be addressed by looking at the exploitation side of industrial R&D. How can the R&D absorptive capacity of local industry be improved within the EU?
- Thirdly, the time lag from discoveries at the level of basic science to producing innovative products and services in some sectors is decreasing. The speed of technological change and the pace of competition between firms is accelerating and this can lead to higher levels of risk and uncertainty.

This chapter analyses outputs and effects of industrial R&D and their longer term effects on GDP, productivity and employment growth, innovation, exports/imports and the trade balance of high-tech industries, and the technology balance of payments. It also studies structural issues such as spillover effects of industrial R&D (including some social impacts) and the role of management in the 'value' of the outcomes of the R&D investments on companies' performance.

It is not easy to obtain a comprehensive picture of R&D effects, including economic and social aspects. Firstly, there is no agreed methodology for measuring R&D effects. Furthermore, the analysis of R&D effects is based on a wide range of indicators of R&D output/outcome.

1.1 R&D and competitiveness

Research and development activities are crucial to economic growth and competitiveness. In theoretical terms the link between R&D, knowledge and economic growth has long been acknowledged. From Marshall (1890) through to Kuznets (1971) there has been the recognition that, directly and indirectly, knowledge changes economic activity and economic activity changes knowledge in self-perpetuating cycles of change. Economic theorists and empirical evidence suggest positive relations between total R&D expenditures and (a) innovation, (b) productivity change³ and (c) economic growth⁴.

1.1.1 R&D and innovation

The descriptive statistics and results arising from R&D growth models suggest a close correlation between R&D activity and technological innovation. R&D is still often taken as the measure of technological innovation, and economic analyses tend to focus on R&D as an input in the innovation process. Of course, R&D still represents an important input into the innovation process, and according to a recent analysis R&D accounts for around 45% of all innovation expenditures in the EU (Lucking, 2004).

Similarly, econometric analysis of the average marginal effects of R&D intensity changes (on the R&D/employee and the number of employees) on the various innovation indicators of innovative firms operating in high-tech and low-tech sectors⁵ showed the relationship of cause and effect (Mairesse and Mohnen, 2004). R&D is positively correlated with all 5 dichotomous indicators of innovation output⁶. However, equally it has become increasingly recognised that R&D is not the only input into the innovation process and R&D only partially covers activities involved in innovation.

3 In an analysis of the relationship between R&D expenditure and total factor productivity in 16 OECD countries over 1980-1998 Guellec and van Pottelsberghe found positive elasticity of 0.13 for business performed R&D, 0.17 for government and university performed R&D and 0.46 for foreign R&D (Guellec and van Pottelsberghe, 2001, p.113).

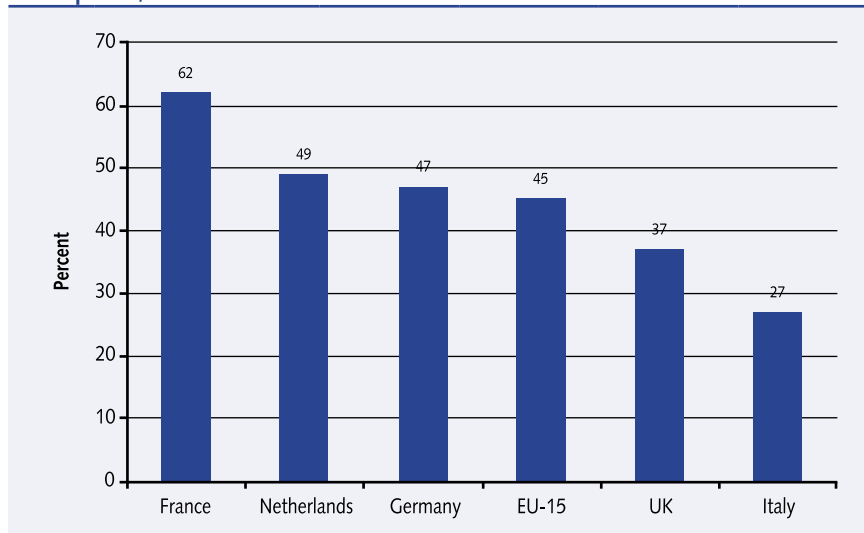
4 An examination of 17 OECD countries over 1960-1999 revealed a positive impact of R&D investment on GDP growth (German Council of Economic Experts, 2002, p.329).

5 The analysis is based on data obtained by merging the French annual R&D survey for 2000 with CIS 3. The proportion of R&D performers in high-tech sectors (firms in the electrical products, chemicals, machinery and vehicles industries) is higher than in low-tech sectors (firms in the textiles, wood, plastics, non-metallic mineral products, basic metals and not elsewhere classified industries).

6 These were namely process innovation and product innovations new to the firm, product innovations new to the market, patent applications and patent holdings. Product and process innovations have different impacts on firms. Process innovations provide opportunities for cost reduction, while product innovation may widen the range of products and increase output, which in turn could result in increasing employment.

Figure 1.1

Intramural R&D as a percentage of innovation expenditures in innovation active enterprises, 2000.



Note: EU-15 excludes Austria, Ireland and Sweden.

Source: Lucking (2004) based on Eurostat data.

In the past there has also been much discussion and analysis around R&D activity and patents, often tending to view patent activity as the main output of research. There have been ongoing issues of how patents should be viewed as technology or innovation indicators and their relationship with R&D activity and these are discussed more fully in Annex 2. However, patents should really be seen as an intermediate output of R&D. Nevertheless, it is interesting to note that there is a strong positive correlation between the number of triadic patent families (i.e. those registered in Europe, the US and Japan) and business R&D expenditure ($R^2=0.955$). Countries having a high level of business R&D expenditure (as the US, Japan and Germany) also have large numbers of triadic patent families. Conversely, Eastern and Southern European countries have a low level of business R&D expenditure and of triadic patent families (OECD, 2004a). However, much of the correlation might be explained by size effects. Big countries may have a large BERD and a large number of patents simply because they are big countries, not necessarily because there is a link between both.

Data on patent intensity by industry-financed R&D (triadic patent families applied for as a percentage of industry-financed R&D) can be used to shed light on the effectiveness of industrial R&D. The higher the ratio, the more patents have been applied for per Euro invested in R&D. In 2002, Japan ranked highest according to this ratio, followed closely by the EU. The US has seen this ratio decrease continuously since 1996 due to a rapid expansion in industry-financed R&D (OECD, 2004a; 2005c). The above provides a picture on the international position of main technology 'producer' countries changes if we analyse their patent data normalised by their business R&D expenditures. The patent per BERD ratio shows the leading position of Sweden and Germany, Japan and the Netherlands, then followed by the US, France and UK (TÁRKI, 2005; European Commission, 2002). Lastly, it is worth noting that there are considerable national variations within the EU in terms of patenting performance in relation to R&D as well as sectoral variations. In this latter respect it is worth noting that European firms often outperform (in terms of R&D efficiency as measured by patents) US firms in certain sectors, such as pharmaceutical and biotechnology (Baudry and Dumont, 2006).

1.1.2 R&D and productivity change

Many studies have attempted to quantify the impact of innovation on productivity, using R&D expenditure as a proxy for technical change. In most of these studies innovation activities were assumed to produce what is known as R&D capital, a stock of knowledge that gradually depreciates if it is not replenished. Moreover, models exploring the link between R&D and productivity have been applied to firm, industry and country data using both cross sectoral and time series analysis.

The bulk of the evidence shows that both the firms performing R&D and society as whole derive considerable benefits from their investments in R&D. It is also underlined that the diffusion of new technologies in an economy is the basis of the realisation of the benefits of technical change. In fact, a considerable part of R&D carried out by companies is actually designed to facilitate the adoption of new technologies.

However, despite the broad positive association between the overall innovative efforts and performance in terms of productivity, past studies have also shown a strong sector-specificity of the link between innovation and productivity. The highest productivity growth rates have been observed in the electronics industry in Northern Europe as well as chemicals and pharmaceuticals industries in several other EU countries. In most countries traditional industries exhibit low rates of innovation and productivity growth⁷.

1.1.3 R&D, economic growth and firm performance

As noted earlier, a key reason of why R&D is important is that it is linked to economic growth and performance. The following sections will explore this association at different levels of analysis to see if the links between R&D and growth and performance hold at these various levels. The levels explored are: national, regional⁸ and firm level.

National level

The findings deriving from a recent R&D based endogenous growth model suggest that there is a significant relationship between R&D, as measured by Gross Expenditure on R&D (GERD), and innovation, as measured by patent applications⁹. In turn innovation has a positive effect on per capita outputs in both developed and developing countries. Given the existence of spillovers, even countries that do not have effective R&D sectors can exploit the know-how produced in other countries to promote their innovation (Ulku, 2004). The OECD report (2003) mentioned above seeks to give a longer term assessment of the impact of innovation and technological progress on economic growth. However, complex effects could have been at play here which could not be identified by regression analysis. For example, whilst

- 7 See Section 1.2.4 for a discussion of the link between R&D and innovation in low-tech sectors.
- 8 Regions in this sense relate to what Freeman (1995, pp.20-21) refers to as 'nether' regions, in contrast to the term regions relating to continental trading blocs which he refers to as 'upper' regions.
- 9 Based on the data of 20 OECD and 10 non-OECD countries

business-performed R&D was likely to be more directly targeted towards innovation and implementation of new innovative processes in production (leading to improvements in productivity), other forms of R&D (for example, energy, health and university research) may not raise technology levels significantly in the short run, but could instead generate basic knowledge with possible 'technology spillovers'. The latter is difficult to identify, not least because of the long lags involved and the possible interactions with human capital and associated institutions (OECD, 2003, p.86; see also Salter and Martin, 2001).

Regional level

The relationship between R&D, innovation and economic growth is also apparent at the regional level¹⁰. The RINNO database, which is based on the Innovation Scoreboard data for 2002, shows a clear correlation between innovation – as measured by the 'revealed regional summary innovation index' (RRSII) – and economic activity and performance – as measured by 'relative per capita GDP' (European Commission, 2002)¹¹.

A UK study by Huggins (2001) has also revealed that an index of innovative knowledge-based businesses was most closely correlated with regional output growth and to the overall improvement of competitiveness (based on a composite index) between 1993 and 1999 (the correlation coefficient was 0.62 at a 95% significance level). Vence-Deza (1996) has, however, warned that the correlation between innovative inputs and innovation outputs does not necessarily remain constant and nor is R&D activity necessarily linked to other economic performance measures, such as changes in productivity levels.

Firm level

At a firm level, the impact of industrial R&D investment on corporate performance has sometimes been questioned. There is some evidence to suggest that increased R&D spending does not guarantee business success. It does, however, seem to lead to higher gross margins (i.e. revenue minus direct expenses incurred in making a product or service) (Jaruzleski, Dehoff and Bordia, 2004). What seems more often the case is that if a firm invests less in R&D than its competitors on a consistent, long-term basis, it will end up with less competitive products, a declining ability to benefit from R&D spillovers and, ultimately, poor corporate performance (Jaruzelski et al., 2004; DTI, 2005b).

The analysis of data merged from the French annual R&D survey for 2000 with CIS 3 (Table 1.1) provides some evidence of the close relationship of R&D, innovation and production¹². Compared to the innovating firms, all variables tend to move to higher values in the group of R&D performers (Mairesse and Mohnen, 2004). This suggests that the R&D performers in the sample show a higher tendency to innovate than their counterparts.

10 Statistically it is perhaps better to view these results as indicating a (static) association rather than a casual, dynamic relationship.

11 This confirms an earlier study by Lewison (1991, pp.392-395) who revealed a link between scientific output (scientific papers) and GDP for the regions of Italy over the period 1981-1986 and found an 'almost perfect correlation ($r^2=0.94$) of scientific output against regional GDP.' This was replicated on a wider European Union (EU) member state level, although to a lesser extent ($r^2=0.83$).

12 Total sample of 2253 firms, the sub-sample of 1399 innovative firms and the sub sample of 855 R&D performers.

Table 1.1

Manufacturing samples of all firms, innovative firms and continuous R&D-performing firms (R&D)* (France, CIS 3, 1998-2000)

Variables	Total sample	CIS Sub-sample	R&D Sub-sample
Number of firms	2253	1399	855
% of firms performing R&D continuously	37.9	61.1	100.0
% firms innovating with products new to the firm**	50.1	80.7	89.8
% firms innovating with products new to the market*	28.3	45.5	58.0
% firms with process innovation	34.7	55.8	57.5
% firms with at least one patent applied for in 1998-2000	32.4	48.2	63.5
% firms with at least one valid patent at the end of 2000*	34.6	49.6	64.7
Share of new to the firm innovative sales for firms of type	n.r.***	12.9	14.5
Share of new to the market innovative sales for firms of type	n.r.	5.9	7.7
Share of total sales covered by patents for firms of type	9.7	13.1	16.7

Notes: *All means are unweighted. **Indicator corrected to 0 if corresponding share =0. ***n.r.: not available or non relevant.
Source: Mairesse and Mohnen (2004)

Depending on the type of organisation (government or firm), the value placed on R&D outcomes and effects are different. Centrally for companies, 'R&D's value comes from its eventual impact on the business' (EIRMA, 2004a)¹³. As such, R&D helps improve firm performance (Section 3.2). In assessing a company's R&D effectiveness the starting point is strategy. The management of the company should find the right balance between R&D investments and business benefits in the short and long run, in line with stakeholders' expectations. Corporate managers favour short-term payoffs; stockholders prefer long-term investments. Depending on their organisational culture, type of activity and the influence of customers, etc. companies and other stakeholders select among R&D output and outcome indicators¹⁴. There is a time lag of at least three years between R&D investments and their output/effects (EIRMA, 2004a; Lin B-W and Chen J-S, 2005).

Case studies looking at the management of trade-offs between exploration and exploitation of R&D output and outcomes in the context of rapid incremental technological change and the firm's relative competitive position (i.e. whether an incumbent or a new entrant) provide evidence of different patterns of R&D values (Cesaroni et al., 2005). Generally, empirical studies show a positive relationship between R&D investments and the market value of the firm. Some new high technology firms have a strategy to develop a technology up to the stage that allows them to sell the company to an incumbent firm.

13 Value of R&D for governments is the growth of tax revenue, employment, competitiveness (productivity, etc.).

14 Main R&D output and outcome indicators: direct revenues; technology; knowledge & know-how; R&D outcome indicators: image, brand & stock value; sustainability; product leadership and customer satisfaction; technology leadership; innovativeness; cost efficiency (EIRMA, 2004a).

The results of an in-depth empirical analysis of the market value¹⁵ of publicly-traded firms in some continental European countries (France, Germany, Italy) and two Anglo-Saxon countries (the US and UK) show that a currency unit spent on R&D by a company in the UK is valued nearly three times higher by the financial investors than in the case of firms in France and Germany¹⁶. One explanation for this phenomenon could be related R&D management at the company level. Another important finding of the study is that in some countries the valuation of R&D investments on the stock market is affected by the corporate ownership structure. Thus R&D investments for firms in France and Italy that have a single shareholder owning more than 33% of the company's shares are not valued, while when there is no majority shareholder R&D is valued in the same as in the other countries (or even higher). This may suggest that the market is discounting the inflexibility of majority shareholders in reacting to market pressures (especially in France, where the government acts as the large, dominant shareholder). The study also provides evidence of the decline of market valuation of R&D expenditures in all the countries over time (Hall and Oriani, 2004).

1.2 R&D, trade and spillovers

There are also a range of wider impacts and effects associated with R&D. Three of these are analysed here in more detail. They are: R&D and trade; R&D and technological spillover effects; and the role of R&D in low technology industries. This section looks at each of these in detail.

1.2.1 R&D and trade

Technology intensity is often used as a proxy for R&D intensity and there is a high degree of overlap between these two terms (Godin, 2004). In turn, high-tech exports are sometimes used as a measure of technological intensity in an economy. This is often inadequate, as the bulk of high-tech exports are at the low-tech end of the product range and do not necessarily require indigenous R&D. Nevertheless, a very general relationship between high-tech exports and R&D intensity can be observed (see Figure 1.3 below).

The United States is the world leader in both imports and exports of high-tech products. In 2002, the US accounted nearly for 20% of high-tech exports on the world market, compared to the 16.7% share accounted for by the EU. In 2003, the EU's high-tech industry exports as a share of total manufacturing exports were one fifth lower than those in Japan or the US (European Commission, 2005a). Between 1996 and 2001 the EU region was able to increase the high-tech exports much faster than its main competitors. Another positive sign is that high tech exports increased nearly by the same rate as high tech imports. Despite these favourable trends, the balance of payments in high-tech trade remained negative for the EU. In the US and Japan imports of high tech products grew faster than high tech exports, but

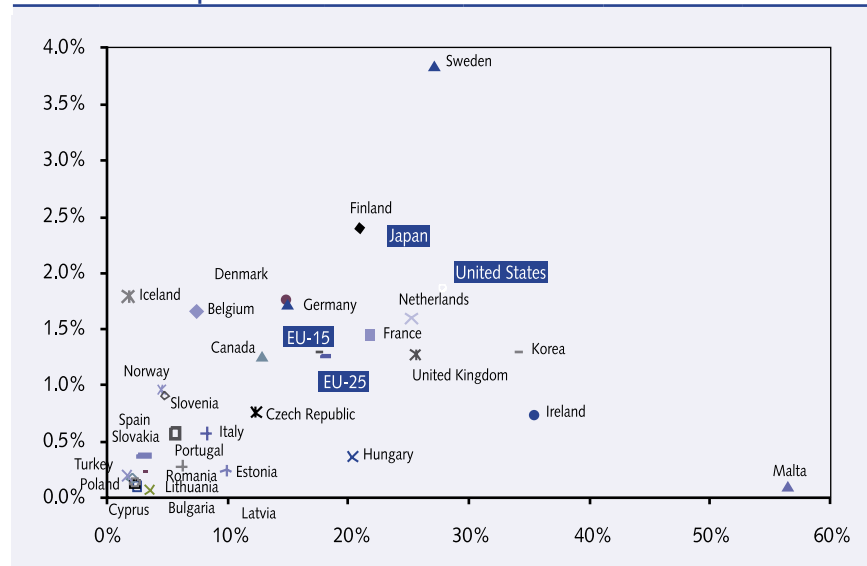
¹⁵ The stock market value has been used as the indicator of the firm's expected R&D outcome in number of empirical studies. The indicator has limitations, thus it can be applied only for publicly traded firms which are traded on a well functioning financial market (Czarnitzki, Hall and Oriani, 2002).

¹⁶ That is in terms of its impact on the stock market value of publicly traded companies.

these countries still had a structural trade surplus in high-tech manufacturing industries (European Commission, 2004a; European Commission, 2005a).

Figure 1.2

Share of business R&D expenditure in GDP and high technology exports as a share of total exports



Source: DG JRC-IPTS. Compiled from Eurostat and OECD data (2001 and 2002).

The figure above shows that there are countries with a comparably low R&D intensity but a high share of high technology exports (e.g. Ireland). These countries benefit from Foreign Direct Investment (FDI) and R&D spillovers. A considerable part of high tech exports in these countries is generated from affiliates of multinational companies utilising outputs of R&D performed elsewhere (EIRMA, 2005; Lucey, 2005). In many cases, FDI induces the development of domestic R&D capacity (see Walsh, 2003).

1.2.2 R&D, diffusion and spillovers

Frequent spillover mechanisms from R&D include patents, licenses, reverse engineering, formal and informal contacts, or the purchase of equipment and technology. Spillovers between firms are an important factor for competitiveness and growth. Often the most successful innovations do not come from 'early adopters' but rather from 'fast followers', who are capable of taking innovations from outside and modifying them to suit their needs and thus conquer markets. In addition, the most successful innovations are those which are based on tried and tested technologies.

Thus, it has been observed that the biggest share of the economic benefits of R&D results occurs during the longer term process of diffusion (DTI, 2005a). This process also works across sectors. Business R&D expenditure is concentrated in just a few sectors. R&D expenditures influence firm performance only in those sectors where R&D is an important input for production (Meister and Verspagen, 2005). Spillover effects can also be seen at the regional level. Thus, it has been revealed that areas close to existing successful innovative areas stand a much better chance of success; by contrast, poor regions surrounded by other poor regions do much less well in terms

of economic performance (Rey, 2001, p.213). 'Innovation poor' regions will therefore, ipso facto, not benefit as much in terms of economic development and growth. Given that there are strong, cumulative feedback processes at work here, these regions will suffer in future rounds of innovative activity and investment and so can become locked into a vicious cycle of innovation stasis or decline¹⁷.

To this analysis we should add an important caveat. We should be careful in terms of what we mean by the use of the term 'spillover'. Often studies imply that spillovers are the unforeseen and unintended consequences of research and technology 'leaking' out of firms and organisations that are then adopted, and provide benefit to, other firms and organisations. More usually they involve considerable effort on the part of the adopting or 'receiving' firm to benefit from such 'free' R&D and technology. It requires considerable effort and resources to effectively absorb, adapt and experiment with implementing such technology inputs. Here the role of applied R&D in such translation and absorption processes needs emphasising and this activity has, in the past, largely been overlooked by studies. On this basis, spillovers are often a much articulated, directed and programmed process than is implied in many studies exploring this issue.

Between countries, spillovers arise through trade in goods and services, technology transfer, or through knowledge exchange by experts (Meister and Verspagen, 2005). Some indications of spillover effects between countries can be revealed by analysing the Technology Balance of Payments (TBP). Payments for commercial technologies among countries are reflected in the TBP, which measures international technology transfers: licences, patents, know-how, research and technical assistance. The payments appearing in the TBP are therefore an indicator of how a country capitalises on R&D related outputs. The analysis of the TBP reinforces the role of spillovers for economic development. Just as shown for high technology exports, the diffusion of technology from an advanced to an emerging country can lead to positive growth and productivity effects (Papageorgiou, Savvides and Zachariadis, 2004).

Technological receipts and payments increased considerably in the OECD area between 1990 and 2000. This is a further sign of the internationalisation of R&D. The European Union's TBP in 2000 showed a deficit which was even higher than 10 years earlier.

For most countries, no disaggregated data are available on affiliated and unaffiliated transactions¹⁸. Nevertheless, the available information suggests that the transactions within the network of multinational companies dominate international technological receipts and payments (OECD, 2005a). This highlights the role of large multinational companies (MNCs) in inducing these spillover effects.

Examining the TBP by country, the main technology exporters per GDP are the UK, Switzerland Belgium, Denmark and the US. The TBP shows a considerable

17 Although it would be unwise to suggest that spatial development patterns get 'locked-in' indefinitely, for as Martin (1999, p.76) notes 'the past is always present, but is not always determining.'

18 The US Bureau of Economic Analysis (BEA) provides disaggregated data on the affiliated and unaffiliated transactions, but the most recent data refer to the beginning of the 1990s. The importance of transactions between unaffiliated parties has been increasing from 1986 to 2000 (OECD, 2005a).

deficit in Ireland, where foreign companies import technology know-how through their local affiliates (OECD, 2005a). Together with the relationship between high tech export share and R&D investment, this further highlights the importance of spillovers for the innovation system of this country. For countries with low R&D investment levels, FDI and R&D spillovers can serve as a seed for the development of domestic R&D capacity.

1.2.3 R&D, low technology and service industries

Traditionally, activities are classified according to their technology intensity, expressed as the relative expenditure of R&D in low, medium and high technology sectors (e.g. the OECD classification¹⁹). Consequently, typical low-technology sectors such as food processing, wood products and textiles are considered less concerned by R&D and technological strategies. Along the same lines, conventional thinking considers high-technology sectors to be the main drivers of the knowledge-based economy and therefore, most of the attention of technology policy is focused on those sectors. However, a number of recent studies have demonstrated the need to reassess the importance of low-technology sectors for economic growth and employment and the role of R&D and innovation on those sectors. There are a number of important arguments backing up the reported findings:

1. In many countries, a significant part of growth and employment is based on low and medium technology sectors (Sandven and Smith, 2005).
2. Less R&D intensity does not mean less innovation and technological development. Low and medium technology industries implement radical and incremental innovations that have important economic results.
3. These sectors also play an important role in the application of technologies developed in high technology sectors and particularly, in the ICT sector where they may be one of the main factors shaping demand and technological developments (Sandven and Smith, 2005).

The results of some recent analyses show that innovation is generally more sensitive to changes in R&D intensity in the low-technology sectors than in the high-technology sectors. Such outcomes suggest the existence of decreasing returns on R&D activity (Conte and Vivarelli, 2005, p.17). One study suggests that, in high-technology sectors, a 1% increase in R&D per employee increases the probability of innovation by around 20 percentage points on five innovation indicators. In the low-technology sector, however, a 1% increase in R&D per employee increases the propensity to introduce a new product to the market, a new process and the probability to hold a patent by around 40%. In the case of process innovation and patent applications, the increment is around 30% (Mairesse and Mohnen, 2004).

The simulation of the effect of the 3% R&D intensity target for European manufacturing indicates a decrease in the productivity gap with the US. Specific simulations focusing the R&D increase on high, medium and low

¹⁹ The OECD classifies sectors according to their technology intensity into high (e.g. aerospace, office machinery, computers, etc.), medium (e.g. automobiles, chemicals, other manufacturing, etc.) and low tech (e.g. food, beverages and tobacco, shipbuilding, textiles, etc.).

technology industries reveal that the low-technology sectors would show the strongest productivity improvements²⁰. Thus, Meister and Verspagen (2005, p.17) in their simulation study of the impact of R&D found that increases in R&D expenditure and intensity in low technology industries could be expected to have the biggest impact on productivity levels.

An important element within this group is the service sector. Thus, although the service sector relies less on R&D for innovation, service-sector investments in R&D appear to be rising rapidly. Between 1990 and 2001, service-sector R&D increased at an average annual rate of 12% across OECD member countries, compared to approximately 3% in manufacturing (OECD, 2005d). Large differences between growth rates in services and manufacturing are most pronounced in countries such as France, Germany, Japan, the Netherlands, Spain and the United States. While it is clear that a portion of the rapid growth in service-sector R&D is a statistical artefact reflecting better measurement of R&D in the service sector and a possible reclassification of some R&D-intensive firms from manufacturing to services (as their service activities have expanded), it also appears to reflect real increases in R&D by service-sector firms, driven by competitive demands or by increased outsourcing of R&D by manufacturing firms and government. However, available statistics indicate that R&D intensity in services has increased quickly in most OECD member countries, even in many in which manufacturing R&D intensity has declined. Denmark, Iceland, Sweden and the United States show relatively high R&D intensity in the service sector (over 1%) and high rates of growth, as each added a half-point or more of R&D intensity during the decade. In Australia, Norway and Portugal, R&D intensities in services and manufacturing are about equal.

1.3 The importance of R&D

Following the Barcelona and Lisbon agendas there has been much discussion about the role and value of R&D in modern knowledge-based economies (see, for example, Kok, 2004; Archibugi and Coco, 2005). Not only have recent trends been seen in negative terms as Europe continues to fall even further behind the rest of world in R&D activities, even in services R&D (Anon., 2005, p.16), but many commentators have gone back to taking a narrow view of R&D as simply about invention and 'blue sky' research which has little meaning for most Europeans.

This chapter has sought to emphasise the importance and significance of R&D in advanced economies not just in terms of directly generating new products and processes, but also indirectly in terms of such activities enabling firms and organisations to absorb new technologies which have been developed outside the firm and to utilise them effectively. In this way, in terms of helping to improve a firm's absorptive capacity and utilisation of technological and non-technological innovation, R&D activity undoubtedly has significant impacts on productivity change and diffusion in modern economies.

²⁰ Sector classification applied in the analysis: High-tech sectors: radio, TV & communication equipment; office & computing machinery; professional goods; aircraft. Medium-tech sectors: industrial chemicals, drugs & medicines; non-electrical machinery; electrical apparatus. Low-tech sectors: food, beverages & tobacco; textiles, apparel & leather; wood products & furniture; paper, paper products & printing; petroleum & coal products; Rubber & plastic products; non-metallic mineral products; iron & steel, nonferrous metals; metal products; shipbuilding & repairing; motor vehicles; other transport; other manufacturing.

Although they may be indirect, these effects may be just as significant as the more direct impacts. Above all it is important to recognise that R&D is a many-faceted activity (Forbes and Wield, 2004, p.268) that should not be narrowly conceived. As such, more research needs to be undertaken to properly gauge the effect of R&D in its true entirety and properly set it within the context of innovation and economic growth.

2. Trends in Industrial R&D

The world's industrial R&D investment experienced a period of turmoil following September 2001. Many companies went through a difficult period financially, particularly in 2002, and faced changes in patterns of consumption behaviour and in the demand for scientific and technological activity. As a result, in many countries the growth rate of R&D expenditure fell noticeably in 2002 and the shock continued into 2003 (Table 2.1).

Table 2.1

Annual Growth Rates of Total/Gross R&D expenditure (GERD) 2000-2003 in selected countries

Annual Growth Rate of Gross R&D Expenditure				
	2000	2001	2002	2003
Total OECD	5.91%	3.02%	0.75%	1.69%
EU-25	5.30%	3.79%	2.40%	0.94%
EU-15	5.27%	3.76%	2.50%	0.88%
US	6.36%	1.17%	-0.79%	0.85%
Japan	3.84%	3.13%	1.25%	3.42%
Non OECD				
China	30.70%	15.03%	23.77%	17.23%
Russian Federation	12.93%	17.81%	11.07%	10.33%

Source: OECD (2004c, 2005e, 2006a), Eurostat (2005a,b,c), PREST elaboration

Total R&D expenditure (GERD) in OECD countries as a whole was US\$ 575 billion in 2002 (USD 1995 PPP), representing an increase of some US\$ 5 billion on the 2001 figure. In 2001 the total R&D volume was \$ 570 billion (US\$ 1995 PPP) (OECD, 2004c, 2005e). This figure is equivalent to € 528 billion. In 2002 GERD was €535 billion at 1995 constant parity²¹.

In 2002 the share of R&D expenditure in OECD countries was about the 80% of world GERD; this means that total world R&D expenditure had reached around US\$ 715 billion. Of this total, R&D expenditure in the EU-25 accounted for 24.6%²², while R&D spending in the US accounted for 34.2% and in Japan 16% (OECD, 2004c, 2005b). The US, EU and Japan together account for approximately three quarters of the world's total R&D expenditure; this indicates a strong geographical concentration of knowledge-related investments.

The main recipient for the world's GERD is the business sector, which performs in the order of two thirds of the overall volume of R&D in terms of expenditure. Within the group of OECD countries, business sectors performed 67.3% of the R&D expenditure in 2003, while in the European Union (EU-25) only 63.4% of the total R&D expenditure was performed by the business sector. In 2001, business accounted for 69.3% of R&D expenditure in the group of OECD countries and 64.1% in the EU-25²³.

²¹ For USD-EURO exchange rates, we used the transfer rates as computed from OECD (2004c) and Eurostat (2005a).

²² US\$ 176 billion 95 PPP is the equivalent of €186 billion at current value.

²³ OECD Science, Technology and Industry Scoreboard, 2005,

In 2003 business financed 61.6% of total R&D expenditure in the OECD countries; a decrease of 2% compared to 2002. In the EU-25, business financed 55.4% of total R&D expenditure in 2001 and 54.3% in 2003²⁴. Within the EU-25, the share of the total R&D expenditure funded by the business sector varies from country to country. In 2003, only in Belgium, Germany, Luxembourg, Finland and Sweden did business account for more than 60% of R&D expenditure²⁵. However, a gap can be seen between R&D performed and R&D financed by the business sector in EU Member States. In 2001 and 2003 this gap was 5.7% on average in the OECD and 8.6% in the EU-25. In Japan the gap between R&D performed and R&D financed by business was 0.5% in 2001 and 0.7% in 2003, furthermore, the percentage of R&D expenditure performed by business grew from 73.7% in 2001 to 75% of the total in 2003. The trend in the EU-25 over the same period was the reverse (OECD, 2004c, 2005b and Eurostat, 2005a,b,c).

2.1 Trends in industrial R&D

In real terms world business (industrial) R&D expenditure more than doubled between 1981 and 2001²⁶. By the end of 2002, the volume of total world R&D expenditure by industry was estimated at \$485 billion (95 PPP), or €450 billion (95 PPP). However, growth was unevenly distributed in time and by country and region.

Table 2.2 shows the evolution of industrial R&D in the main groups of countries or countries spending on research around the world.

Table 2.2

Average annual growth rates of R&D expenditure performed by the business sector in selected economies, 1981-2002

	'81-'91	'91-'01	'01-'04
EU25	n.a.	n.a.	3.50%
EU15	4.31%	2.50%	n.a.%
US	4.60%	3.45%	2.76%
Japan	8.18%	2.02%	4.98%
Korea	n.a.	n.a.	10.42%
OECD	5.38%	3.31%	3.69%
China	n.a.	19.13%	25.63%
India*	n.a.	n.a.	n.a.
Russia	n.a.	1.37%	8.05%

Source: DG JRC-IPTS calculations based on OECD (2004b, 2006b) data and estimates from OECD reports.

* Data on India are not comparable with data in the table; detailed account is given in Chapter 4.

²⁴ Eurostat (2005b,c)

²⁵ See previous footnote.

²⁶ Computations were made on the basis of data reported in constant 1995 PPP (purchasing parity standards).

Over the period 1981-2001 the US economy showed a higher average growth rate of business R&D expenditure than the EU economy (which during this period was the EU-15)²⁷. Japanese companies increased their R&D expenditure at twice the US or EU rate during the 1980s, but decelerated afterwards, particularly in the early 1990s. It is only recently (after 1995) that EU R&D expenditure started to grow at rate a similar to that of its main competitors in the world. As may be observed in Table 2.3 below, the result of these changes is that the shares of world industrial R&D accounted for by the various different countries or regions have varied quite significantly in recent years.

Comparable data for India are unavailable, but the dynamic of R&D expenditure of the Indian economic system has been considerable over recent years (Chapter 4). The stagnation of business R&D expenditure in the major countries of the OECD group in 2002-2003 has coincided with rapid development in research spending in some non-OECD countries such as China, India, Russia and Israel. This phenomenon explains the significant decrease in the share of the world's total business R&D expenditure accounted for by the OECD countries over a period of only 7 years. The main contributor to this trend is the US economy, which has been showing practically constant figures for its business R&D expenditure (in real terms) since 2000.

A slight recovery was seen in 2004 and according to estimates and trend analyses, the picture expected for 2005 is much more optimistic: 'companies are more willing to increase R&D and capital spending as well as do more hiring' in their research units (Industrial Research Institute, 2005). Table 2. shows the growth rates of the share R&D expenditure financed by the business sector for the main countries spending on business R&D during 2000-2003:

	2000-01	2001-02	2002-03	2003-04
EU25	6.9%	4.3%	2.2%	3.9%
Germany	2.7%	3.6%	3.9%	3.9%
UK	8.7%	8.7%	1.6%	-2.0%
France	9.3%	5.1%	-1.3%	2.4%
US	1.0%	-4.0%	5.2%	7.5%
Japan	9.4%	5.1%	5.1%	4.8%
Canada	16.5%	-7.4%	-1.0%	1.3%
Korea	18.4%	3.4%	11.1%	17.3%

Source: DG JRC-IPTS calculations based on OECD (2006b) reports. Growth rates are calculated on the basis of 2006 PPP US dollars.

The short time-frame of this analysis (3 to 4 years) does not capture the effects of business cycle on R&D expenditure. From detailed studies (Rafferty, 2003; Maliar & Maliar, 2004) we can deduce that business cycles influence R&D expenditure in two ways. Firstly, business cycles are asymmetric, meaning that they do not occur at the same time all over the world. Secondly, as

²⁷ It needs to be pointed out that 2001 was a local peak, which may distort the picture.

business R&D expenditure is mainly funded from cash flow, the growth of R&D expenditure in a certain area is linked to the economic growth in the same region. There is also another factor to mention here: while long term R&D investment programmes (large investments in 'blue sky' research and long term investments in human capital) are negatively correlated with economic growth, the cumulative dynamic of total R&D expenditure is procyclical; this means that in periods of economic expansion total business R&D expenditure tends to increase and R&D programmes tend to favour shorter-term applied R&D, whereas during times of economic contraction the reverse is true.

2.2 Trends in major R&D-investing companies

The 2005 EU Industrial R&D Investment Scoreboard (European Commission, 2005d) captures over 50% of the total European industrial R&D investments as funded by the top 700 European R&D investors (€102.2 billion in cash terms) and in excess of 50% of the world's R&D expenditure by the top 1,400 R&D spenders in the same year (for a total of €315 billion in cash terms)²⁸. The figures published in the 2005 EU Scoreboard show that for the financial year ended in 2004, the R&D expenditure of the top European performers grew by 0.7%, reversing the trend of the previous year. Although this is a positive result, the gap between the top EU investors in R&D and the top non-EU 700 R&D spenders is still wide as on aggregate they experienced a growth rate in R&D spending of 6.9%²⁹.

DG JRC-IPTS's calculations show that the overall R&D investment of the top 1000 companies investing worldwide in research and development reached € 324.87 billion in cash terms during the 2004 financial year³⁰. This figure represents approximately 54% of the overall world's industrial (business) R&D investment.

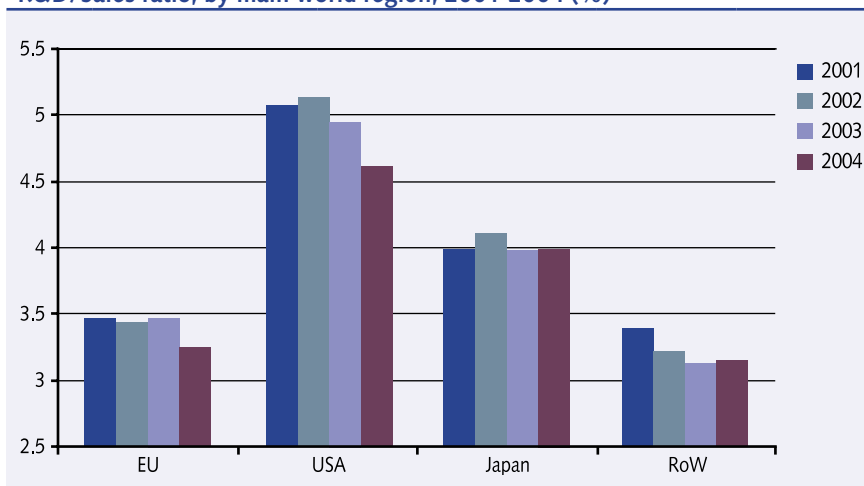
28 The R&D investment included in the Scoreboard is the cash investment which is funded by the companies themselves. It excludes R&D undertaken under contract for customers such as governments or other companies. It also excludes the companies' share of any associated company or joint venture R&D investment. Where part or all of R&D costs have been capitalised, the additions to the appropriate intangible assets are included to calculate the cash investment and any amortisation eliminated. In order to perform the calculation itself, the R&D expensed to the profit and loss account (i.e. R&D 'expenditure') is added to any capitalised R&D intangibles (i.e. R&D 'investment') and then any amortisation of capitalised R&D charged to the profit and loss account is subtracted from the resulting total R&D expenditure

29 Sectoral difference adjustments need to be taken into account: highly R&D-intensive sectors in the EU account for a smaller proportion of total output than in the US or Japan (see Section 2.5).

30 The R&D results for the top worldwide R&D investors are very close or similar regardless the source of information. However, the figures reported by the three main Scoreboards are different due to different currencies used as the basis for reporting (Euro, US dollar or Pounds Sterling) and may also present some small variations (following currency conversion equivalence) for several companies for which the different dates of sampling the financial accounts caused variations (either coming from different financial years that were taken into account, or as a result of changes made by companies themselves during the reporting period). For example, the UK's Department of Trade and Industry estimates an overall increase in the spending by major companies investing on R&D worldwide which reached € 309.78 billion in cash terms in 2004-5. This estimate is based on the top 1,000 R&D investing firms (DTI 2005b, p.33).

The 2005 EU Scoreboard also shows that R&D intensity (calculated as the ratio of R&D expenditure to Sales) decreased between 2003 and 2004 in the EU and decreased for the third year running in the US. As some of this tendency is due to the relatively fast growth of sales with respect to R&D expenditure over the last two years, the regional differences in R&D intensity can be attributed to the different industrial structure of the regions.

Figure 2.1
R&D/Sales ratio, by main world region, 2001-2004 (%)



Source: European Commission (2005d).

DG JRC-IPTS calculations on 2005 EU Scoreboard data show a high degree of concentration of business R&D expenditure by company. The same is true of data from the US Scoreboard. The 10 biggest firms support 30% of corporate R&D investment by US firms, the 100 biggest companies bear around two-thirds of the total and the 1000 biggest, 90% of the total. Among the top 100 US R&D investors, 9 companies were new entries on the list, and there was significant change in the relative rankings of companies, depending primarily on the sector of their main activity. ICTs, pharmaceuticals, biotechnology and health showed the most dynamism within this group.

One feature that emerges is that, although mergers and acquisitions are still having a powerful effect in terms of changing the rankings of top R&D-investing companies (see also Sections 2.4 and 4.2), the dynamism of the firms engaged in R&D in emerging sectors is off-setting the tendency towards concentration at the top. Thus the share of medium and small R&D-investors increased during the last period. The explanation is the surge in outsourcing by big companies and an increase of R&D performed by small and medium-sized enterprises. In the US, for 12 out of 17 sectors, R&D investment increased in parallel with sales. In the office & computing, telephone & telecommunications and Internet & communications sectors, R&D spending decreased while corporate profits increased significantly. Comparing the US firms with the international (worldwide) companies in the US Scoreboard, the latter increased their R&D investment by an average 10.2%, almost twice the increase observed for the US companies.

This analysis, although it describes general trends in R&D investments, should be considered with some caveats, the most important of which is probably the systematic underestimation of the contribution to the R&D base of a country or a region of research and technological development

by small to medium-sized companies (SMEs), whose investments in R&D are less conspicuous than those of the 'big spenders'. Specifically, a country with an industrial structure based on an extended systems of SMEs can be a significant contributor to R&D expenditure and indeed to the system of innovation of the region but have only a limited presence in R&D Scoreboards. This is in fact the case of Italy, whose productive structure is dominated by SMEs and its position in the following analysis is limited only to a few entries (25 companies in the EU-based top 700) despite its relatively significant contribution to shaping R&D trends. Italy's contribution to business R&D expenditure is in the region of 8 - 10% of the total EU-25 BERD. Nonetheless the study so far raises a cogent question regarding the structure of the EU productive system and the effectiveness of the R&D. Indeed some companies claim to make better or more efficient use of R&D spending even though their R&D investment is lower than other companies involved in the same line of business. The issue of whether, in order to boost innovation, a system needs more R&D rather than better R&D is the heart of the debate on strategic R&D management and policy.

2.3 Industrial R&D by sector

R&D expenditure is highly concentrated in certain sectors of the economy³¹. According to Eurostat (2003) data, four sectors accounted for 55-56% of the total R&D expenditure performed in the EU and US, and for 61-62% in Japan, in 2000. These four sectors were motor vehicle manufacturing, pharmaceuticals, office equipment, electronics and electrical machinery.

Similarly, the 2005 EU Scoreboard shows that 67% of R&D investments are concentrated in four sectors: automobiles and parts (19%), IT hardware (18.6%), pharmaceuticals and biotechnology (18.2%), and electronic and electrical equipment (11.2%)^{32,33}. These four sectors accounted for only 4.1% of the total gross value added generated in 2000 in the European Union economy and for 4.6% of total value added in the OECD countries.

However, when accounting for the impact of the investment in R&D throughout the entire economic system, one can identify the horizontal and multiplicative effects of innovation, technology transfers or development of new products, processes and technologies originated in R&D-intensive sectors and consider the net advantage of the overall investment in research and technological development.

According to the results for companies listed in the 2004 and 2005 EU Scoreboards, the EU has higher R&D intensities (R&D investment/net sales ratios) than the non-EU world in six of the top ten R&D-performing sectors

31 In the following discussion the NACE (Nomenclature générale des Activités économiques dans les Communautés Européennes) classification, used within the European Commission (Eurostat) has been taken into consideration unless otherwise stated.

32 The classification is based on the self declaration of main activity by companies when registering on stock exchanges, here the FTSE (Financial Times and London Stock Exchange) classification has been used.

33 The 2005 DTI R&D Scoreboard shows a similar picture: R&D investment of the top 1,000 R&D-investing companies in the world is concentrated in four sectors of main activity, which together accounted for 67.3% of the overall world's R&D investment in 2004: automobiles and parts (18.8%), IT hardware (18.6%), pharmaceuticals and biotechnology (18.1%), and electronics and electrical (10.8%).

(Table 2.4). However, in the EU average R&D intensity across all sectors is lower. This is explained by the fact that high R&D-intensive sectors make up a smaller share of the EU economy.

Table 2.4

Sector R&D/Sales ratios for top R&D-investing companies registered in EU vs. companies registered outside EU

FTSE Sector	EU TOP 700		Non-EU TOP 700	
	R&D/ Sales ratio (%) 2004	R&D/ Sales ratio (%) 2003	R&D/ Sales ratio (%) 2004	R&D/ Sales ratio (%)2003
Automobiles & parts	4.6	4.6	4.0	3.9
Pharmaceuticals & biotechnology	12.5	12.4	15.4	14.9
IT hardware	13.7	15.4	7.9	8.4
Electronic & electrical equipment	6.0	6.4	5.4	5.5
Chemicals	3.9	4.2	3.5	3.7
Aerospace & defence	8.4	8.1	2.8	2.7
Engineering & machinery	2.4	2.5	2.6	2.7
Telecommunication services	1.1	1.1	1.9	2.2
Software & computer services	11.3	11.5	10.6	11.5
Oil & gas	0.3	0.3	0.4	0.5

Source: European Commission (2005d)

The development of business R&D expenditure per sector (as a percentage of total business R&D expenditures) shows a shift from R&D in manufacturing to R&D in services in both the EU and the US. In 1991, firms from the manufacturing sector in the OECD were responsible for 83.9% of total business R&D expenditure, while in 1999 this percentage decreased to 76.8% (OECD, 2004b). This shift was mainly caused by the decrease of BERD in the manufacturing sector in the US and to a lesser extent the EU. This means that the relative importance of industrial R&D in the service sector increased in these regions.

Within the manufacturing sector, industrial R&D in the automobiles & parts industry as a percentage of total industrial R&D increased in Europe (from 13.3% in 1992 to 16.9% in 2003), but stagnated somewhat in the US (from 8.9% to 8.3%). One reason for this could be the mergers and acquisitions (M&A) activities in Europe. In particular, the German company Daimler Benz (one of the top R&D-investing companies in the world) acquired the American Chrysler Corporation in 1998.

R&D expenditure in the pharmaceutical sector (as a share of the total industrial R&D) shows substantial growth rates during 1991 to 2003. The EU increased BERD from 9.9% to 13.4% of total business R&D expenditures and the US from 6.0% to 7.8%. Pharmaceuticals in Japan also showed an important rate of growth of R&D expenditure over this period: from 6.1% to 7.5% of total business R&D expenditures.

Table 2.5

Business R&D expenditures by sector as a percentage of total business R&D expenditure, 1991-2003

	US		EU1		Japan	
	1991	2003	1992	2003	1991	2003
Total manufacturing	75.7	63.3	88.7	82.8	96.3	88.9
Motor vehicles	8.9	8.3	13.3	16.9	12.8	15.1
Pharmaceuticals	6.0	7.8	9.9	13.4	6.1	7.5
Office & computing machinery	9.6	3.8	4.0	2.0	9.5	12.7
Total services ²	24.3	36.1	8.0	15.0	0.2	9.1

1. EU includes the 15 EU Members before 1 May 2004 excluding Austria and Luxembourg.

2. Due to differences in data reporting methodologies, service sector R&D figures are not fully comparable across countries. Based on ISIC classification.

Source: OECD (2006c)

The service sector shows the largest relative increase in BERD; in the OECD countries it increased from 14.4% to 20.8% during 1991 to 1999 (OECD, 2004b). In the EU, it increased from 8.0% to 15.0% from 1992 to 2003. In Japan and the US, the change was also very significant (see Table 2.5).

An analysis of the stock of researchers in each Member State location of the EU shows a substantial growth in industry, and that this growth is mainly driven by the service sectors. The analysis also demonstrates smaller EU countries rather than large countries are driving the overall growth in the number of researchers in the private sector, and that in these smaller EU countries researchers in the private sector are mainly employed by SMEs.

The total growth of the stock of researchers in the EU between 1995 and 2003 (29%) is driven by the business sector (38%). This can be seen as a proxy indicator for R&D investment given that much of industrial R&D investment, especially in the EU, goes on human resources. This growth in the stock of researchers in industry is driven by services sectors, which corroborates the findings of the 2005 *Scoreboard*. As an example, the evolution from 1995 to 2003 resulted in a halving of researchers in computer manufacturing, and a doubling of the number of researchers in computer-based services.

Table 2.6

Evolution of the numbers of researchers (full time equivalent) and of BERD (in constant 1995 PPS) between 1995 and 2003

	Total	Business	Manufacturing	Services
Researchers	29%	38%	24%	151%
Expenditures	29%	33%	25%	122%

Source: Eurostat New Cronos (2005).

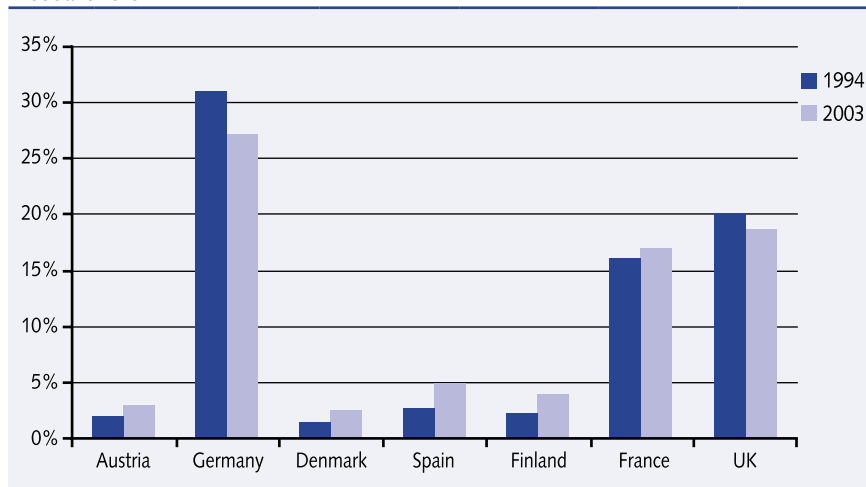
Although three EU countries (i.e. DE, UK and FR) still account for a large fraction of the researchers in industry (62%), their share in the overall EU-25 figure has decreased between 1994 and 2003 by over 7%. Some of

the smaller countries (e.g. ES, DK, FI, AT) have substantially increased their weight during the same period.

There are striking differences in the distribution of researchers according to the size of the companies they work for. In Germany, about 80% of researchers work for companies with more than 500 employees. In the UK or Sweden, the respective figures are 65% and 75%. On the other hand, the proportion of researchers in large firms is only 30% in Spain or Ireland and around 50% in the Netherlands, Denmark and the Czech Republic.

Figure 2.2

Relative weight of selected countries in EU total number of industrial researchers



Source: DG JRC-IPTS calculation based on Eurostat New Cronos (2005) data.

2.4 Sector outlook

The differences between the EU and non-EU (mainly US and Japan) industrial structures referred to in the previous sub-section are particularly clear in the case of emerging high-tech sectors such as ICT (IT hardware and software & computer services), pharmaceuticals & biotechnology and health. Figures for 2004 explain the poor performance of the EU on R&D expenditure – at a systemic level – even if some European companies are amongst the top performers in their respective sectors.

2.4.1 ICT

The 2005 EU Scoreboard findings suggest that the structure of EU industry differs from that of the non-EU countries, with the EU having a smaller proportion of output from high R&D/sales sectors and a much larger proportion of output from relatively low R&D/sales sectors. This is particularly noticeable in IT hardware and software & computer services. The proportion of US companies in the ICT sector is almost twice as large as the proportion of EU companies. Indeed, much of the difference in overall R&D intensity can be explained by the differences in size in IT hardware and software &

computer services between the EU and non-EU companies. Together, IT hardware and software & computer services represent only 3.0% of the sales of the top EU firms in this Scoreboard, compared to 15.3% for the non-EU firms (Table 2.7).

Table 2.7
R&D indicators for top R&D-investing companies registered in EU vs. companies registered outside EU, active in ICT sectors, financial year 2004

Factor	EU-700	Non-EU 700
R&D Investment (€ million)	13906	64366
R&D Investment (% of Top 500)	13.6%	30.2%
Number of companies	132	219
R&D Investment /Company (€ million)	105	294
Net Sales (€ million)	105996	782070
Net Sales (% of Top 500)	3.0%	15.3%
Employees (thousands)	436	3212
Sales/Employee (k€)	243	243
R&D Investment per Employee (k€)	32	20
R&D / Sales Ratio (%)	13.1%	8.2%

Source: DG JRC-IPTS own calculation based on data from the 2005 EU Industrial R&D Investment Scoreboard (European Commission, 2005d).

The total investment of non-EU companies active in the ICT sector is more than four times the corresponding value of the top EU ICT firms. The net sales of the non-EU companies in ICT are seven times those of the EU companies. Additionally, average R&D investment per company by non-EU firms is almost three times that of EU companies. Sales per employee are exactly the same, although the employment in non-EU companies is considerably higher, which leads to a smaller R&D investment per employee than their EU counterparts. Considering also that R&D intensity (R&D expenditure over sales) is higher for European companies, this suggests that the European ICT sector is formed by companies of a smaller average size and with a more distributed structure with respect to their non-European counterparts. Moreover, European R&D 'champions' active in the ICT sector are more technology-oriented than non-EU companies, which have a more commercial orientation.

2.4.2 Pharmaceuticals & biotechnology

In the pharmaceuticals & biotechnology sector, the EU and the non-EU companies have a similar share of R&D investment out of their respective groups and also have a similar R&D intensity. It seems that both the EU and the non-EU pharmaceuticals and biotechnology sector have a similar structure and that the general performance of the firms in the two regions is quite similar. However, non-EU companies are, on average, twice the size of their EU counterparts. This is true in terms of net sales, R&D investment and total employment. Nevertheless, a slightly higher efficiency per employee can be observed among non-EU companies, this may be a result of stricter regulatory policy in Europe, particularly as concerns the labour markets.

Table 2.8

R&D indicators for top R&D-investing companies registered in EU vs. companies registered outside EU, operating in pharmaceuticals & biotechnology, 2004 financial year

Factor	EU-700	Non-EU 700
R&D Investment (€ million)	17571	39409
R&D Investment (% of Top 500)	17.2%	18.5%
Number of companies	94	93
R&D Investment /Company (€ million)	187	424
Net Sales (€ million)	140716	297753
Net Sales (% of Top 500)	3.9%	5.8%
Employees (thousands)	532	907
Sales/Employee (k€)	265	328
R&D Investment per Employee (k€)	33	43
R&D / Sales Ratio (%)	12.5%	13.2%

Source: DG JRC-IPTS calculation based on data from the 2005 *EU Industrial R&D Investment Scoreboard* (European Commission, 2005d)

2.4.3 Health

In the health sector, the EU companies are smaller in size, have a much smaller output and invest far less in R&D than non-EU companies. Also their R&D-to-sales ratio is smaller than that of their counterparts. However, they have a similar presence in the top 700 in terms of number (Table 2.9). This suggests structural differences between the two company groups. In terms of sales and R&D intensity, the non-EU companies (mainly US companies) are expected to benefit from efficiencies of scale, following their earlier movement towards internationalisation through mergers & acquisitions.

Table 2.9

R&D indicators for top R&D-investing companies registered in EU vs. companies registered outside EU, acting in health sector, financial year 2004

Factor	EU-700	Non-EU 700
R&D Investment (€ million)	1713	4748
R&D Investment (% of Top 500)	1.7%	2.2%
Number of companies	23	22
R&D Investment /Company (€ million)	74	216
Net Sales (€ million)	34002	61624
Net Sales (% of Top 500)	1.1%	1.2%
Employees (thousands)	239	313
Sales/Employee (k€)	142	196
R&D Investment per Employee (k€)	7	15
R&D / Sales Ratio (%)	5.0%	7.7%

Source: DG JRC-IPTS calculation based on data from The 2005 *EU Industrial R&D Investment Scoreboard* (European Commission, 2005d).

2.5 Industrial R&D expenditure by funding source

The largest share of the business R&D expenditure is financed throughout the world by the business sector, whether the financing company is domestic or foreign-owned. Moreover, this share has increased over the last two decades, as figures for the OECD group of countries prove: in 1981, the share of business R&D expenditure financed by industry in total was 76.1%; in 1991, the same share was up at 82.6% reaching 89.2% in 2002 (OECD, 2004c). Thus the business enterprise sector constitutes the most important source of funding of domestic R&D in the EU, but the growth rate of the share has not been as high as that for the OECD as a whole. In 2002, the share of R&D financed by business amounted to 55.6% in Europe, compared to 63.1% in the US and 73.9% in Japan. Within the EU, Luxembourg, Sweden, Finland and Germany ranked highest in terms of the share of R&D expenditure funded by the business sector (European Commission, 2005a).

Thus there is a large variability in the above-mentioned share among countries: in Japan, Korea, United States, Germany, Finland, Ireland, Luxemburg, Switzerland or Sweden, the share of industry-financed business R&D expenditure in total BERD has traditionally been high or has increased significantly in latest years, surpassing 90%. By contrast, there are countries in which this share has traditionally low or recently fell, such as United Kingdom (around two thirds is financed by domestically registered industry), Canada (three quarters), Austria (around 65%), Belgium, and the Netherlands (where it has dropped by almost ten percent in the last ten years, towards a level of 80%). The fiscal treatment of foreign-owned companies and the general financial legislation may produce changes in the statistical series reported for this indicator and may be one of the main reasons explaining the big differences between countries.

Another clear trend was the continuous decline in the share of the government-financed business R&D expenditure over the last twenty years, as a result of a world-wide effort to curb subsidies offered to domestic industry and to find other policy measures to support industrial R&D. This share was traditionally very high in ex-communist countries (and continues to be high in the Russian Federation: around 50%) or in countries with a strongly centralised administration (such as India, Turkey, Brazil), but also in some of the G-7 countries (including the US, Italy, France and the United Kingdom). Between 1981 and 1991, the share of government-financed industrial R&D came down in OECD countries from 22.3% to 14.7% and continued to decrease further until 2002, when it reached 7.1% only. However, the government sector is still a large source of R&D funding in low R&D-intensive countries such as the Southern European countries and the new Member States. Thus, in 2002, Cyprus, Lithuania, Poland and Portugal still received more than 60% of their R&D funding from the government sector.

3. Factors Influencing Industrial R&D

Why firms invest in R&D is an important aspect of why R&D spending is distributed as it is. Companies are influenced by competitors' activity and so certain norms can emerge in an industry. The reasons for doing R&D are also understood in various ways. For example, companies might use R&D to develop new and improved products, processes and services or to develop new business opportunities. What is not known in detail is why many companies do not invest in R&D, or do not invest more in R&D, or do not invest more widely in R&D opportunities across their potential business and technological capability. This absence of activity is more difficult to determine. Some firms are more entrepreneurial and are prepared to address ambitious challenges. Some firms have narrowly defined objectives; some for example have emerged from larger business organisations as a result of restructuring or business simplification exercises. The rationale was often to create lean highly focused and dedicated enterprises. R&D centres have often been closed down for similar reasons. Comprehensive evidence about these changes would need to encompass a vast number of specific changes within companies and so information about the trends tends to be anecdotal or illustrative.

This chapter focuses, from a company perspective, on the motivational factors and acknowledged trends in industrial R&D strategy and their implications for an understanding of R&D investment decisions and hence their policy implications.

As is often stated by business managers, a stable and conducive business environment is a major influence on investment decisions. There are, however, some paradoxes in R&D investments. Decisions can be related to the business cycle even though it might make better sense to invest more heavily while the economy is weak in order to prepare for the future. In the short term R&D may be bad for the share price, as business performance and profits can be 'massaged' by cutting 'non essential' expenditures such as R&D. The roles of R&D and technology champions at a senior level in an organisation may therefore be very important to overcoming these short-term pressures.

In addition to encouraging more activity by firms with an existing European base it is desirable to attract new activities and centres to Europe. Europe and its regions and member states need to identify and create incentives and good conditions but these are different from influencing more expenditure since companies seeking to locate new or additional R&D in Europe have already decided to make the investment but have not decided the location.

European regions, and Europe as whole, have other factors to consider such as creating high calibre jobs or stemming the brain drain. These might be negotiation points with business managers but are not primary driving factors except in so far as R&D can be used to support graduate recruitment to a business or region. The wider aspects of R&D investments therefore need to be considered³⁴.

³⁴ See for example the recent Communication from the Commission to the Spring European Council 'Working together for growth and jobs: A new start for the Lisbon Strategy' (European Commission, 2005c).

3.1 Reasons to undertake R&D

Firms use R&D to improve their competitive advantage and to respond to commercial pressures. They must also comply with environmental and regulatory standards and R&D is useful for this purpose. The strategic management of R&D therefore depends on the sector in which a firm operates and even more specifically on the position of the company within its sector. This may explain why, when measured by expenditure, R&D is concentrated heavily in a relatively small number of firms (the top R&D-investing firms in Europe, or globally, are identified in R&D scoreboards). Levels of R&D investment also depend on the business, technology and innovation strategies which management teams formulate for their companies, according to their vision and ambitions for the future. Stakeholders (especially shareholder's expectations) play an important part in influencing those processes.

Other factors are historical or are determined by scientific and technological prospects, and industry maturity. For example, science-based firms – such as pharmaceuticals – tend to concentrate more on basic science in order to create new products, while scale-intensive firms – such as chemicals – tend to concentrate on process innovation and incremental product development. Within each sector firms can adopt quite different R&D strategies. Sectors also comprise a range of types of company, some of which may work together in a value chain. A better understanding of these differences in R&D strategy and purpose could lead to more effective policy measures to encourage and promote industrial R&D. Nevertheless, within a sector different firms can adopt quite different R&D strategies; patent protection and the time needed to commercialise R&D outputs and test new products in the marketplace can influence this.

Over the last few decades managers have become progressively more concerned about the effectiveness of R&D. They have become more sophisticated both at deciding what is an appropriate level of R&D activity for the business and at measuring its R&D performance. They have established new organisational structures and management systems for R&D and have created new R&D ecologies in which knowledge is developed and shared between companies, including suppliers and customers, and with universities and research institutes.

Much R&D is financed internally but in recent years R&D has increasingly become more dispersed and decentralised across networks of firms. As businesses have become more specialised, R&D performers have become more specialised too. Some businesses have decided to exploit their R&D capability as a business and have become technology suppliers. Industries have significantly restructured in the last decade and as a result much R&D has been refocused on the exploitation of technology (e.g. via open innovation or fifth generation R&D management methods³⁵) rather than just the internal appropriation of R&D results within a single business.

The cost of R&D activities depends on the characteristics of the work required. In general it becomes more expensive as work progresses from idea or concept (or laboratory) towards detailed design, prototyping, and the production facility or marketplace. The scale of work increases although

35 See Rothwell (1992).

not all the foregoing steps are needed for all products and services, and market and technical testing can be prohibitive for many firms. So some companies may be deterred from embarking upon R&D because they cannot afford to follow through to full scale market introduction. They might lack management experience in obtaining finance or negotiating partnerships which will eliminate that downstream challenge. Companies use 'stage gate' processes to evaluate which projects and programmes to proceed with, and how quickly to do this. Investing in early stage work or deciding to acquire knowledge at a later stage (analogous to the classic 'make or buy' decision) are important choices; options thinking and internal venture capital to acquire expertise are approaches employed by some companies to reduce risks and cost. Working with universities and collaborating in networks is a related strategy.

Companies finance their R&D in various ways. Internal finance is used extensively but the changes in R&D ecologies described above have also changed the way in which R&D is financed. The use of public funding to support industrial R&D can modify perceptions of risk and induce companies to share their expertise. Public funding and measures such as R&D specifications within public procurement can leverage private efforts.

Over the years companies have experimented with different systems and structures for organising R&D. The kinds of changes seen have involve restructuring or even closing down R&D departments, and decentralising R&D to business divisions and closing corporate laboratories. There has also been a shift in emphasis from technology push to market pull and towards more interactive models such as fifth generation management. Many companies have introduced TQM and knowledge management systems. They have learned to measure R&D performance with increasing sophistication and have devised various methods to reduce risk. These include the acquisition of technology from external sources, strategic alliances and collaborative R&D networking, contracting out R&D, running R&D departments 'as a business', and exploiting intellectual property. R&D programmes have been focused more closely on innovation requirements. Forecasting and roadmapping techniques have also been deployed. The use of these approaches is not uniform across industries and so policies that can help to improve the efficiency and effectiveness of R&D might be as useful to the economy as policies which help to raise investments in R&D.

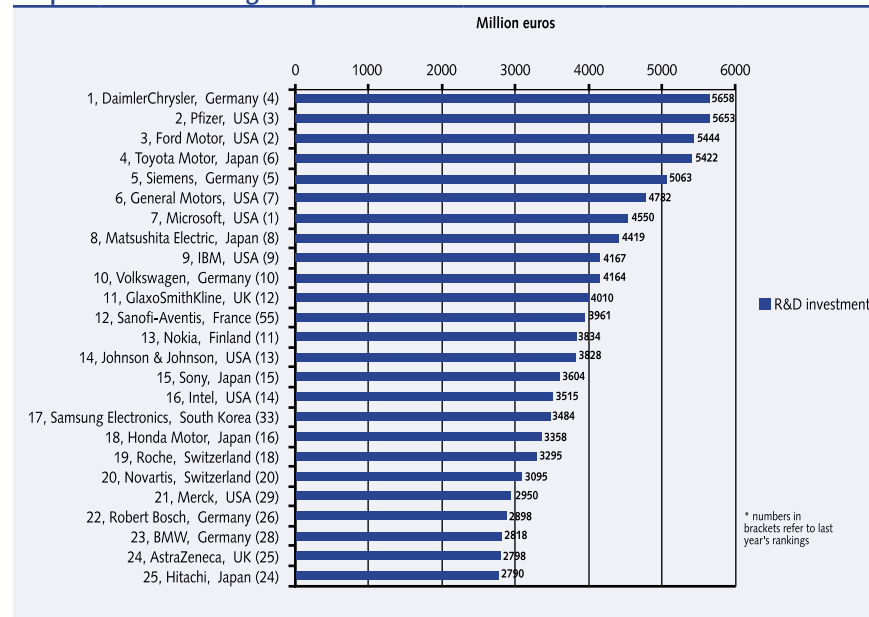
Companies have used benchmarking and industry clubs to learn more about the R&D management methods of competitors or similar size companies. The UK R&D Scoreboard has helped to fulfil this function. There may not be fixed norms that need to be adhered to for a sector but there can be useful insights and stimuli to discussion. According to the 2005 EU Industrial R&D Investment Scoreboard (European Commission, 2005d), Daimler-Chrysler, designated as a European company after the merger of its US and European activities, invests more in R&D than any other company in the world. But the automotive sector is not as R&D intensive as pharmaceuticals. The Scoreboard shows that R&D investment among the top 700 EU companies grew slightly in the year running up to August 2005, in contrast to 2003-4 when spending went down. However, a wide investment gap remains between the top 700 companies inside and the top 700 outside the EU. The Scoreboard shows there are fewer EU companies present in sectors which invest more than 5% (of their sales) in R&D, including sectors with the fastest growing R&D.

The Scoreboard shows that, on average, EU companies invest a smaller proportion of their sales in R&D. One explanation for this is the spectrum

of industrial activities represented: most EU companies are in sectors characterised by a medium sales-to-R&D investment ratio (e.g. automobiles & parts). There are fewer companies in the EU active in sectors where a higher proportion of sales is invested in R&D) such as biotechnology, health and ICTs. Thus total R&D expenditures, proportional R&D expenditures, and the size of industry and market served by an appropriate R&D programme are important factors when trying to understand the effectiveness of R&D expenditures. The more that open innovation concepts permeate an industry the less likely R&D efforts will be duplicated. If a country is strongly represented by major companies in a particular sector, its overall R&D investments will be high but there may be much duplication of effort which is being absorbed by the individual businesses.

Figure 3.1

Top 25 R&D investing companies in the world in 2004



Source: European Commission (2005d)

In Figure 3.1, nine out of the top 25 companies are EU-based. This is a reasonable proportion compared with the US or Japan, but in general terms, in order to understand what might be done about the overall status of industrial R&D in Europe we need to clearly understand what motivates private firms to invest in R&D. Trends (see Chapter 2) seem to suggest that Europe is suffering from a fundamental deficiency or lack of propensity to invest in R&D.

A recent qualitative survey of companies shows a positive outlook for R&D over the next few years (European Commission, 2005b). The survey shows that 95 of the top 500 EU corporate R&D investors expect their R&D investment to grow by about the same rates for the next year (+ 5.6%) and the next three years (+ 5.8% p.a.). They also expect a recovery in R&D investment growth compared to previous years. 16 of the 22 sectors surveyed stated positive expectations for R&D investment, with companies in the most R&D intensive sectors expecting higher growth rates for R&D investment than those in other sectors. The survey (European Commission,

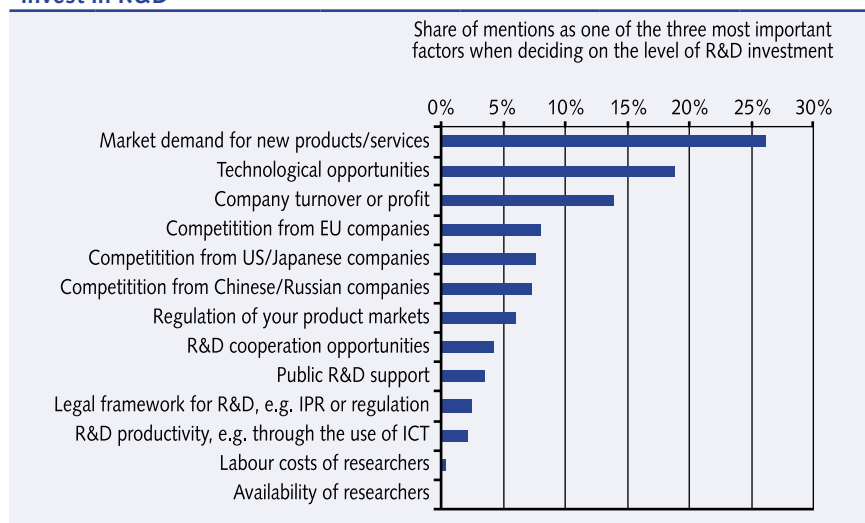
2005b) reveals that the strongest factors affecting companies' intentions to increase R&D investment are:

- market demand for new products and services (mentioned as the most important factor in 26% of cases),
- technological opportunities (the most important factor in 19% of cases),
- turnover or profit (14% of cases).

As Figure 3.2. shows, labour costs of researchers and the availability of researchers are the least important factors

Figure 3.2

Importance of factors influencing companies' decisions as to how much to invest in R&D



Source: European Commission (2005b)

The main reason private firms invest in R&D is to improve performance and generate profits and industrial growth (see Chapter 1 for the importance of this). In addition, there are a number of other, more general factors which drive innovation (and hence R&D) within firms (European Commission, 2004a):

1. Response to consumer needs: this is the most important factor mentioned by more than a third of respondents. Firms that are aware of consumer needs can integrate them into new products to increase market share. Market-driven companies often not only improve products but also increase process efficiency to use fewer financial resources and enable shorter development times (see Fuller, 1994). Response to consumer needs is particularly important for large companies (those with more than 250 employees), companies in the service sector and younger firms (less than 10 years old).
2. Increasing price competition: this is identified by 14% of respondents as the most important factor. Innovation processes induced by price competition do not focus on basic research but rather on ways to reduce costs via incremental process and product improvements. This kind of development work is less costly than basic research or new product development.

3. The need to improve staff productivity: this is rated by 13% of the managers as the most important factor. It is more important for SMEs than for large firms. In particular, process improvements can increase the productivity of the workforce and hence lead to lower product costs.
4. The need to improve the efficiency of machinery and equipment: this is rated by 13% of the managers as the most important factor. Efficient machinery and equipment enables faster and production at lower cost and with higher productivity, which is important in order to remain or obtain a competitive advantage. SMEs are more motivated by improved machinery and equipment efficiency than large firms.
5. Increasing product competition: this is rated by 13% of managers as the most important incentive to innovate because it leads to a higher product quality that can be turned into competitive advantage. R&D investment plays an important role here. This factor is more important for large firms than for SMEs.

The results of a study (Economist, 2004a) underline the overlap between motivations for innovation and R&D. It shows that the most significant drivers behind R&D activity are more demanding customers (factor 1 above), market pressure to keep up with competitors (factors 2 and 5), the development of new technologies and short product life cycles (factor 4). Another study has shown that managers are likely to invest in R&D if they detect unexploited scientific and technical opportunities, if they expect that there will be a market for their new products and processes, and when there is a prospect of receiving economic benefit from R&D (Dosi, 1988).

A study of 25 large multinational R&D performers indicated that virtually all research within these firms was applied research focused on areas relevant to the firm's business. Very little, if any, fundamental research was undertaken by these companies (see Dougherty et al., 2003).

Innovative activity faces numerous barriers and these often hamper R&D investment. Out of nine obstacles to innovation, managers mentioned economic and internal factors as being the most important (European Commission, 2004c).

Economic factors are the most frequent barrier to innovation for all firms. They consist of innovation costs³⁶, followed by a lack of appropriate sources of finance and excessive perceived economic risks³⁷. Among innovators, the importance of excessive perceived economic risks plays a bigger role than the lack of appropriate sources of finance. Non-innovators are likely to reverse the relative importance of these two factors. Innovation costs, the lack of appropriate sources of finance and excessive perceived economic risks are regarded as more serious barriers in industry than in services.

Internal factors include organisational rigidities within the enterprise, the lack of qualified personnel, and the lack of information on technology and markets. More enterprises generally felt constrained by economic circumstances than

³⁶ The only sector that did not feel this was the most important hampering factor was the electricity, gas and water supply sector.

³⁷ Within the EU, almost one quarter (24%) of enterprises with innovation activity cited the cost of innovation as a hampering factor, while 19% cited a lack of appropriate sources of finance and 17% excessive perceived economic risks.

by internal factors, although a lack of qualified personnel was often viewed as one of the most important factors constraining innovation.

Other factors comprise insufficient flexibility of regulations or standards and the lack of customer responsiveness to new goods or services. The service sector saw the insufficient flexibility of regulations or standards as a much greater obstacle than manufacturing industry.

Innovators recognise these barriers more than non-innovators do.

While the differences between services and industry were generally small, only one factor discouraged innovation in a greater proportion of manufacturing enterprises than in service enterprises, namely, the lack of information about technology.

3.2 R&D investment factors

This section focuses on factors that influence managers in their R&D investment decisions and firms' R&D investment strategy. The aim is to give an insight into the most important factors from a manager's perspective³⁸.

R&D is creative work undertaken on a systematic basis in order to create new or improved products, processes and services. In contrast to marketing, which deals with the perception of the company's products, processes and services in the market, novelty or improvement through R&D are technology related. The role of R&D for a company is therefore highly sector specific.

From a company perspective, incentives for investing in R&D can stem from:

- *Market pull*, where market demand stimulates R&D to find a new technological solutions. Many empirical investigations on industrial organisation have examined the relation between R&D investment and market structure (see for example, Cayseele, 1998; Greer, 1992; Scherer and Ross, 1990 and Cohen and Levin, 1989). Strong competition can have two different impacts on R&D investment. On the one hand, it can reduce profit margins and thus reduce the capacity to invest in R&D. On the other, it can constitute an incentive to invest in R&D where companies consider R&D a factor of competitive advantage. Empirical evidence has found a generally positive effect of competition on R&D (Becker and Pain, 2003). However, this effect is more pronounced in high-tech than in low-tech sectors. In the latter, standardisation and absorption of technologies developed outside the company itself play a bigger role than in the former.
- *Technology push*, where technology-related developments (e.g. discoveries, process know-how or the level of technology expertise) lead to a new technological solution which then has to find its market. R&D intensities within sectors follow characteristic patterns, which are closely related to the companies' technological competence. Technological competence is a result of sector-specific technological opportunity and firm-specific technological expertise (acquisition and accumulation) and technology management capability. Examining 1600 companies in seven

³⁸ An interesting paper is Ryan and Wiggins (2002), especially part II.B on determinants of R&D investment with links to articles on factors that influence R&D investments.

industries and six countries in different stages of development, Lee (2003) found that technological competence determines the firms' individual R&D investment, the distribution of R&D investment within the sector and the average R&D intensity of the sector. However, technological competence alone is not sufficient as these findings are only valid for cases where technological competence is related to market demand.

Incentives for R&D investment therefore result from a combination of market- and technology-related aspects at the corporate level. In addition to that, a Dutch study identified a number of factors from outside the firm which affect private R&D funding (Erken, Kleijn and Lantzenhöffer, 2004):

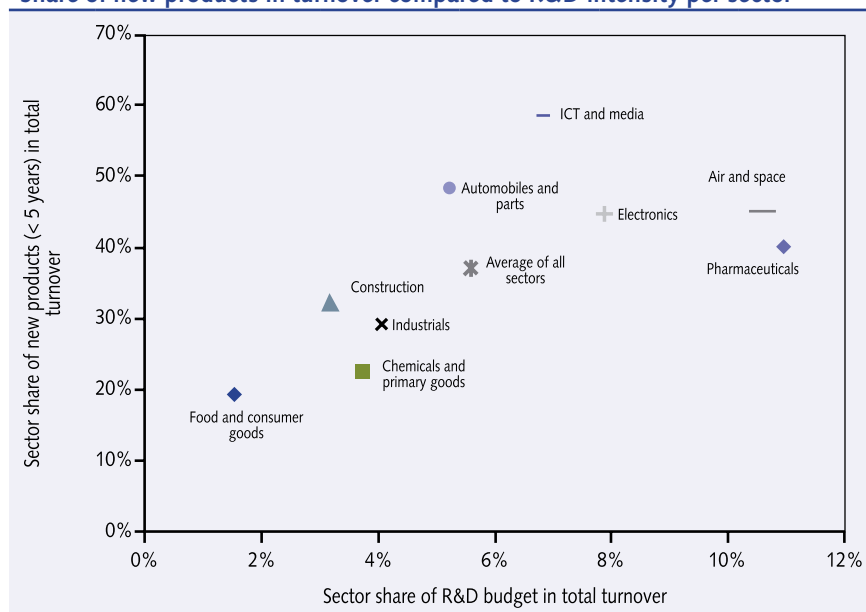
- *Following competitors:* Often companies follow their main competitors on R&D expenses. When competitors of firms are saving on R&D expenses, other firms will follow, because of the direct negative effect on a firm's shorter-term profitability of R&D expenditures. In other words, an industry norm tends to emerge, and in the past was used by companies as the basis for setting R&D budgets. There can however be different types of enterprises within a sector – e.g. in pharmaceuticals there are research intensive companies and generic drug companies.
- *Broadening base of R&D firms:* a growing number of knowledge intensive SMEs, high-tech start-ups and spin-offs are performing R&D work, sometimes as a service to other companies.
- *Other R&D location-related factors:* other general framework conditions, e.g. the general economic environment or political stability, influence the firm in their choice of location for R&D investment.

Sector characteristics

Figure 3.3 maps the importance of new products compared to the R&D intensity of the sector for each of nine sectors.

Figure 3.3

Share of new products in turnover compared to R&D intensity per sector



Source: A.D. Little (2004)

This data shows that companies in the more R&D intensive sectors introduce new products more frequently than companies in less R&D-intensive sectors. It implies that the more R&D intensive sectors (such as pharmaceuticals, aerospace, ICTs & media or electronics) conduct R&D in order to introduce new products more often. The other sectors, (e.g. foods and consumer goods) have a lower R&D intensity and a lower sales dependency on new products.

Further explanation or insight into R&D investment behaviour can be derived from the following industry characterisation or sector classification framework (Pavitt, 1984):

- *Science-based industries:* Firms in this industry tend to focus more on scientific research into new, technological products, e.g. pharmaceuticals and biotechnology and IT hardware.
- *Scale-intensive industries:* This industry contains mainly firms that focus on technology driven process innovations and incremental product innovations, e.g. chemicals, steel & other metals.
- *Specialised equipment industries:* Firms with its main activity in this industry focus on process and product innovations through close collaboration with customers or outsourcers in industries like IT hardware.
- *Supplier-dominated industries:* Firms in this industry particularly focus on the adoption of process innovations developed by suppliers (such as the ICT sector), such as in the case of health services, banking and other finance sectors. The growth of R&D carried out through specialised service providers has changed the pattern of how industrial R&D is carried out. Computer software firms and companies performing R&D on a contract basis primarily led this growth. US service sector R&D volume surged during the late 1980s and early 1990s and again after 1997. The EU shows a trend toward an increasing the share of R&D by service industries, but it remains well below 15 percent of the total R&D spending (NIST Planning Report, 2005).
- *Information-intensive industries:* These firms mainly invest in product innovations that are largely market driven, such as firms from the software, banking and support services.

An analysis of R&D in service intensive businesses and the service industries deserves special attention.

Knowledge of behaviour with regard to R&D in different sectors is valuable for more effective policy measures. It makes clear that policy measures cannot be too general in their character, but need to be focused on specific, narrowly-defined objectives.

It needs to be remembered as a cautionary note that disruptive innovations and technologies can suddenly threaten or transform an industry structure and that sector classifications evolve as new technologies and applications take effect. ICTs, for example, permeate many sectors and interdisciplinary work (such as bioinformatics) transcends sectors. Successful Internet-based firms can challenge methods in various sectors and generate new kinds of economic activity.

It can be argued that a dynamic and increasingly knowledge-intensive economy must simultaneously encourage and depend on R&D that is not based wholly within the current classification of sectors. The term 'service industry' is increasingly being used to recognise and distinguish the changing nature of business; even manufacturing companies are becoming more service intensive. We may in the near future need to classify more carefully the different types of services and appreciate their different R&D characteristics. It may be desirable to stimulate and facilitate R&D that transcends sectors and requires new kinds of enterprises or consortia so that ambitious socio-economic challenges and opportunities can be addressed.

The distinction between activities within R&D can also be examined. Technical services and design services for example are needed to help support customers in the implementation of solutions or the adaptation of bespoke products. These are becoming industries and not just functions within R&D departments.

3.3 Firm level factors

3.3.1 Firm strategy

Business strategies for managing the R&D process have changed significantly during the last decade. For example, many companies now exploit R&D more systematically from within a global strategic perspective, organising R&D activities in multiple locations. Firms collaborate and carry out R&D in an interactive way with a multitude of other players. Businesses have become more specialised, which has consequences for their technology strategy and hence innovation and R&D strategy. Overall, they are more likely now than a decade ago to acquire technology from external sources. They are also more likely to exploit technology through partnerships. R&D has become a business opportunity and has come to be managed more commercially (i.e. 'as a business' in itself rather than as a function within a business). These changes are the cumulative effect of several sequential pressures on business which include industry restructuring and business simplification, the internationalisation of R&D, outsourcing and knowledge management. Performance measurement of R&D has in parallel become more sophisticated and emphasises the effectiveness of R&D in terms of its innovation potential. Concepts such as 'options thinking' and 'organisational learning' recognise the importance of technological capabilities as well as tangible project outputs. Many companies have adopted the balanced scorecard approach to strategic management which encourages a holistic viewpoint of technologies, markets, user needs, environmental issues, and operational and strategic requirements as well as financial performance. Institutional investors are scrutinising business performance more rigorously. A focus on equity prices and short-termism around 'city' institutions and markets may still, however, unduly influence CEO's performance targets and their attention towards innovation and R&D (Haour, 2004).

More attention is being paid by accountants and other professions to the importance of intangible assets. As the appreciation of intangibles becomes more sophisticated, the ways in which R&D investments can be justified will evolve. R&D capability needs considerable time to develop and is therefore a valuable intangible asset. Reputation (one of the most important intangibles) is crucial to R&D and technology agreements.

An important effect of many of these changes is that R&D activity is now decentralised and diffused across networks, supply chains and value chains. It is less easily measured or confined to a single enterprise. Even competitors may sometimes depend on R&D capabilities in a third party enterprise. R&D activities are therefore not just internal investments but are based around contracts, partnerships and strategic alliances. Companies are explicitly or implicitly sharing and reducing the risks inherent in R&D.

Some companies (such as Cisco and Intel) use their own venture capital funds to acquire technology-based companies with relevant R&D capabilities instead of investing in early stage research. This kind of R&D strategy is widely promoted and encouraged by business schools and consultants.

More generally innovation processes are being organised around the 'open innovation' concept as coined by Chesbrough (2003). This networked approach is also regarded as fifth-generation R&D and innovation management (Rothwell, 1992; Rogers, 1996). Coombs and Georghiou (2002) refer to these changes as a new R&D ecology. The other side of the coin, science in universities, has been termed 'Mode 2 research' (Gibbons et al., 1994).

Technology results (typically from previous R&D activities) are combined in complex interdependent ways to meet new interpretations of market or user needs. Jolly (1997) encouraged such an approach to technology commercialisation, pointing out, *inter alia*, that R&D projects could more easily be justified and failure could more easily be tolerated if there were several customers for project results and not just one single internal customer. Major companies have struggled for three decades to find satisfactory ways of selecting projects and steering R&D activity; they have moved from first generation (technology push) models in the 1960s through 2nd generation (market pull) models in the 1970s towards 3rd generation thinking (1990s) and 5th generation models (2000+). During these transitions corporate laboratories have been closed down, R&D has been decentralised to business divisions, customers and providers have entered useful ('post TQM') dialogue; business process engineering and knowledge management have been deployed. R&D has been contracted out, outsourced, run 'as a business', offshored and now dispersed.

The evolution is continuing and more forms of virtual R&D organisation are emerging. Haour advocates 'distributed innovation'. Eli Lilly Corporation has established the open source concept in Innocentive.com to engage scientists worldwide in their R&D problem solving. NASA has a similar system. The x-factor organisation offers prizes (for example, X-Ansari prize for space travel) as an incentive to accelerate solutions to major challenges. Prizes can be seen as a more cost effective way of identifying and attracting suitable resources; (there might be something of an analogy with competitions for prestige architecture projects). Regional consortia and clusters of R&D capabilities are being formally represented via new forms of legal entity; ETEPS, a partner with DG JRC-IPTS in this Annual Digest project, is one such organisation.

The EU Framework Programme uses expressions of interest and other mechanisms to engage private sector R&D capability and investment in the definition and implementation of R&D programmes.

The roles of foundations in sponsoring R&D activities in businesses must also be investigated in order to get a complete picture of industrial R&D and R&D potential.

What emerges as a strategic consequence of these trends is that R&D can be globally dispersed and technology 'components' (including expertise, projects and companies) can be assembled from across various sectors and with support from universities and research institutes. The motivations and behaviour of managers in R&D providers and R&D customers or users might therefore need to be distinguished more clearly in order to understand industry reasons for investing in R&D. It is not yet so easy to identify and survey representatives of networks and consortia or dispersed projects as it is to survey managers in single enterprises. Some new maps of R&D distribution patterns may need to be drawn in the future.

Technology 'markets' including internet based systems for trading IP have been established (Arora et al., 2000). For example, IBM, Dow and other companies have very significant levels of trade in technology. It can become so significant an activity that it transforms even large corporations into a different kind of business; IBM is no longer a PC manufacturer, having sold that business to Lenovo. Psion, the Cambridge UK supplier of PDAs decided to stop manufacturing and concentrate on the Symbian technology consortium. ARM Holdings based its business strategy on technology exploitation. AEA Technology and Qinetiq were spun out of the nuclear and defence R&D industries as specialist technology brokers and consultancies. Scipher plc has its origins in a corporate laboratory that was successfully divested from its parent company to generate profits as an independent contract R&D and thence 'technology' business.

Such trends make sectoral classifications of R&D statistics more complex and difficult to interpret; although much might be captured by growth in R&D services, this does not explain or illuminate the R&D interdependencies of technology markets. The establishment and growth of markets might be generally regarded as a positive step towards increasing R&D activity.

Large firms now approach R&D investment on a global scale. Lead markets and poles of excellence become magnets for R&D investment. A stronger focus on R&D productivity, combined with a systematic co-ordination and organisation, increases competition among the different R&D locations within the firm. Further R&D competition is introduced through the assessment of new R&D sites and the possibility of outsourcing, which intertwines the decisions of what kind of R&D to do and where to do it. Increasingly shared R&D processes within and outside the company also increase the role of Intellectual Property Rights (IPR).

These trends imply a need for new R&D and innovation management methodologies. There is for example a need for better communication between enterprises about technology developments and strategic planning. Technology or strategic roadmapping offers a solution and is now being used by a significant number of companies. The implications for how R&D investments should be determined are very significant. Basically technology expertise is recognised as a valuable intangible asset which takes time and resources to develop; R&D projects can be designated to provide or increase technological capability so that future markets and business needs can be adequately addressed. This liberates R&D planning from the constraint of too-pervasive linear models of innovation. It also recognises that innovation is often now a product or focus of networks rather than single enterprises. In Portugal a method of supporting the R&D capability of SMEs has been introduced ('R&D nuclei') in recognition of this trend. There is scope for strategic policy intervention in R&D organisation and R&D stimulation via involvement in industry roadmapping exercises.

Basic research appears to play a shrinking role in the industrial goods sector because it is a longer term investment with a highly uncertain return (Boston Consulting Group, 2003). In most cases, companies focus on 'applied R&D' and buy the results of basic research from specialised outsiders in order to combine them with corporate knowledge internally. More than focusing on research, companies have become aware that product success increasingly depends on the development side of the R&D process. The main trends include a strong emphasis on the pre-development steps (through initial product screening, technology feasibility analysis and a good project definition) and a strong early market orientation (through understanding user needs, undertaking market research, and more spending on up-front marketing activities) (Cooper and Kleinschmidt, 2001).

In this respect, it is important to note that the successful management of the R&D portfolio, which at the corporate level finally determines the size of R&D investment and the projects undertaken, depends much less on a purely financial assessment than often assumed. Although financial assessment methods dominate R&D portfolio management, evidence suggests that the most successful companies let their business strategy decide the R&D portfolio and rely much less on the financial assessment³⁹.

In addition, such companies tend to use a wider variety of different assessment methods and are aware of the fact that no single method gives the correct results. These findings are confirmed by a recent benchmarking exercise in the industrial goods sector in Germany, which found no relation between the size of the R&D budget and return on net sales⁴⁰. Companies face a paradigm shift in their R&D investment decisions. Instead of addressing the question of how big their R&D budget should be they start by focusing on how to get most out of the given R&D budget. As a success factor, the size of the R&D budget becomes less important than its efficient use and exploitation. This means that also R&D investment policies need to put more emphasis on factors that increase R&D efficiency rather than the absolute amount of R&D investment.

Another trend in R&D management strategies is that companies are becoming increasingly aware of the fact that different products need different R&D management strategies. At the level of the organisation, this is where R&D management overlaps with innovation management. Many users innovate⁴¹, and in sectors like software development, ICTs, aerospace, medical devices or sports consumer goods, companies that systematically involve 'lead-users' into their R&D process can reap a considerable competitive advantage (von Hippel, 2005). Lead-users are customers who have a close relationship with the company that wants to develop a new product. The company provides the new product to the lead-user under preferential conditions. The lead-user uses the product and modifies it, either alone or together with the producer, according to its needs. In return, the producer incorporates the

39 In an in-depth study of 30 large companies in the US, financial methods clearly dominate the management of R&D portfolios. They are followed by the business strategy, bubble diagrams, scoring models, checklists and other methods (see Cooper, Edgett and Kleinschmidt, 2001, p.367).

40 The representative benchmarking exercise included 13 companies from the industrial goods sector in Germany (see Boston Consulting Group, 2003). The benchmarking of the correlation between the R&D budget and return on net sales included also the 500 companies from the UK R&D Investment Scoreboard.

41 Between 10% and 40% in the industrial and consumer product industries (see von Hippel, 2005, p.20)

changes into the final product. This approach provides considerable value-added for both sides, especially in the case of products where user needs are very heterogeneous, markets are highly segmented and customers are willing to pay for improvements. In these cases, the R&D process comes closer to an innovation process and tends to result in breakthrough innovations rather than incremental product improvements. The concept of lead-user or user-driven innovation was recognised by von Hippel in the 1970s and has now become embedded within the wider concept of open innovation (see von Hippel, 2005, for the historical development).

For the company, this means that different types of R&D strategies have to be combined depending on the objective of the R&D process. On the one hand, a rather routine R&D process for incremental development and, on the other, an innovation process for breakthroughs. This underlines the importance of technology clusters, knowledge poles and producer-customer relations as magnets for R&D performers and places where R&D strategies can be executed. In addition, also the public sector can serve as a lead-user and thus foster R&D investment and innovation as, for example, first buyer of innovative technologies.

The purpose of this description of how R&D strategies and management methods have evolved is to provide a basic understanding that might be useful when designing new policy interventions. There have been situations where methods used in industry have subsequently been introduced into government. Consultation and foresight processes between industry and government are familiar in R&D activities and there is scope for more creative and ambitious use of such approaches in order to address the Barcelona objectives.

3.3.2 Leadership characteristics

Creative and technology leadership is important in assembling high calibre R&D teams. The roles of technology directors, R&D managers and Chief Technology Officers (CTOs) in major corporations and in smaller companies are vitally important. It has been argued (Haour, 2004) that Chief Executive Officers (CEOs) understand the importance of technology and innovation but are hampered by shareholder pressure, including institutional pressure for short-term financial performance. Strong and charismatic technology directors can support CEOs and help convince Boards of the need and importance of R&D investments. They can also help to attract and build up a high calibre team, which may be crucial in allowing the firm to work in the most important collaborative projects.

The CEO shapes corporate behaviour and performance (see, for example, Van den Steen, 2005 and Saloner and Rotemberg, 2000). It is therefore not surprising that the CEO's age has been considered to have an impact on R&D spending. However, this effect may be stronger in relatively small firms especially since the CEOs of major corporations usually need to have acquired broad management experience across various global divisions, etc. before being appointed. Some studies on individual managers found that R&D spending is greater in firms led by younger CEOs. These younger CEOs were managers with had considerable investments of their own equity in the firm and significant career experience in marketing and/or engineering.

CEO incentives should be carefully linked to growth and R&D performance in order to prevent a cut in R&D expenditures to favour short-term accountancy profits (see Gibbons and Murphy, 1992). Many companies might be aware of the long-term implications of CEO compensation on R&D investments. For CEO incentives, they strive to strike a balance between short-term profitability and long-term investment goals.

3.3.3 Firm age and size

The question whether or not to undertake R&D is often decided when the company is founded. According to a recent study in the German manufacturing sector, 32% of the young companies are continuously active in R&D, compared to 20% of older firms. More than two thirds of the companies that are active in R&D when they are established still conduct R&D five years later. Only one out of ten of those firms that do not undertake R&D during their first year of existence start R&D activities within the following four years (Rammer, 2004). In addition, the R&D orientation of young companies has increased by 20% between 1998 and 2002, which has prevented the R&D orientation of all firms from decreasing. However, the R&D orientation of these young companies is also a sign of their lack of long-term relations with customers or suppliers in order to source technologies. Younger firms are less likely to access new technologies through cooperation than through acquisition (see Tether, 2004, p.14).

Studies have also indicated that the age of the firm is negatively related to R&D investments (Shefer and Frenkel, 2005). In general, large firms are older than small firms. For high-tech firms it has been found that firm size has a negative impact on the share of labour engaged in R&D and the rate of investment in R&D (Galende and de la Fuente, 2003).

A study of 2,253 R&D performers in manufacturing, divided into high-tech firms (vehicles, chemicals, machinery, and electrical) and low-tech firms (textiles, wood, plastics, non-metallic mineral products, basic metals and other industries), shows that the tendency to engage continuously in R&D increases significantly with size, foreign exposure and demand pull and cost push. This effect is even greater in high-tech than in low-tech sectors. While R&D engagement in high-tech sectors increases with diversification, it grows in low-tech sectors in line with market share. The role of firm size, demand pull, market share and cooperation differs for high and low-tech sectors. These determinants of R&D intensity play a less important role in high-tech than in low-tech sectors. For example, high-tech sectors are more affected by information from basic research institutions (increases R&D intensity by 29%) and information from clients (increases R&D intensity by 22.2%). For low-tech industries, on the other hand, a doubling in size would mean a decrease in R&D intensity by 31.2%, and demand pull, market share or cooperation increase in a similar order of magnitude. While R&D intensity is affected by information from clients (increases R&D intensity by 25.5%) in a similar way as in high tech sectors, other information sources, such as information from within the enterprise and suppliers, are not significant in low tech sectors (Mairesse and Mohnen, 2004).

R&D investment does not depend only on the sector in which a firm is active, but also on the size of a firm. This insight can lead to more effective policy measures, for example on the shortcoming that Europe has, compared to the US, on the strength of SMEs in R&D investment.

3.3.4 Firm ownership

It has been observed that firms with significant stock ownership by directors and the management have comparatively low levels of government-funded R&D. Furthermore, R&D productivity increases with the proportion of stock held by managers. A possible explanation is that, for privately-funded R&D, a higher minimum profit is required in order to make the investment decision (see Billings et al., 2004). Public R&D is more prone to be used for projects with a lower expected profitability, e.g. basic research.

These findings have implications for stakeholders of R&D-intensive firms and policymakers:

1. For governments, manager-owner content of a firm should be part of the overall evaluation of the awarding of government-sponsored R&D.
2. For stock market analysts who use R&D productivity as a valuation method, equal amounts of R&D spending by two firms may be valued differently when the partition of the sources is known.
3. For accounting reasons, current disclosure standards of the source of R&D should be improved in order to get a better valuation of R&D as an intangible asset⁴² (Billings et al., 2004).

An extensive study on the relation between stock ownership by institutions that focus on long-term results and the influence on R&D investment shows that these institutions are less likely to put pressure on managers to reduce R&D investment (see Bushee, 1998). However, ownership by institutions that have high portfolio turnover and engage in momentum trading significantly increases the probability that managers reduce R&D to reverse an earnings decline.

3.3.5 R&D funding

The availability of R&D funds can influence R&D investment decisions. A French survey of 334 companies revealed that more than two thirds of R&D investment is financed from companies' equity (Ministère de l'éducation nationale, 2004).

It is a commonly held perception that R&D is labour intensive and so R&D expenditures are primarily labour costs. However, NISTEP (2005), using 2004 indicators show that the percentage of labour costs in Germany was as high as 61.5% in 1997, but then fell to 59.3% in 1999. In the U.S.A, the percentage of labour costs declined from 46.0% in 1981 to 39.9% in 1989 then increased to 44.8% in 1999. In Japan, the share of labour costs increased from 38.7% in the 1991 financial year to 43.5% in 1999 and 41.0% in 2002. The variations over time may be due to the other costs (including buildings, facilities and equipment and other significant miscellaneous costs).

The number of researchers in business may have a more significant impact on these figures than wages. The number of researchers in all industries in Japan increased steadily until 2000, declined slightly in 2001 then recovered in 2002 and levelled off in 2003. The number of researchers in industry in

42 E.g. through a valuation based on expected productivity.

Japan roughly equals the total number in the EU. In the US, the number of researchers increased considerably by 248,100 persons between 1995 and 2000. NISTEP's examination of NSF data⁴³ revealed rates of increase to be similar between the manufacturing and non-manufacturing sectors, with most growth in the US manufacturing sector being attributable to the electrical equipment and transportation equipment industries.

Examining R&D expenditure per researcher in the business sector, France is shown to have a larger business R&D expenditure per researcher than China, Korea, Japan, the US and the EU average, although it has declined since its peak in 1991. Japan ranks last among these economies. In Japan and the US, both R&D expenditure and the number of researchers in the business sector have increased steadily, but until recently R&D expenditure per researcher remained flat.

Another factor is the number of businesses in which R&D workers are employed. Based on real R&D expenditure and comparing R&D expenditure in the 2000 and 2001 financial years with 1980, the growth rate of R&D expenditure in manufacturing industry in Japan was 178.0% between 1980 and 2000. It was 183.4% between 1980 and 2001. The highest growth rate was recorded by the communication and electronic equipment industry with 321.2% in 2000 and 333.4% in FY2001. Industries with the highest growth rates of R&D expenditure between 1980 and 2002 were drugs and medicines (318.8%), precision instruments (275.4%), and general machinery (253.3%) (NISTEP, 2005).

Private funding

At the company level, some sources indicate that a higher return rate for privately-funded R&D is expected compared to publicly-funded R&D (see e.g. Lichtenberg and Siegel 1991; Billings et al., 2004 for the chemical industry).

According to the Innobarometer survey (see European Commission, 2004b), a lack of appropriate sources is mentioned as one of the biggest obstacles to R&D investment. This can be interpreted three ways – not enough public support for R&D, so many firms do not do it, so the French survey only interviewed firms which did do R&D, because they had funding (Ministère de l'éducation nationale, 2004). Alternatively, managers have difficulty finding or securing funds.

Public funding

Whether government-sponsored R&D is more or less productive than privately-funded R&D is a current issue of debate. A study by Billings, Musazi and Moore (2004), based on a sample of US firms in five industrial groups with a history of obtaining government-sponsored R&D funds, suggest that other factors come into play when determining the productivity of government-sponsored R&D, such as the proportion of stock held by managers and directors of firms.

However, what seems certain is that public funding can have a leverage effect on business R&D. An OECD study found that one dollar given as direct

43 'Research and Development in Industry' NSF

government funding of R&D to firms in the US resulted in 1.70 dollars of research (Guellec and van Pottelsberghe, 2000). It also concluded that public funding of business R&D (either via direct funding or tax incentives) was more effective when it was stable over time. Firms seem reluctant to invest in additional R&D if they are unsure whether government support will be sustained over time.

The OECD study offers a number of additional findings. For example, it claims that direct government funding and tax incentives have a substitutive effect: an increased intensity of one reduces the effectiveness of the other in stimulating industrial R&D (Guellec and van Pottelsberghe, 2000). But the policy design implications arising from these (or indeed any) results need to be considered carefully, taking into account differences in economic structure and current levels of R&D intensity, if government support to industrial R&D investment is to be effective.

3.3.6 R&D collaboration

Firms are continuously looking for new ways of gaining knowledge to integrate into the increasingly complex development of new products and processes. The formation of research joint ventures enables companies to pool resources and risk, to exploit research synergies and to reduce the duplication of R&D effort (Abramovsky et al., 2005). From a traditional transaction-cost perspective, one would expect that companies are somewhat hesitant to enter into R&D partnerships with foreign companies due to the lack of control over long-distances, lack of trust between companies from different countries and the high asset specificity of R&D. However, as increased international competition has led many companies to follow a strategy of gradual internationalisation, one can assume that this experience gradually also opens the way to non-domestic R&D partnerships (Hagedoorn and Narula, 1996). The importance of the intangible 'relationship capital' is becoming more recognised.

Evidence shows that since the 1980s the number of newly established international strategic technology alliances has increased considerably. It could thus be expected that international R&D partnerships would have increased as a proportion of the total number of all R&D partnerships. However, the past forty years indicate a slightly downward trend in the share of international R&D partnerships out of the total number of R&D partnerships. The late 1990s end with a share of international partnerships below 50% of all newly made R&D partnerships (Hagedoorn, 2001)⁴⁴.

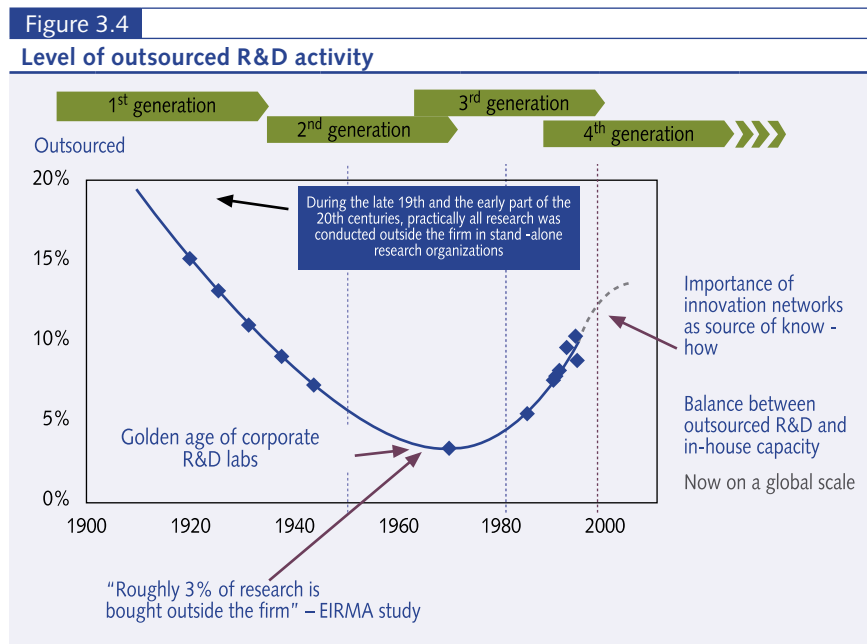
R&D collaboration is dominated by companies from the world's most developed economies, paralleling the world-wide distribution of R&D resources and capabilities. The dominance of the US also reflects the leading role that this country plays in R&D and production in major high-tech industries. This dominance has not only led companies from other countries to actively search for R&D partnerships with North American (mainly US) companies, but also most of the recent R&D partnerships are formed between companies within North America.

⁴⁴ This research uses the MERIT/CATI database containing information on nearly 10,000 cooperative agreements involving about 3500 parent companies and covering the period 1960-1998, reported in specialised journals (Hagedoorn and Schakenraad, 1990).

The largest share of R&D partnerships is intra-North American, followed by EU–North-American and intra-EU alliances as third. But while intra-North-American alliances accounted for 23.5% of the total between 1980 and 1989, the figure has increased to 41.4% in the period 1990-1998. Also the EU-North-American category has increased slightly in importance: from 21.6% to 25.2%. An interesting observation is the declining importance of intra-EU cooperation: from 19% in 1980-89 to 11.3% in 1990-1998. The growing relative importance of intra-US R&D partnerships largely explains why international partnerships, despite a strong growth in absolute numbers, still account for only about 50% of all R&D partnerships and why the trend towards a further internationalisation appears to be stagnating (Hagedoorn, 2001).

3.4 Outsourcing of R&D

The changing R&D paradigm has also influenced the level of outsourced R&D as revealed Figure 3.5. R&D outsourcing has increased constantly during the last thirty years (Howells, 1999), following a long phase of R&D insourcing, which peaked in the late 1960s when around three percent of corporate R&D was done outside the firm. Since then, this amount has almost quadrupled.



These changes in the R&D management strategies have important implications for S&T policies (OECD, 2001). The latest survey of large R&D performers in the US shows that outsourcing and placing more emphasis on concrete business results from R&D, combined with reducing focus on basic research seem to be long-standing and ongoing trends (Industrial Research Institute, 2005). This is supported by evidence from the National Science Foundation (2005) which indicated that between 1993-2001 manufacturing firms increased R&D expenditures on outsourced R&D by 4.8% in terms of

average annual percentage in real terms compared with 3.8% for in-house company-funded expenditures. These shifts indicate the growing importance of outside sources of technology for a number of key corporate technology objectives.

Figures from Ireland for 2003 revealed that R&D outsourcing amounted to some €156.4 million compared to total BERD of €1,075.6 million in the same year (Forfás, 2005, pp. 7 and 37), equivalent to 14.5% of the total Irish industry R&D budget. What is significant here is the international dimension to these figures (Chapter 4). Of the €156.4 million outsourced, some €101 million, nearly two-thirds (64.6%) was spent outside Ireland⁴⁵.

Moreover, 88% (€138.8 million) of this outsourcing was undertaken by foreign owned companies, usually via related companies (parent, subsidiary or affiliate companies); this might be seen as intra-firm offshoring. Outsourcing with public research establishments was low (1%), and links with higher education institutions (HEIs) was higher - 21%; although only 14% for Irish owned firms (Forfás, 2005, p.37).

⁴⁵ And on this basis were not included in the total BERD figures for Ireland listed above (Forfás, 2005, p.37).

4. The Internationalisation of Industrial R&D

The internationalisation of R&D is an emerging issue which is having an ever larger impact on the EU policy agenda. Multinational firms, which are constantly looking for the most favourable setting for their activities, have increased the size and reach of their overseas R&D operations over the last decade. Products are becoming ever more complex as they embody a growing number of technologies and components, and are thus becoming increasingly reliant upon an expanding number of specialised fields of knowledge. In order to remain competitive, firms must master innovations across a range of technology fields. Often this requires tapping into different centres of excellence around the world.

Policy interest in the internationalisation of R&D is fuelled by the underlying fear that moving ('offshoring') R&D operations outside the EU might undermine its efforts to become a competitive, knowledge-based society (i.e. the 'hollowing out' effect). The fear is compounded by the suspicion that the R&D capabilities being lost correspond to sectors which have been traditionally strong in the EU, such as the automotive, pharmaceutical and telecommunications sectors.

This chapter seeks to identify and characterise the phenomenon of internationalisation of R&D, assesses its potential impact, examine what makes a location attractive for R&D and looks into firms' motivations to move their R&D facilities abroad.

4.1 What drives firms to internationalise their R&D?

The R&D environment has changed as a result of various factors. These include developing global markets; closer links between R&D and the creation of new products, services, and markets; and, the opportunities offered by advances in ICT. Industry has responded by outsourcing R&D both nationally and internationally (Section 3.4) by opening R&D operations abroad, forming strategic technology alliances with overseas partners, and by divesting or acquiring strategic technology units. What, however, are firms looking for when they decide to relocate or set up their R&D operations abroad?

One of the main reasons why firms internationalise their R&D is to tap into the new centres of scientific and technological talent that are emerging around the globe (Table 4.1). Access to expertise is a major driver for globalisation of R&D (Economist, 2004b). Innovating firms hope to benefit from spillovers produced by the presence of other firms and the overall availability of skilled R&D personnel. Another important factor is to be close to the local market, especially if it is a large one. This is why countries with large and affluent markets (such as the US) continue to be a magnet for foreign R&D investment. The logic behind this is that the closer R&D is to the customer, the more customer-tailored products will be and the larger the share of the market that they will be able to capture.

However, there are also potential problems that firms must deal with, such as

- the reduction of the economies of scale by distributing R&D across dispersed units;

- the disadvantage of being an outsider in the host country's innovation system;
- increased obstacles in the internal knowledge transfer due to inter-unit geographical and technological distance;
- the leakage of key technology to foreign competitors; and
- the costs of coordinating R&D across multiple countries (OECD 2005a, Economist, 2004b).

It is interesting to note that, while high labour costs, measured on a 'per R&D worker' basis, constitute a limiting factor for firms investments in R&D generally, a wide number of sources suggest that this factor is relatively less important when deciding to set up or relocate R&D activities in foreign countries (Jones and Teegan, 2003; Papanastassiou, 1997; Voelker and Stead, 1999; Economist, 2004b). This is potentially an encouraging message to the EU, whose advantage does not lie in low R&D labour costs. From a supply side viewpoint the aim is to encourage the supply of science and engineering graduates and to avoid a brain drain; on this basis, R&D investment should then flow in.

Table 4.1
Reasons for investing in R&D at home and abroad and for selecting a particular location for undertaking R&D

	Factors from the perspective of science and technology supply	Factors from the perspective of demand for goods and services
Reasons why firms undertake R&D in their home country	<ul style="list-style-type: none"> - Historical capabilities of the home country - Economies of scale - Firm is an insider in the innovation system - Fewer problems of internal knowledge transfer due to geographical proximity - Fewer costs of co-ordination - Greater control of knowledge leaks to competitors 	<ul style="list-style-type: none"> - Leading home market
Reasons why firms decide to internationalise their R&D operations	<ul style="list-style-type: none"> - Centres of excellence abroad - Spillovers from other firms operating in the area - Access to high-quality science and engineering talent - Better cost-efficiency for some activities - 	<ul style="list-style-type: none"> - Adaptation to local markets - Existence of leading markets abroad
Reasons to select a particular location for undertaking R&D	<ul style="list-style-type: none"> - Availability of high-quality personnel - Quality of education - Centres of excellence - Quality of research-industry relations - Cost efficiency of R&D activities - Presence of other foreign firms - The stock of private R&D capital - Favourable regulatory regime 	<ul style="list-style-type: none"> - Large local market (size, purchasing power) - Leading market - Market where innovations can be introduced with ease and support - Strong intellectual property legislation

Source: DG JRC-IPTS adaptation from Sachwald (2005), Economist (2004b), Jones and Teegan (2003), and OECD (2005a).

4.2 Trends in R&D internationalisation

Robust trends in the internationalisation of R&D are difficult to identify, since it is a complex process and one which is difficult to capture in indicators. Also, it is a phenomenon which has received attention only recently, and therefore there is insufficient data available, and existing data are not readily comparable (OECD, 2005a).

In order to measure trends in the internationalisation of R&D, the OECD analyses 'R&D expenditures by foreign affiliates of multi-national enterprises (MNEs) in the host market'. This indicator measures the amount of R&D being spent in a particular host country by affiliates of companies that have their home base somewhere else. Thus, the higher this number, the more foreign R&D is undertaken in a host country.

The trend is that the proportion of R&D undertaken abroad is increasing rapidly. For example: the share of R&D performed by foreign affiliates in total industrial R&D for the majority of countries in the world grew during the period 1991-2002. In the OECD area, total R&D expenditures by foreign affiliates increased by more than 50% between 1991 and 2001 (OECD, 2005a).

In the US, R&D spending by affiliates of foreign firms increased at a real average rate of 10.8% between 1994 and 2000 (National Science Foundation, 2005). This compares with a real average rate of 5.8% for total R&D expenditure in the US over the same period (National Science Foundation, 2005).

- In the case of several countries in which foreign affiliates are very active, such as Ireland, Hungary, Czech Republic, Australia, Canada, and the UK, the share of R&D performed by foreign affiliates in total industrial R&D surpasses 50% or hovers around 40%.
- In the biggest R&D investing countries, such as the US, Japan, Germany, France, Sweden or Switzerland, the share of foreign affiliates has increased by average annual growth rates between 0.5% and 1% in latest years (Table 4.2).

For European countries, the growth in foreign sources of R&D is also the result of the Framework Programmes for Research and Development. Although the growth of foreign R&D funding is not smooth, there is a clear upward trend (Figure 4.1).

It is also noticeable that not all countries are exposed to the globalisation of R&D to the same degree. As shown in Figure 4.2, foreign R&D funding tends to be more important for smaller countries.

All of these findings suggest the internationalisation of R&D is a growing phenomenon. The OECD however, stresses that this is a slow process.

Most R&D internationalisation takes place on a 'triadic' basis between the US, the EU and Japan. The EU and the US are the major locations for foreign R&D. MNEs, especially from small European countries, have increased their foreign R&D activities over the last decade. Emerging markets are currently attracting an increasing share of overseas R&D outlays by MNEs. The sectors that have the most highly internationalised R&D remain the high-tech sectors, especially the pharmaceuticals industry.

Table 4.2

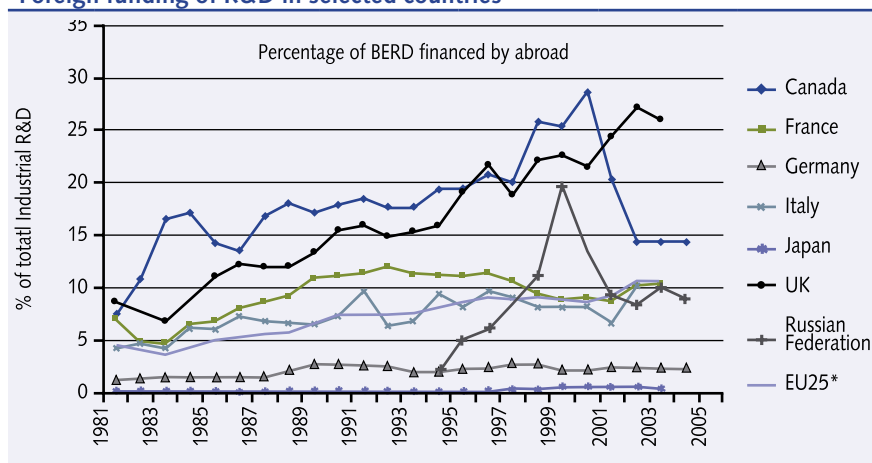
Share of foreign affiliates in business R&D expenditure for selected economies, during 1995-2001 (in %)

Country \ Year	1995	2001	2003
France	17.1	21.5	22.6
Germany	16.1	24.8	26.7
Japan	1.4	3.4	4.3
Sweden	18.4	38.2	34.4 (2002)
United Kingdom	29.2	40.6	45.0
United States	13.3	13.3	14.5

Source: OECD (2004b, 2006b) and Stifterverband für die Deutsche Wissenschaft (2004) for Germany.

Figure 4.1

Foreign funding of R&D in selected countries



Source: OECD (2005e)

4.2.1 Patent data

The internationalisation of R&D can also be observed through two indicators of patent activity (Annex 1), namely:

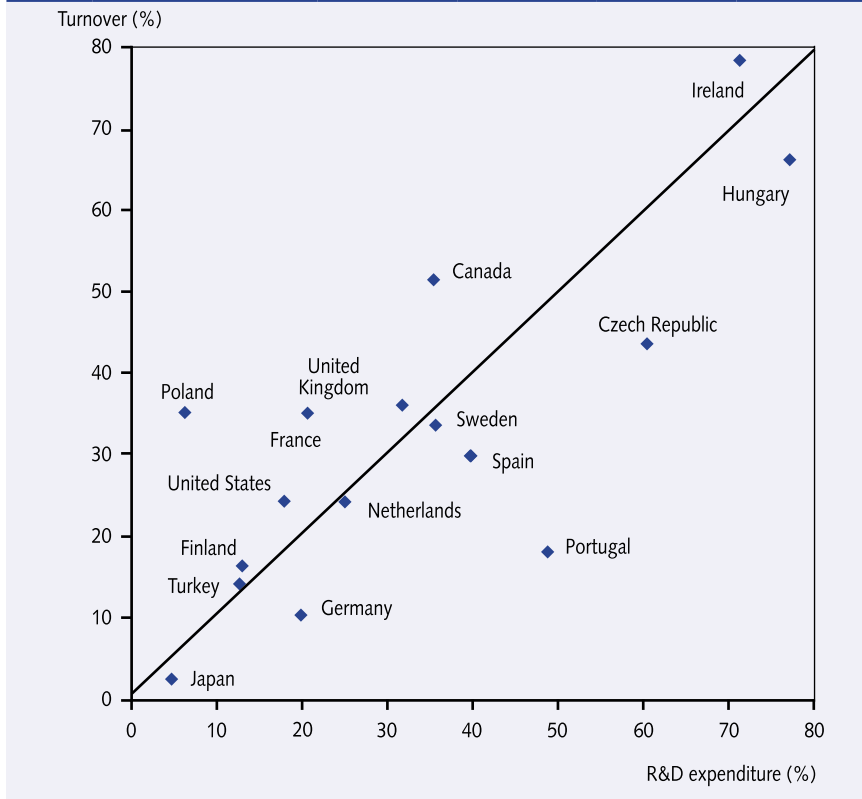
(a) the share of patents with a domestic inventor and a foreign applicant in the country's total domestic inventions. This reflects the extent to which foreign firms control domestic inventions and indicates inward R&D FDI.

(b) the share of patents with a foreign inventor and a domestic applicant in the country's total domestic applications. This reflects the extent to which domestic firms control foreign inventions and indicates outward R&D FDI.

On average, 14.3% of all inventions in OECD countries were owned or co-owned by foreign residents in 2000, compared to 10.7% in 1992. The proportion of foreign-owned domestic inventions in the EU was lower than in the US and lower than the OECD on average. Similarly, domestic ownership of foreign inventions from abroad was also less for the EU than the US and the OECD average (OECD, 2005a).

Figure 4.2

Share of affiliates under foreign control in total manufacturing R&D and turnover



Source: OECD (2005a)

4.2.2 Effect of international mergers and acquisitions

It is also important to highlight that the internationalisation of R&D may be strongly correlated with the increasing FDI flows that have characterised the operations of major companies in recent decades (Zedtwitz and Gassman, 2002). The growth in overseas R&D may therefore have much to do with it being part of this wider internationalisation process.

Moreover, the increase in R&D expenditures abroad may be less due to 'greenfield' R&D investment strategies (delocalisation of R&D based on factor-related decisions), but rather to 'brownfield', following the process of general mergers and acquisitions. Thus, strikingly, a study of some 27 major French multinationals revealed that in three-quarters of the cases studied, the R&D centre is established as the result of a takeover of an existing site (Ministère de l'éducation nationale, 2001). Only in the remaining 25% of cases was the R&D centre newly created. There are, however, sectoral variations. In R&D-intensive sectors like ICTs, electronics, chemicals and pharmaceuticals the option to create an R&D centre from the scratch was more frequently chosen than, for example, in machinery & electrical goods.

Being chained to an existing R&D facility in this way may arise because it is often too inefficient and cumbersome for a foreign owner to reduce R&D activities at established locations belonging to the newly acquired subsidiary. This has been shown to be frequently the case in the biotechnology, pharmaceuticals

and ICT sectors. For example, the sharp increase from 1997 to 1998 in the share of foreign controlled affiliates in industrial R&D in the US automobile sector was not a direct inflow of R&D investment, but a takeover of one of the major US car producers (Chrysler) by a foreign company (Daimler-Benz). In the same year, the overall domestic business R&D expenditure in automobiles sector remained practically unchanged.

4.3 Key characteristics of the internationalisation of R&D

4.3.1 Geographic concentration

The internationalisation of R&D by establishing R&D affiliates abroad through foreign direct investment (R&D FDI) is what has captured the attention of policy-makers. However, it is only one part of the global process of technology and know-how transfer. While most of the policy debate surrounds R&D FDI, we must keep in mind the wider perspective on international knowledge transfers.

Data on R&D investment flows within the so-called 'triad' formed by the EU, US and Japan (Table 4.3 and Figure 4.3) suggest that the EU is not attracting as much investment in R&D as the US and Japan. Between 2000 and 2001, there was a 4.2% increase in R&D flows from the EU towards the US and Japan and a 7.1% decrease in R&D flows from the US and Japan towards the EU.

Table 4.3

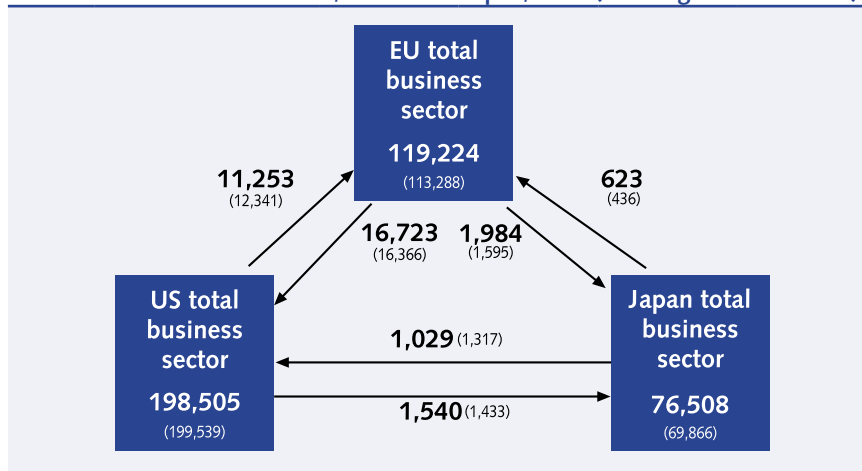
Business R&D expenditure flows between the European Union and its two main competitors – US and Japan – during 2000-2001

R&D flows	2000	2001	Change (%)
From EU-15 → Japan and US	17 961	18 707	+ 4.2
From Japan and US → EU-15	12 777	11 876	- 7.1

Note: 2000 and 2001 data are PPS \$
Source: DG JRC-IPTS calculations based on OECD data

Figure 4.3

R&D flows between the EU-15, the US and Japan, 2001 (2000 figures in brackets)



Note: The figures are in USD million at PPS equivalent of the current year
Source: OECD (2004b), Eurostat, European Commission (2005a) and DG JRC-IPTS own calculations.

However, the EU is not only losing its ability to attract R&D investment from external investors compared with the US and Japan, but also it is finding it difficult to compete with emerging markets which are rapidly becoming knowledge-intensive economies, with multi-national corporations flocking to set up R&D operations in countries such as China, India and Brazil (Section 4.5).

4.3.2 Sector concentration

Despite the overall trend towards R&D globalisation, it is also worth highlighting sectoral differences in these trends. Most of the foreign R&D investment is concentrated in a few sectors, such as: pharmaceuticals, biotechnology, chemicals, health, automobiles & parts, IT hardware and electronics (UNCTAD, 2005, pp.123 and 125), although the figures are lower in electronics and electricals because of the dominance of Japanese companies, which still concentrate their R&D more in their domestic economy. Similarly, according to the figures published by the National Science Foundation (2004), R&D expenditures of foreign affiliates in the US in chemicals (including pharmaceuticals and biotechnology), computer and electronic products, and automobiles and parts accounted for 63% of total foreign R&D expenditures in 2000. Conversely, affiliates of US companies abroad spent more than 74% of their total R&D spending in these same three groupings of economic sectors in 2002.

The picture is similar in the UK, where pharmaceuticals, ICTs (including software services) and automobiles accounted for 65% of total R&D expenditure by foreign affiliates in 2002 (Office of National Statistics, 2004). More than 60% of the R&D expenditure by US affiliates in Germany is in automobiles & parts industry, while almost 50% of German companies' R&D activity in US occurs within the same economic sector.

The outlook by sector shows different dynamics for different sectors of economic activity in terms of R&D expenditures by foreign affiliates. In US, the fastest growing sectors in this field were, during 1997-2000, computer and electronic products (doubled their volume in only four years) and automobiles and parts (five times bigger values in 2000 as compared to 1997). In recent years (after 2000) there was a surge in pharmaceuticals and biotechnology.

4.3.3 Firm size

The study in France (Ministère de l'éducation nationale, 2001) also showed the degree of R&D globalisation to increase with the size of the R&D budget. Four of the 27 companies accounted for more than two thirds of R&D investment and these four companies were the most globalised ones in the sample, with more than 70% of their sales outside France. In these cases, R&D globalisation is strongly related to sales globalisation.

This matches the observation that large firms have a higher R&D activity abroad than SMEs (Patel and Vega, 1999). Smaller firms are constrained in globalising their R&D because they do not only lack financial resources but also management capacity and critical mass to engage in strategic alliances as well (Narula and Duysters, 2004, p.159).

4.4 What makes a location attractive to firms?

4.4.1 R&D location: demand and supply factors

The main factor that makes a location attractive for locating R&D operations is the availability of qualified personnel who have state-of-the-art knowledge (Economist, 2004b). Other relevant factors are:

- international accessibility
- good links to academic research (i.e. proximity to a university)
- the presence of other foreign firms which provide added value
- a local market where innovations can be introduced easily
- the stock of private R&D capital
- strong intellectual property legislation to ensure innovations are protected

According to the Economist's (2004b) survey, in western economies, three countries are the favoured destinations: the US (29%), the UK (24%) and Germany (19%)⁴⁶. These countries have a history of R&D success, an established infrastructure, good academic links and robust IP laws. The trend here is more of the asset-augmenting type (see below; Economist, 2004b; Ernst & Young, 2004).

Up until recently, the dominant trend of R&D internationalisation has been not so much about a rush to ship low-cost R&D operations to less affluent regions, but more of a 'swapping between nations'. This, according to the Economist (2004b), is the 'new R&D model' where R&D offshoring is not only being done in Bangalore or Beijing, but also in Munich, Tokyo and New York. However, as R&D skills improve in less affluent nations, these will claim a larger slice of the total amount of R&D being outsourced. As such, the threat from developing countries does not necessarily come from the fact that less affluent countries have lower R&D costs, but that they have a growing population of R&D talent which is quickly becoming very well educated and which will draw investments from the rest of the world (i.e. R&D supply issues). This is what Europe, with its ageing population, will have to compete against.

Jones and Teegan (2003) undertook research on supply and demand factors driving the internationalisation of R&D by US companies. The study used country-level aggregate data from several agencies and organisations, thereby complementing those studies undertaken at the firm level, such as that by the Economist (2004b) and the European Commission (2005b). Jones and Teegan (2003) divided the factors motivating the foreign R&D phenomenon into three main types: demand factors, (the size of the market, the speed with which firms can develop products), supply factors (the availability of creative talent, proximity to a university centre) and other, non-technical competitive considerations (such as political motivations of potential host countries and the desire to monitor and scan the technological and competitive environment in a particular location). These latter considerations are difficult to treat systematically and are not dealt with in their study.

⁴⁶ c.f. UNCTAD (2005, p.133) 2004 survey which lists the United States, the United Kingdom, China, France and Japan being the top five R&D locations in the world.

For demand factors, the hypothesis being investigated was that host market potential was positively correlated to foreign R&D investment in that country. This notion follows from the idea that overseas operations by multinational corporations have long been driven by the need to be close to the markets they serve, in particular to be more receptive to market demands and variations and to respond to them more quickly. This hypothesis was confirmed and suggests a direct link between the location where firms focus their sales efforts and where they conduct their R&D activities.

For *supply* factors, Jones and Teegan's (2003) hypotheses were:

1. *The availability of scientific and technical personnel to work in R&D operations in a host country is positively associated with foreign R&D investment in that country.* This looks basically into the supply of qualified personnel and is the basis of the supply-side argument. This hypothesis was corroborated in the case of 'scientists and engineers', but not for 'scientists, engineers and technicians'. So, taking the technicians out, there was a significant and positive correlation. The explanation might lie in the fact that scientists and engineers represent creative talent, while technicians do not.
2. *The availability of science and technical education curricula and graduates, supporting the development of potential R&D-related workers in a host country, is positively associated with foreign R&D investment in that country.* This looks into the educational foundations and infrastructure, and is an important factor in the supply-side argument. This hypothesis was found to be true only when looking at university education and PhDs. High school maths and science scores were not significant. However, for university and education the variable measure quantity of talent, while for high school education it measured quality (scores).
3. *Electronic communications capabilities available to facilitate R&D operations in a host country are positively associated with foreign R&D investment in that country.* This seeks to demonstrate the impact of communications on R&D, which is already well-documented in the technology management literature. There was some support for this hypothesis
4. *The strength of the host's technological competitiveness (in terms of national orientation and technological infrastructure) is positively associated with foreign R&D in that country.* The premise here is that MNEs will be attracted to those locations displaying a positive and continued commitment to maintaining or improving their position in terms of technological competitiveness. There was some support for this hypothesis
5. *The average cost of R&D activities in a host country is negatively associated with foreign R&D investment in that country.* This looks at the cost of undertaking R&D operations in another country. There was no support for this hypothesis

In sum, the results support the general view that demand factors are strongly correlated with foreign R&D activities. Firms apparently locate their innovative capacity in important final markets. Indeed, a significant portion of overseas R&D activities are focused on adapting technologies and products to local market requirements (Hakanson, 1992). In terms of the supply side, what

was found to be correlated was the amount of university and PhD-trained scientists and engineers. High school was less important, as were technicians. It is highly-trained scientists and engineers which are being sought, and which attract foreign investment in R&D. These latter findings suggest some support for supply side factors and asset-augmenting motives for locating R&D overseas. Thus, some MNEs seem to be setting up shop overseas in order to tap into knowledge and technology sources in centres of scientific excellence located worldwide. It seems, therefore, that the *supply* of creative and science and engineering talent deserves closer attention by policy-makers in light of the internationalisation of R&D phenomenon.

Florida (2004) has also highlighted more generally the role of the supply of talent for R&D. Florida's (2004) point is that innovation depends on people. If this creative talent is not available, then no matter how much money you 'throw' at R&D, nothing will come of it. Florida talks about a creativity crisis in the USA which has worsened in the post 9/11 climate. With visa applications becoming ever more cumbersome, foreign talent is being dissuaded from entering the USA. And this is a competitive edge over other countries that the USA is losing. Florida's premise is that America's growth has hinged on one key factor, namely its openness to new ideas. However, the US is facing the prospect of fewer ideas pouring in, since ideas are embedded in people. To stay innovative, the US must continue to attract the world's sharpest minds. According to Florida, wherever creativity goes (and wherever talent goes) innovation and economic growth are sure to follow. In this vein, immigration is a way of attracting talent that is essential for economic growth.

4.4.2 How are international R&D operations structured?

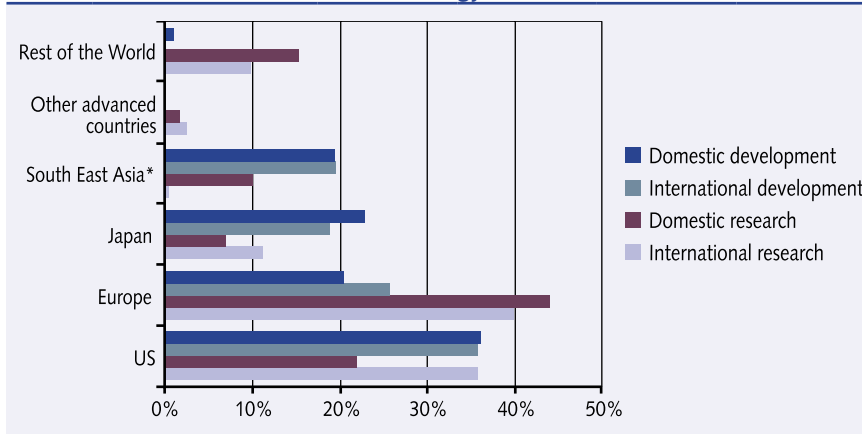
One way of looking at the internationalisation of R&D hinges on the distinction between research activities and development activities. Depending on the location of an R&D site and its orientation, a typology with four types of sites has been developed by Zedtwitz and Gassmann (2001):

1. 'National treasure' R&D: both research and development are domestic;
2. 'Technology-driven' R&D: dispersed research and domestic development;
3. 'Market-driven' R&D: domestic research and dispersed development; and
4. 'Global' R&D: dispersed research and dispersed development.

From this typology, two main drivers for the internationalisation of R&D can be derived. According to one, access to local markets is an incentive to establish a decentralised development structure. According to the other, access to critical scientific knowledge at a local level motivates the establishment of an international research site which feeds back results to the company's R&D system. These two drivers resemble the traditional distinction between market-pull and technology-push factors for R&D incentives at the corporate level. The R&D sites studied by Zedtwitz and Gassmann (2001) are concentrated mainly in Europe, the US and Japan, but there are significant R&D poles in South Korea, Singapore and other countries in South East Asia (Figure 5.4).

Figure 4.4

Research Location versus Research Strategy



*South East Asia = Hong Kong, Singapore, South Korea, Taiwan, Indonesia, Malaysia, Thailand and Vietnam.

Source: Compiled from v. Zedtwitz and Gassmann (2001).

The R&D sites in the US show a comparable lack of strength in domestic research, while those in Japan and South East Asia are more oriented towards development than research. Although the sample of 81 companies was not very big, it contained a wide representation of S&T intensive industries: 27 companies in the pharmaceutical, chemicals, and food sectors; 32 in the electrical and information & software technology sectors; and 22 in the machinery, petroleum and automotive sectors. Also, a considerable number of R&D sites were covered⁴⁷. Another interesting finding from this study is that, although the main research poles coincide with the main development poles, research sites are more concentrated than development sites. 75% of research sites are located in 8 countries, while 75% of development sites are located in 19 countries. Furthermore, a company's research and development sites do not always share the same location.

Finally, the literature (OECD, 2005a) suggests that firms with home-base augmenting motives are more attracted to industries and countries with relative technology strengths, especially when outsourcing 'research'. On the other hand, firms with home-base exploiting motives are more likely to offshore 'development' type of R&D activities.

Another study covering 12 multinational companies presents another model of how firms organise global R&D projects in this international R&D environment. A distinction is made between different types of R&D units, categories of global R&D structures and the different phases of a R&D project (Chiesa, 2000):

1. *Managers see the centre of excellence* structure – where one lab is assigned a global mandate in a certain technology/product/process area in order to increase the R&D efficiency (economies of

⁴⁷ For example, the Dialog 'Research Centres and Services Directory' covers around 15 000 private for profit R&D sites world-wide (see: <http://library.dialog.com/bluesheets/html/bl0115.html>). That means that the study of von Zedtwitz and Gassmann (2001) covers around 7% of them in a non-representative sample.

scale, easier to coordinate) by concentrating the needed resources in one location – as most preferable, but also the most unlikely way to organise global R&D, because the appropriate conditions seldom occur.

2. *The supported specialisation* structure – where resources in a technology/product/process area are concentrated in one location and a number of small units are dispersed worldwide to supply the market and technical information to the global centre – is a more realistic structure. Managers will choose this organization option in order to harvest the benefits of specialisation of concentration (efficiency, economies of scale, low coordination costs), without missing innovation opportunities.
3. *The network* structure – which consists of a network of dispersed labs in different countries working in the same technology/product/process and where each lab is free to undertake its own R&D initiatives and allocate resources to locally developed projects – increases research costs and is more difficult to manage due to the need for fluid interpersonal communication. The decision for this organisation form will be made when cross-fertilization of knowledge and internal competition will increase the research process speed and shortens the time to market.
4. *The specialised contributors* – where each unit is specialised in one or a few disciplines and contributes by developing a piece of the R&D work with an 'integrator' R&D centre having overall management and control – combine the benefits of specialisation with the superior creativity and innovation potential of the network structure.

All these different firm-level reasons for locating R&D abroad have been sought to be explained by two larger motives (Narula and Zanfei, 2004; OECD, 2005a)⁴⁸:

- *'Asset-exploiting R&D' or 'home-base exploiting' (HBE) activity.* Here, firms seek to promote the use of their technological assets in conjunction with, or in response to, specific foreign local conditions. This type of activity allows multinationals to appropriate more benefits from their innovations. It is a way to squeeze more value out of the firm's technological innovations, and of course a way to be closer to the market and make modifications, if necessary, to suit local requirements. According to this perspective, it is the technological advantages of the source firm, which in turn reflect those advantages of its home country (e.g. Nokia and Finland) which prevail.

On this view of the internationalisation of R&D, strategic decisions (which include R&D and innovation) remain rigidly centralised in the home country, which is the preferred location for R&D. The R&D activities of foreign subsidiaries, on the other hand, are limited to

48 Jones and Davis (2000) presents three main types of internationalised R&D facilities along similar lines: Locally-Oriented Support/Adaptation (mainly concerned with the application, in the host nation, of technological innovations carried out in the home country), Locally-Oriented Research and Development (concerned with accommodating the local market but recognising the potential supply of technical resources in the local environment) and Globally-Oriented Research and Development (facilities which are part of a global system of product research, development and introduction).

adopting and diffusion the technologies which were created centrally. Crucially, knowledge tends to flow from the parent home's laboratory to the foreign based facility.

- *'Strategic asset-augmenting activity' or 'home-base augmenting' (HBA) activity.* Here the role of foreign-located R&D is more prominent, and the aim is to acquire or create entirely new technological assets. The point here is not only to increase the efficiency of the firm's R&D process, but also to absorb technological spillovers that occur in the foreign location (often due to the presence of other firms). Foreign locations are understood to have something to offer, something complementary which cannot be found (or is more difficult to find) in the home country.

The asset-augmenting perspective considers local contexts as sources of opportunities and competences, and not as mere extensions of an industrial empire. The premise that the competitive advantage lies in the home country is negated here. Instead, the premise is that there are competitive advantages in many countries, and a successful MNE will capitalise on them. Contrary to the asset-exploiting perspective, knowledge tends to flow *from* the foreign laboratory *to* the central home laboratory. The stickiness of tacit knowledge is an important factor in asset-augmenting activities. If a significant number of firms engage in R&D activity in a foreign location, setting up R&D in that location allows a firm to benefit from knowledge spillovers generated there. The tacit nature of knowledge associated with production and innovations activity means that physical proximity is important for accessing it and absorbing it. In this case, distance is not dead and this is why firms cluster in particular locations (Narula and Zanfei, 2004; Audretsch and Feldman, 1996).

It should also be recognised that there is a trade-off, which MNEs must face when trying to achieve knowledge diffusion within the company. This is a trade-off between the autonomy of the subsidiary and the internal cohesion of the organisation (Blanc and Sierra, 1999; Zanfei, 2000). On the one hand, the MNE has to allow its subsidiary some independence to let it become embedded in the local context and to be able to build on local sources of knowledge. On the other hand, the subsidiary has to be integrated into the overall organisational structure of the MNE in order to allow for the knowledge to be transferred and capitalised upon by the rest of the company. This is particularly relevant in the case of acquired subsidiaries (i.e. the kind that are simply bought) – they might be more embedded in the local culture, but they will be less integrated with the rest of the company (OECD, 2005a).

Asset-exploiting activity represents an extension of home R&D activity, while asset-augmenting activity represents a diversification into other issues and areas. In general, asset-exploiting activities are primarily associated with demand-driven motives. For example, a large potential market might require adjustments to products or processes, or being near to the market might allow for quicker response rates to new requirements. Asset-augmenting activities, on the other hand, aim to acquire and internalise technological spillovers that are specific to the host country. They seek to absorb as much knowledge from the host country as possible (Narula and Zanfei, 2004).

When looking at the motivations for the relocation of R&D by EU firms abroad and by foreign firms in the EU, it ought to be interesting to distinguish between asset-exploiting activities and asset-augmenting activities. The

presumption is that asset-exploiting activities have – as a primary motivating factor – the potential market that the host location represents. The asset-augmenting activities, on the other hand, might have as a primary motivation factor the presence of a highly skilled labour force.

- The OECD (2005a) argues that technology flows from the subsidiary to the parent company are more likely to occur if R&D offshoring is driven by home-base augmenting motives than by home-base exploiting motives.
- Moreover, regarding the previous discussion on mergers and acquisitions, there will be a lower knowledge flow from subsidiary to parent company when a subsidiary has been acquired. This is so because even though the subsidiary is very much embedded in the local context, it is not really so well integrated with the rest of the organisation.

Empirical analysis shedding light on the relative importance of asset-augmenting versus asset-exploiting motives for R&D investment is scarce⁴⁹. Some research suggests that the asset-exploiting strategy is one of the most widely implemented strategies in electronics and metals, while asset-augmenting was more prominent among chemicals, pharmaceuticals, mining, food and materials (Patel and Vega, 1999). More significantly, there has been a shift from believing that asset-exploiting motives were dominant (namely highlighting the role played by foreign markets) to acknowledging the role of asset-augmenting motives. Le Bas and Sierra (2002), in a study focusing on patent applications to the European Patent Office, found that, overall, the asset-augmenting strategy was more prevalent. It dominated in 22 out of 30 technological fields. Generally speaking, over the last twenty years, international activities of R&D have been characterised by an increasing trend towards asset-augmenting activities. Three factors stand out and can be identified as leading this trend (Narula and Zanfei, 2004):

- Technological development has become increasingly costly and complex, so firms need to expand sourcing and interaction with many actors around the world, each contributing a specific part of the equation.
- Innovation has become a faster process in a number of industries, so if firms wish to develop a product for a particular market, they need to be close to that market and develop it there, rather than developing it in the home country and then modifying it to suit particular needs in the target country.
- There has also been pressure from host governments, which have told MNEs to increase their interaction with local partners as key conditions to gaining access into their markets.

While a trend towards more asset-augmenting activities is noticeable, asset-exploiting motivations remain important as well. There is empirical evidence showing that firms offshore activities in which they are strong at home (i.e. they have high revealed technological advantages). This would lend support to the idea that they are conducting asset-exploiting activities, namely adapting products and processes to foreign markets and lending technical support to offshore manufacturing plants. There is also

⁴⁹ From a firm's point of view, delocalised R&D activities are not distinguished from R&D activities in the home country. Therefore, sources such as the EU Industrial R&D Investment Scoreboard (European Commission 2004d and 2005d), which rely on company data, do not shed light on the phenomenon of internationalisation of R&D.

evidence that shows MNEs rarely internationalise R&D to compensate for technological weaknesses at home. A study by Le Bas and Sierra (2002) showed that, most often, R&D offshoring takes place in locations which are strong in technology and in technologies where the parent firm has an advantage. In such instances, the fact that the parent company is exploiting its technological advantages suggests asset-exploiting motives, but the fact that the host country is strong in technology suggests asset-augmenting motives. Both motives, therefore, coexist.

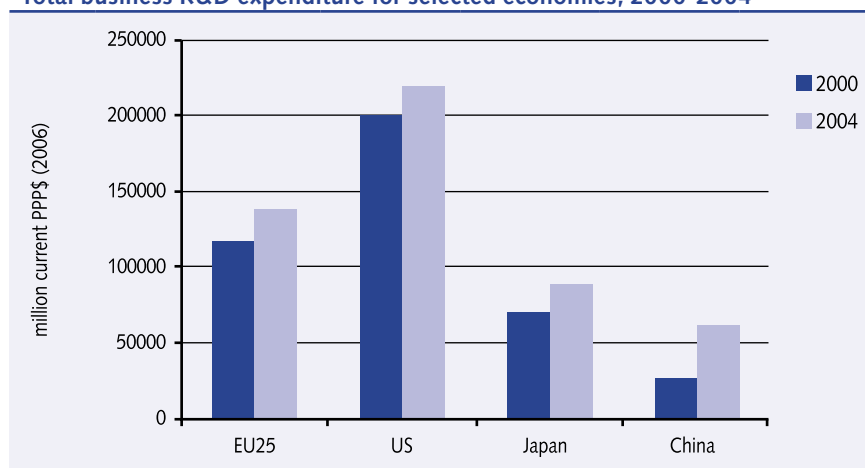
4.5 China and India as emerging R&D locations

4.5.1 Recent trends

China and India are now emerging as major competitors to the EU in terms of R&D growth and as locations for R&D activity. Part of the observed growth may derive from improved measurement methods and through increased government funding (via, for example, China's boost to R&D funding under the framework of the 10th Five-Year Plan, 2001-2005). Traditionally in China the share of R&D undertaken by the government sector is much higher than in other countries (by nearly 30%, according to the OECD report, see Schaaper, 2004). However, the main driver has been in private R&D. Data from OECD show that BERD increased over six-fold from 1991 to 2002, and BERD intensity has been growing at an annual rate of about 10% in recent years⁵⁰. As a percentage of GERD, private R&D has been increasing rapidly since 1998 and reached 61% in 2002⁵¹. Its current level is close to that of the EU average. The share of industrial R&D carried out in high-technology sectors is lower in China than in some main competitor countries, although this difference is fairly small when compared with the US and Japan (Schaaper, 2004).

Figure 4.5

Total business R&D expenditure for selected economies, 2000-2004



Source: DG JRC-IPTS calculations based on OECD (2006b) data

⁵⁰ China's S&T system was radically transformed in the late 1990s, which may have affected standards for reporting R&D statistics. Therefore, figures for China before the late 1990s should be used with great caution.

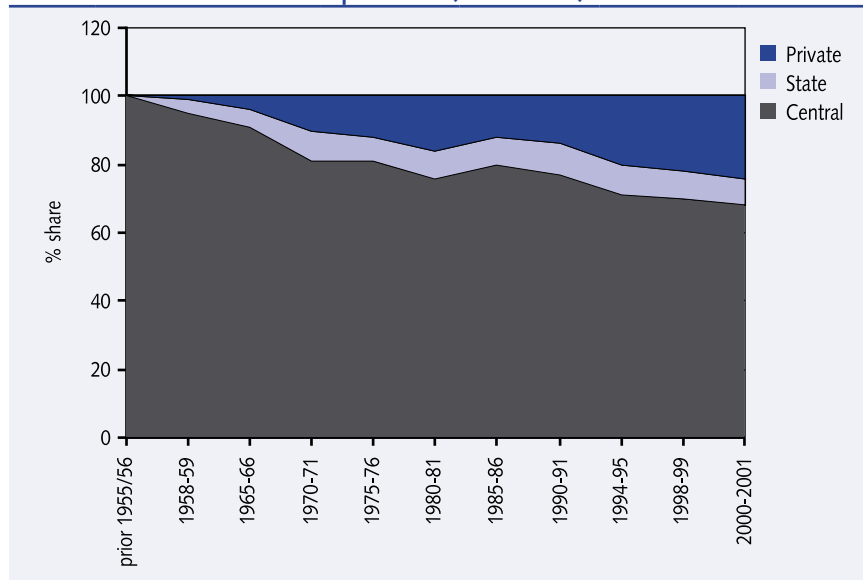
⁵¹ Part of this increase derives from changes of the measurement methods such as the reclassification of privatised government laboratories.

The volume of R&D investments, in real terms and on average, has grown annually by 15.2% between 1991 and 2002, and by 20.6% between 2000 and 2002. R&D intensity increased from 0.7% of GDP to 1.3% between 1991 and 2002, and, according to recent prospects, will reach 1.5% in 2005 and the EU level before 2010. Since 1999 the growth of R&D personnel in China has also been impressive. It increased from around 531,000 in 1999 to around 811,000 in 2002. Thus, China has more researchers than Japan (around 676 000 in 2001) and their number is getting close to that of the EU (1 million in 2001).

In India R&D expenditure has also grown rapidly, from almost zero before the 1950s and became 0.74% of GNP in 1983/84. Given the fast GNP growth experienced during the same period (an average of over 4% per year), this result is certainly noteworthy. Over the last twenty years R&D expenditure as a proportion of the GNP has risen even further to reach a balance between 0.8 and 0.91% between 1999 and 2004. The evolution of India's R&D expenditure has also followed a slow-but-steady process of disengagement of Central Government and local States from its funding. Figure 4.6 shows that in forty years the private funding of R&D has been growing from 0% in the '50s to over 20% of the total business R&D spending by the end of the '90s. Although 12 major scientific governmental agencies have a primary role in deciding the investment budget and in shaping allocations and trends of business R&D spending, for the period 2002-3 the estimate of the share of R&D funded by private industries was 25% of total GERD (Department of Science and Technology, 2005). Furthermore, in 2003/04 India granted about 2,500 patents doubling the 2002-3 figure, of these, 1,078 patents were awarded to Indian companies. In 2002-3 American companies applied for 38.1% of patents (Department of Science and Technology, 2006).

Figure 4.6

Contributors to Gross R&D Expenditure (1955-2001)



Source: PREST elaboration on Chamarik and Goonatilake (1994) and Department of Science and Technology (2005, 2006).

Foreign-owned R&D has been dominated by service sector R&D. Thus, in 2002 three-quarters of foreign-owned R&D units were in non-manufacturing industries, reflecting in particular the focus of software-based R&D in the country (UNCTAD, 2005, p.136).

On the output side, some important changes in growth and structure can be observed. China initially entered the market for low-cost manufactured goods. While it still has a strong comparative advantage in low-technology industries, the importance of the high-technology sectors has increased (Schaaper, 2004).

The number of registrations of Chinese patents has increased considerably since 1995. However, China's share of patents registered at the US Patent and Trademark Office and European Patent Office is very small. It amounts only to 0.2% and 0.3% of all patent grants/applications compared to 90% share collectively accounted for by the US, Japan and the EU (Schaaper, 2004).

4.5.2 Moving forward

Although the volume of industrial R&D investment in China is low compared to other countries, it has grown rapidly and these investments are paying off (EIRMA, 2005). Moreover, barriers to undertaking R&D in China now seem to be coming down (Gassmann and Han, 2004). These changes are being reflected in the changing value put on China and India as destinations for R&D investments in recent years. Thus, in 1994 China was only ranked 30th in 1994 (\$7 million) in terms of where US firms conducted their R&D, but 11th by 2000 (\$506 million; National Science Foundation, 2005, pp. 4-69). More specifically, in the most recent UNCTAD survey of the largest R&D spenders among TNCs for 2004 revealed that China now was the third largest global destination (Figure 4.7), behind the United States and the United Kingdom, and India the sixth most important location (UNCTAD 2005, p.133). Of the 885 R&D-oriented greenfield FDI projects announced in the Asian region, covered by the UNCTAD survey, three-quarters (723) were in China and India. The survey also indicates the extent of global R&D off-shoring that is going to India (25% of current foreign location of R&D). Projections over the period 2005 – 2009 indicate that India constitutes an attractive potential R&D location for about 30% of respondents.

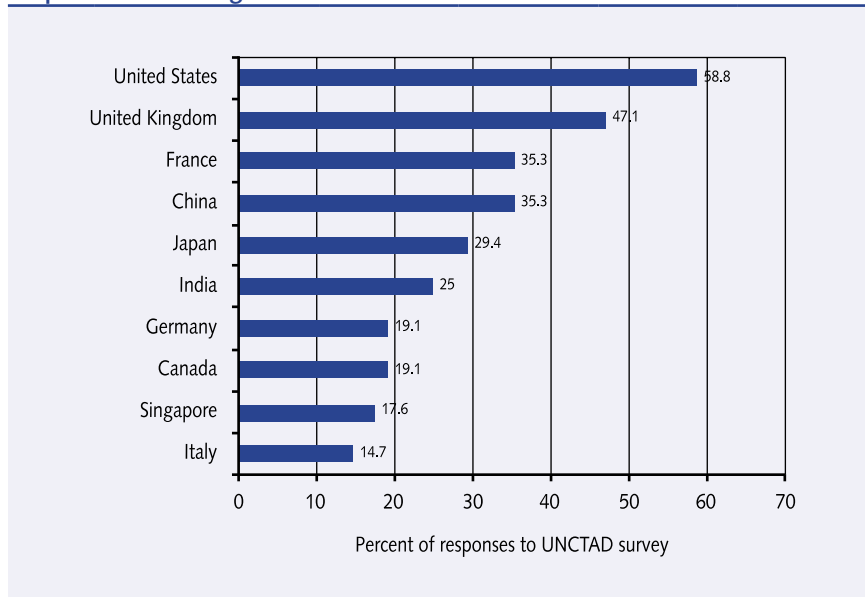
Another survey by the Economist (2004b) also revealed that when managers were asked where they would spend the most on R&D in the next three years, two emerging countries stood out: China (39% of answers) and India (28% of answers). Factors behind their attraction were:

China: Companies are attracted to China, first and foremost, because of its huge market of nearly 1.3 billion people. It is also rich in R&D skills: it had the second-highest number of researchers in the world in 2001. China used to have inadequate intellectual property (IP) legislation, and therefore R&D operations there focussed mainly on the local market. However, IP legislation has improved and as a result China has begun 'to climb the R&D value chain'. So there is a move towards more asset-augmenting R&D.

India: Part of the key of India's attractiveness to foreign R&D is that it is a large Asian country where English is widely spoken and western education is available.

Figure 4.7

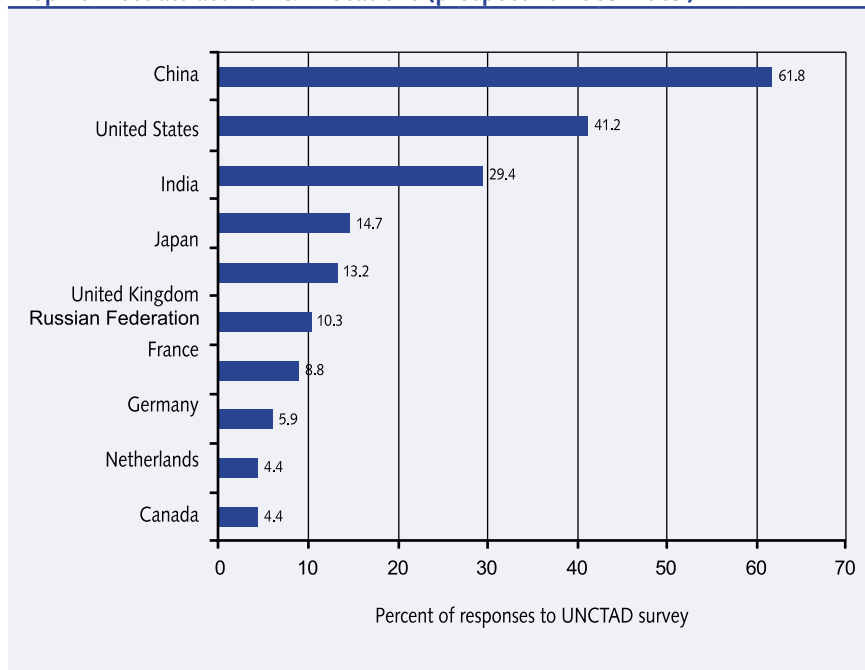
Top 10 current foreign locations of R&D



Source: UNCTAD (2005).

Figure 4.8

Top 10 most attractive R&D locations (prospective 2005-2009)



Source: UNCTAD (2005).

Table 4.4

Envisaged destination countries

Countries where companies will spend the most on R&D in the next three years	Percentage of companies giving this answer
1. China	39
2. US	29
3. India	28
4. UK	24
5. Germany	19
6. Brazil	11
7. Japan	10

Source: Economist (2004b)

4.6 Potential impacts of the internationalisation of R&D

Before summarising some of the problems and issues surrounding R&D globalisation it is worth noting the potentially positive aspects of the internationalisation of R&D, which should not be forgotten nor overshadowed by fears over loss of jobs and innovative capacity. Foreign R&D activities may provide access to foreign technologies and therefore can represent a channel for transferring knowledge back to the home country. This is referred to in the literature as 'reverse technology transfer'. Firm level studies have shown some support for this effect, but in general the evidence is mixed (OECD, 2005a; Griffith et al., 2004)⁵². One indication seems to be that R&D facilities set up abroad need to be embedded in both the host country and the parent company ('dual embeddedness') for knowledge to flow back to the home country.

Fears remain at a European level. Countries that are net sources of foreign R&D investment are worried that the internationalisation of R&D might end up substituting the R&D undertaken in the home country. According to this fear, home countries will lose their innovation-based competitive edge and will 'ship out' high-quality jobs to other countries producing a 'hollowing out' effect. If this trend is true, there is nothing much that can be done to avoid companies from offshoring their R&D activities other than making the EU an attractive place to invest in R&D. This is also true for European countries which currently have low levels of industrial R&D. Making Europe an attractive location would help motivate companies to keep R&D at home (for those who are already undertaking R&D activities in Europe) or attract foreign R&D investment into Europe (by firms who are not already doing so). In order to attract investment, policy-makers must first understand the motivations behind firms' decisions to internationalise their R&D, the various strategies involved, and the empirical evidence on factors which affect the decision to set up R&D activities in a certain country and this has been covered in earlier sections of this chapter.

⁵² Griffith et al. (2004) show that the total factor productivity of UK firms who established a high proportion of US-based inventors benefited disproportionately from the growth in R&D in the US during the 1990s.

Table 4.5

Impacts of the internationalisation of industrial R&D

	On host country	On home country
Positive impact	<ul style="list-style-type: none"> - Increased local technical capability - Knowledge & economic spillovers - Job creation - Better tailored products 	<ul style="list-style-type: none"> - Tap into other sources of expertise - Enhance access to foreign markets - Results may be exploited at home, producing economic benefits
Negative impact	<ul style="list-style-type: none"> - Foreign control over domestic R&D resources - Results may be exploited elsewhere; loss of economic benefit 	<ul style="list-style-type: none"> - Loss of jobs - Loss of technical capability - Hollowing out of industry – will manufacturing follow? - Loss of economic benefits if results are exploited locally

Source: Sheehan (2004).

There are both demand and supply side issues here which in the context of the firm can be seen as primarily asset-exploiting (demand issues) or asset-augmenting (supply issues). Policy-makers must identify the motives lying behind the drive to internationalise R&D, whether it be asset-exploiting or asset-augmenting. The evidence suggests that different motives are sensitive to particular factors. MNEs with asset-exploiting motives might search for large markets, while those with asset-augmenting motives might be more receptive to those locations that offer large amounts of qualified science and engineering (S&E) talent. In practice, however, both motives (and therefore different factors) are involved and interrelated. There has, however, been a tendency to over-emphasise supply side factors in relation to R&D. Making Europe a good place to do research is important but not the only issue here. Moreover in terms of the supply issues associated with the supply of scientific and technical labour and the cost of their labour, Europe has a major challenge with regard to China and India (and no doubt Brazil and Russia in the longer term). This becomes even more problematic in that both these economies represent major markets which would be attractive to the asset-exploiting strategies of certain multinationals. Demand side issues need to be recognised here as well. It should be emphasised that R&D activity within and beyond Europe is not a zero sum game. We need to emphasise the benefits of R&D to especially the private sector so that they demand (and in turn supply) more R&D. Thus, part of this demand may be fulfilled in-house but it may also be outsourced either within the home territory or offshored to other organisations overseas. By encouraging firms (especially SMEs and those in services and low and medium technology sectors) to undertake R&D for the first time, or to undertake more of it, can only benefit Europe given the strong links between R&D and economic performance.

Annex 1: Definitions and explanations

R&D based endogenous growth models

The R&D based endogenous growth models are based on the following assumptions (Ulku, 2004):

- Technological innovation is created in R&D-performing sectors, using other factors (such as human capital, existing knowledge stock).
- Technological innovation applied to the production of goods leads to permanent increases in the growth rate of output.
- There are constant returns to innovation.

Technology Balance of Payments

The technology balance of payments (TBP) measures the international exploitation of technology in form of trade in licenses, patents, know-how, research and technology assistance. Although the technology balance of payments indicates the ability of a country to sell and apply foreign technology, some additional qualitative and quantitative information is required for a correct the analysis of the position of a given country. Thus a deficit 'does not necessarily indicate low competitiveness. In some cases, it results from increased imports of foreign technology; in others, it is due to declining receipts from technology exports. Likewise, if the balance is in surplus, this may be the result of a high degree of technological autonomy, a low level of technology imports or a lack of capacity to assimilate foreign technologies. In addition, since most transactions also correspond to operations between parent companies and affiliates, this may create distortions in the valuation of the technology transfer' (OECD, 2005a).

Product sales

R&D as percent of sales in short run is an input indicator, in dynamics it is an output indicator.

Annex 2: Methodological aspects of the evaluation of R&D effects

R&D

The general methodology and analysis of R&D output/outcome have several constraints, as the lack of unified theory and concept. The main limitations of the methodology and analysis are summarised in the Table A2.1.

Table A2.1

Evaluation of R&D output/outcome: main limitations of the methodology and analysis

Category	Key issues
Methodology, selection and structure of indicators	<ul style="list-style-type: none"> - Lack of a unifying theory or conceptual scheme. - Influence of goals, motives, and biases of evaluators. - Problem inherent in output indicators. - Preference for available data. - Difficulties with convergence and macro indicators.
Analysis and interpretation	<ul style="list-style-type: none"> - Do these indicators really represent the state and progress of science? If so, to what extent? - 'Leap of faith' from the indicators to policy conclusions. - Manipulations, correlations, and indices may lead to erroneous trends and conclusions. - Indicators selected that are based on distinct theories (e.g., economic theories) may lead to conclusions biased by these theories.

Source: Geisler (2004).

R&D outputs and outcomes (effects) are often used in confusing manner. Nevertheless the R&D outputs are the epistemic, immediate results that flow from the research process (findings or data). They can generate multiple effects: immediate ones and effects accruing over a time frame. Outcomes (effects) emerge over time.

R&D output: all values, concepts and prototypes coming directly out of the R&D function. The most fundamental output will be knowledge that has a direct impact on the company and is related either to research, development, or technology. This knowledge can be applied to products, processes, services, etc.

R&D outcome: all benefits from R&D after implementation of output involving partners in other functions as direct products or services produced and delivered to a target group or population. Outcome could be:

- short-, medium-, or longer-term;
- immediate, intermediate, or final;
- direct or indirect;
- intended or unintended (Geisler, 2004).

All indicators of R&D output/outcome have their own constraints which reduce their effectiveness if they are used in isolation. All of them should be complemented with other indicators or sources of information (as interviews) in order to obtain a complete picture of the trends and patterns of the developments in the countries and regions. Companies' perspectives to evaluate the R&D effectiveness are shown in Table A2.2.

Table A2.2

R&D results, key areas and their indicators**Output of the R&D function****Technological options generated by R&D function**

- number of process improvements
- number of new process concepts
- number of product improvements
- number of new product prototypes
- number of ideas and pipeline projects
- number of defensive products created to respond to a competitive threat
- % of (new) developments implemented successfully (e.g. to BU's operations)
- number of patents utilised in-house

Knowledge, know-how, familiarity, awareness, understanding

- number and quality of patents
- number of publications or conference presentations

Direct revenues from sales of services, patents, licences, etc

- % income based upon R&D licenses
- % income from technical services

Outcome of Final Results of the R&D

Product leadership and customer satisfaction, preference/market share

- proprietary position
- number of new products
- time to market
- change in product portfolio/ BU potential
- time to breakeven per new product family
- sales and margin generated from products less than five years old
- profit from new products

Technology leadership: ahead of competitors, integration of external and internal knowledge

- proprietary position
- profit from new technologies
- less downtime and reduction of transition time
- time to breakeven per new technology
- ratio between R&D spending versus profit per product family

Innovativeness, new product/service sales, new business models, creation of new businesses

- market share improvement
- share of sales from new products

Cost efficiency: leaner/cheaper, better/more valuable

- improvement of productivity
- reduction in capital investment due to R&D
- labour reduction, investment reduction
- savings in catalyst, additives, energy
- higher % of prime quality resulting in additional margin versus off-grade
- more output from the same capacity resulting in increased sales
- improvement of product consistency

Sustainability, resource use, energy efficiency, social and ethical issues

- environment
- social
- economic (continuity)

Image, brand and stock value*

- shareholder/stock market value
- change in technology asset value
- motivation personal
- renewal of the company
- image of company and/or products

* Value of company/product as perceived by customers, employees, shareholders and the community at large.

Source: EIRMA, 2004a.

R&D and patents

Patents are generally seen as an intermediate output of R&D activity. There have been ongoing issues of how patents should be viewed as technology or innovation indicators and their relationship with R&D activity. Some of these issues are highlighted in Box A2.1 below.

In order to reduce the comparability problems affecting the data derived from patents filed at a single patent office⁵³, the triadic patent family indicator has been constructed by OECD. A patent is considered 'triadic' if it is filed at the European Patent Office (EPO), the Japanese Patent Office (JPO) and the United States Patent and Trademark Office (USPTO). The differences in patenting activity between countries (or trading blocks) are reduced if we analyse the triadic patent family indicator. The holders of triadic patents are mainly large firms. In general, only inventions with a very high potential for world-wide exploitation are patented as triadic patents (Office of National Statistics, 2005).

The propensity to patent⁵⁴ of European firms is lower than that of US firms. The comparison of patent propensity of the large US and European firms is presented in Table A2.3. The data emerging from the most recent European innovation survey provides some evidence on the low patenting propensity of innovative European firms. Only 12% of these companies have applied for a patent and 14% have registered one or more international trademarks. Large firms are more active in patenting and registering trademarks than small ones (Table A2.4).

Table A2.3

Patent propensity* in Europe and the USA		
	Product innovations (%)	Process innovations (%)
Europe	44	26
United States	52	44

* Ratio of the number actually patented innovations to the number of all patentable innovations.

Source: MERIT in Foray (2004)

Patents as indicators

There are some problems associated with patents as an indicator (many of which are widely known) especially if related to the emergence of new patterns of knowledge management. There some new considerations on this issue which have arisen and the quality of patent data differs from one country to another.

The propensity to patent in a particular country depends on the recent and future market potential of the country⁵⁵. As for many foreign companies the US is an important market, their propensity to patent is high in the country.

⁵³ As home advantage, costs effects, difference in industrial structures and in propensity to patent.

⁵⁴ Patent propensity: ratio of the number of actually patented innovations to the number of all patentable innovations.

⁵⁵ Propensity to patent is calculated as the ratio between the number of patents per real R&D spending (or per number of innovations).

The ratio of the number of patents per real unit of R&D spending varies across industries and technologies. Thus in biotechnology or organic chemistry the dominant forms are purely academic and collaborative patents. In telecommunications industrial patents dominate. In electronics related industries a greater number of patents are typically granted to cover a single product/invention than in the machinery or chemical industries (Meyer, 2004).

Not all inventions are patented as tools other than patenting may be used to protect inventions. According to the results of a recent survey, secrecy and other informal measures (such as customer relation management, lead-time advantages, or complex product design) are more widely used in companies' protection strategies than patenting (Blind and Thumm, 2004).

The value of patents differs considerably and the value distribution is highly asymmetric. A few patents are of considerable value, whereas the value of many is limited (Office of National Statistics, 2004).

Motivations for patenting may change over time. The economic importance of intellectual property rights has gained a new status among firms in the last two decades.

Both the value and role of intellectual property have changed. The reasons behind this feature are the changes to US government policy (legislation and operation of concerned public agencies) and as well as to the management strategy and practice of the companies (Foray, 2004).

The content of patent data is being changed in the light of the internationalisation of R&D. The consideration of the domestic (resident), national-foreign dimensions could result in different pictures on the developments.

Table A2.4

Patenting and licensing propensity of innovative firms in the EU, 2004 (%)

	In the last two years, did your firm	
	Apply for one or more patents?	Register one or more international trademarks?
	Response: yes	
EU 25	12	14
<i>Company size*</i>		
20 – 49	9	13
50 – 249	18	17
250 – 499	25	23

*Number of employees
Source: European Commission (2004b)

At the same time US companies are developing aggressive patent strategies both at home and abroad. Changes in the patenting behaviour of US firms have occurred over the past twenty years. A number of considerable changes to the patent system took place since 1980 in the US, most notably the scope of patentable subject matter was extended⁵⁶. The changes to the framework

⁵⁶ For example, genetically-modified organisms, software, and business methods gained the status of patentable matter.

of legislative procedures and operation of US patent offices have enhanced the ability of patent holders to enforce their patents (Foray, 2004). The series of infringement cases had a strong demonstrative effect on the management of companies to avoid the possibly considerable damages to which they may be liable for the use of the supposedly infringing technology (even at considerable cost)⁵⁷ (Hall, 2004).

The creation of intellectual property has become a central objective in the global strategy of US firms. The companies use patents as a tool for traditional defensive purposes, for protecting their knowledge assets and securing a monopoly position, aiming at the exploitation of their knowledge assets for a definite period of time more widely than in the past. At the same time they develop aggressive patent strategies. Thus they create a wide patent portfolio⁵⁸ in order to control future developments in a field of technology through licensing and 'employ' the patents as a means of generating income from their intangible assets through licensing (i.e. large patent owners increased the royalty rates, sought royalty-bearing licenses from smaller firms more aggressively). Aggressive patenting is 'applied' by larger companies that have the relevant capacities (Foray, 2004; Hall, 2004; Blind and Thumm, 2004).

A strong patent portfolio contributes to a stronger market position. Patents are used as bargaining chips. Industries with discrete products (food, textiles, paper, chemicals, drugs, metals and metal production), tend to patent for the traditional reasons, namely to exclude competitors and prevent litigation, whereas those in industries with complex products (machinery, computers, electrical equipment, electronic components, instruments, and transportation equipment) are significantly more likely to patent for cross-licensing and trading/negotiation purposes, as well as to prevent litigation (Hall, 2004). The patent explosion at the USPTO happened sometime between 1983 and 1984. Utility patent applications to the USPTO have more than tripled between 1983 and 2003 (Hall, 2004).

57 The Kodak-Polaroid case 'ultimately cost Kodak a billion dollar judgment and shut down their instant camera business in 1986'. (Hall, 2004)

58 Patent portfolios may contain a number of patents having low value on the market in financial terms.

Annex 3: Availability of information on top R&D-investing companies

The three main R&D Scoreboards giving worldwide lists of top companies spending or investing in R&D are:

- The UK's Department of Trade and Industry Scoreboard (DTI, 2005b).
- The EU's Industrial R&D Investment Scoreboard (European Commission, 2004d and 2005d).
- The US's Industrial Research Institute Scoreboard (available at www.iriinc.org).

These scoreboards primarily focus on the R&D investment of the top companies registered in the regions or countries of concern (UK, EU and US, respectively), but they all contain a section dedicated to the top companies worldwide.

The UK's DTI Scoreboard has been producing this kind of information since 1991, the EU R&D Scoreboard only started reporting data on both EU and non-EU regions in 2004, and the IRI R&D Scoreboard is in its 6th year of US company data listing and has offered R&D data on the top 100 R&D-investing companies worldwide for two years now.

For some individual countries, such as Canada (see Research Infosource, 2004) or Australia (see Melbourne IAESR, 2004), R&D Scoreboards were also published in 2004. In many other countries (e.g. Germany and the Netherlands) the activity of top companies in the area of R&D is gathered and analysed on a regular basis, but the surveys are not always available.

Often, information concerning the R&D expenditure or investment of major companies, worldwide or on national/regional level, can be found in Scoreboards ranked by revenues or value added. Examples are the Standard and Poors' company database, the Dun & Bradstreet company database or the sector-oriented reports of top companies (such as pharmaceuticals by *Contract Pharma*).

References

- A.D. Little (2004). *Innovation Excellence: Innovationsmanagement als strategischer Hebel zur Ergebnisverbesserung*. Frankfurt: Author.
- Abramovsky, L. Kremp, E. López, Schmidt, T. and Simpson, H. (2005). *Understanding Co-operative R&D Activity: Evidence from four European countries, mimeo*. London: Institute for Fiscal Studies.
- Anon. (2005). When disenchantment leads to disengagement. *Research Fortnight*, 26 January, 18-19.
- Archibugi, D. and Coco, A. (2005). Is Europe becoming the most dynamic knowledge economy in the world? *Journal of Common Market Studies* 43, 433-459.
- Arora, A., Fosfuri, A., Gambardella, A. (2000). *Markets for Technology: Economics of innovation and corporate strategy*. Cambridge, MA: MIT Press.
- Audretsch, D., and Feldman, M. (1996). R&D spillovers and the geography of innovation and production. *American Economic Review*, 86, 253-273.
- Baudry, M. and Dumont, B. (2006) Comparing firms' triadic patent applications across countries: Is there a gap in terms of R&D effort or a gap in terms of performances? *Research Policy*, 35, 324-342.
- Becker, B., and Pain, N. (2003). *What determines Industrial R&D Expenditure in the UK?* London: National Institute of Economic and Social Research.
- Billings, B.A., Musazi, B.G.N. and Moore, J.W. (2004). The effects of funding source and management ownership on the productivity of R&D. *R&D Management*, 34, 3.
- Blanc, H. and Sierra, C. (1999). The internationalisation of R&D by MNEs: A trade-off between external and internal proximity. *Cambridge Journal of Economics*, 23, 187-206.
- Blind, K., and Thumm, N. (2004). Interrelation between patenting and standardisation strategies: Empirical evidence and policy implications. *Research Policy*, 33, 10.
- Boston Consulting Group (2003). *World-Class Innovation; R&D Management: Rules for success in manufacturing industry*. Munich: Author.
- Bushee, B. (1998) The influence of institutional investors on myopic R&D investment behavior. *Accounting Review*, 73, 305-333.
- Cayseele, P. van (1998). Market structure and innovation: a survey of the last twenty years. *De Economist*, 146, 391-417.
- Cesaroni, F., Di Minin, A. and Piccaluga, A. (2005). Exploration and exploitation strategies in industrial R&D. *Creativity and Innovation Management*, 14(3), 222-232.
- Chamarik, S. and Goonatilake, S. (Eds.) (1994). *Technological independence: The Asian experience*. Tokyo: The United Nations University Press.
- Chesbrough, H. (2003). *Open Innovation: The new imperative for creating and profiting from technology*. Cambridge, MA: Harvard Business School Press.

Chiesa, V. (2000). Global R&D project management and organization: A taxonomy. *Journal of Product Innovation Management*, 17, 341-359.

Cohen, W. M. and Levin, R. (1989). Empirical studies on innovation and market structure. In R. Schmalensee and R.D. Willig (Eds.), *Handbook of Industrial Organisation*, 1059-1107. Amsterdam: Elsevier.

Conte, A. and Vivarelli, M. (2005). One or many knowledge production functions? Mapping innovative activity using microdata. *IZA Discussion Paper Series No. 1878*. Bonn: Institute for the Study of Labor.

Coombs R. and Georghiou L. (2002). Research And Development: A new 'industrial ecology'. *Science*, Vol. 296, no. 5567, p.471.

Cooper, R., and Kleinschmidt, E. (2001). *The Stage Gate Process for Product Success*. Copenhagen: Innovation Management.

Cooper, R., Edgett, S. and Kleinschmidt, E. (2001). Portfolio management for new product development: Results of an industry practices study. *R&D Management*, 31, 361-380.

Czarnitzki, D., Hall, B.H. and Oriani, R. (2002). The market valuation of knowledge assets in US and European firms, *mimeo*. KU Leuven, UC Berkeley and University of Bologna.

Dosi, G. (1988). Sources, procedures and microeconomic effects of innovation. *Journal of Economic Literature*, 25, 1120-117.

Dougherty, S.M., Inklaar, R., McGuckin, R.H. and Van Ark, B. (2003). Internationalization and the changing structure of business R&D: Recent trends and measurement implications. First draft, February. The Conference Board and Growth and Development Centre of the University of Groningen.

Department of Science & Technology (DST) (2005). Ministry of Science and Technology, Indian Government, National Science & Technology Management Information System (NSTMIS-DST), Research and Development Statistics 2000 – 01.

Department of Science & Technology (DST) (2006). Ministry of Science and Technology, Indian Government, Research and Development Statistics at a Glance 2004-2005.

DTI (2005a). R&D Intensive Businesses in the UK. *DTI Economics Paper*, No. 11. London: DTI.

DTI (2005b). The 2005 R&D Scoreboard: Volumes 1 and 2. London: HMSO.

Economist, The (2004a). Harnessing innovation: R&D in a global growth economy. London: The Economist.

Economist, The (2004b). Scattering the seeds of invention: The globalisation of research and development. London: The Economist Intelligence Unit.

EIRMA (2004a). Assessing Research and Development Effectiveness. Paris: EIRMA.

EIRMA (2004b). *Effective Collaborative R&D and Knowledge Transfer*. Conference Report, Brussels 5-6 February.

EIRMA (2005). Can research revitalise Japan's growth? Japan has embraced competition from China but needs to restructure to make the most of its research strength. Quarterly, Spring.

Erken, H.P.G., Kleijn, M. and Lantzendörffer, F.J.H. (2004). *Buitenlandse Directe Investerings in Research & Development*. The Hague, NL: Dutch Ministry of Economic Affairs.

Ernst & Young (2004). The Opportunity of Diversity: Attractiveness of Europe survey. Ernst & Young.

European Commission (2002). Final Report of the Expert Group on Benchmarking S&T Productivity.

European Commission (2004a). *Statistics on Science and Technology in Europe: Data 1991-2002. Part 2*. Luxembourg: Office for Official Publications of the European Communities.

European Commission (2004b). *Innobarometer 2004: Flash Eurobarometer 164*. TNS Sofres / EOS Gallup Europe. DG Enterprise, DG Press and Communication.

European Commission (2004c). *Innovation in Europe: Results for the EU, Iceland and Norway*. Luxembourg: Office for Official Publications of the European Communities.

European Commission (2004d) *The 2004 EU Industrial R&D Investment Scoreboard*. DG JRC and DG RTD. Seville, Spain.

European Commission (2005a). *Key Figures on Science, Technology and Innovation*. Luxembourg: Office for Official Publications of the European Communities.

European Commission (2005b). *The Survey on Business Trends on R&D Investment*. EUR 22162. DG JRC and DG RTD. Seville, Spain.

European Commission (2005c) Working together for growth and jobs: A new start for the Lisbon Strategy.

European Commission (2005d) *The 2005 EU Industrial R&D Investment Scoreboard*. DG JRC and DG RTD. Seville, Spain.

Eurostat (2003). *The Third European Report on S&T Indicators*. European Commission Eurostat Service.

Eurostat (2005a). *Science and Technology: Statistics in focus, 2/2005*. European Commission Eurostat Service.

Eurostat (2005b). News Release 26/2005 – 24 February.

Eurostat (2005c). News Release 156/2005 – 6 December.

Florida, R. (2004). America's looming creativity crisis. *Harvard Business Review*, 82(10), 122-136.

Foray, D. (2004). The patent systems and the dynamics of innovation in Europe. *Science and Public Policy*, 31, 6.

Forbes, N. and Wield, D. (2004). What is R&D? Why does it matter? *Science and Public Policy*, 31, 267-277.

Forfás (2005). *Business Expenditure on Research and Development (BERD): Ireland 2003/4*. Dublin: Forfás, Science and Technology Indicators Unit.

Freeman, C. (1995). The 'National System of Innovation' in historical perspective. *Cambridge Journal of Economics*, 19, 5-24.

Fuller, G.W. (1994). *New Food Product Development: From concept to marketplace*. Ann Arbor, MI: CRC Press.

Galende, J. and Fuente, J. M. de la (2003). Internal factors determining a firm's innovative behaviour. *Research Policy*, 32, 715-736.

Gassmann, O. & Han, Z. (2004). Motivations and barriers of foreign R&D activities in China. *R&D Management*, 34(4), pp.423-437.

Geisler, E. (2004). Measuring the impact from public-sector science and technology: Methods. Prepared for Presentation at the 'Workshop on Measuring the Impacts of Science,' Montreal, Canada, June 16-18.

German Council of Economic Experts (2002). *Report 2002/03: Einflussfaktoren des wirtschaftlichen Wachstums in den Industrieländern*. Wiesbaden: Author.

Gibbons, M., Limoges, C., Nowotny, H., Schwartzman, S., Scott, P. and Trow, M. (1994). *The New Production of Knowledge: The dynamics of science and research in contemporary society*. London: Sage Publications.

Gibbons, R., and Murphy, K. (1992). Does executive compensation affect investment? *Journal of Applied Corporate Finance*, 5, 99-109.

Godin, B. (2004). The obsession for competitiveness and its impact on statistics: The construction of high technology indicators. *Research Policy*, 33, 1217-1229.

Greer, D.F. (1992). *Industrial Organization and Public Policy, 3rd ed.* New York: Macmillan Publishing Co.

Griffith, R., Harrison, R. and Van Reenen, J. (2004), How special is the special relationship? Using the impact of US R&D spillovers on UK firms as a test of technology sourcing. *IFS Working Papers W04/32*.

Guellec, D., and Pottelsberghe de la Potterie, B. van (2000). The impact of public R&D expenditure on business R&D. *DSTI Working Paper*. Paris: OECD.

Guellec, D., and Pottelsberghe de la Potterie, B. van (2001). R&D and productivity growth: Panel data analysis of 16 OECD countries. *OECD Economic Studies*, 33(3), 103-126.

Hagedoorn, J. (2001). Inter-firm R&D partnerships. An overview of major trends and patterns since 1960. In J.E. Jankowski, A.N. Link and N.S. Vonortas, *Strategic Research Partnerships: Proceedings from a NSF workshop*, Washington DC, National Science Foundation, 63-92.

Hagedoorn, J. and Narula, R. (1996). Choosing organizational modes of strategic technology partnering: International and sectoral differences. *Journal of International Business Studies*, 27, 265-284.

- Hagedoorn, J. and Schakenraad, J. (1990). Inter-firm partnerships and co-operative strategies in core technologies. In C. Freeman and L. Soete (Eds.), *New Explorations in the Economics of Technological Change*.
- Hakanson, L. (1992). Locational determinants of foreign R&D in Swedish multinationals. In O. Granstrand, L. Hakanson and S. Sjolander (Eds.), *Technology Management and International Business*. Chichester: John Wiley and Sons.
- Hall, B. H. (2004). Exploring the patent explosion. *NBER Working Paper 10605*. Cambridge, MA: National Bureau of Economic Research.
- Hall, B. H. and Oriani, R. (2004). Does the market value R&D investments by European firms? Evidence from a panel of manufacturing firms in France, Germany, and Italy. *NBER Working Paper 10408*.
- Haour, G. (2004) Resolving the Innovation Paradox: Enhancing growth in technology companies. Houndmills: Palgrave MacMillan.
- Hippel, E. von (2005). *Democratizing Innovation*. Cambridge, MA: The MIT Press.
- Howells, J. (1999). Research and technology outsourcing. *Technology Analysis & Strategic Management*, 11, 17-29.
- Huggins R. (2001). Global Index of Regional Knowledge Economies: Benchmarking South East England. Guildford, UK: South East England Development Agency.
- Industrial Research Institute (IRI). (2005). IRI's R&D trends forecast for 2005. *Research Technology Management*, 48(1):18-22.
- Jaruzelski, B., Dehoff, K. and Bordia, R. (2005). The Booz Hamilton Global Innovation 1000: Money isn't everything. *Strategy + Business*, issue 41, winter.
- Jolly, V K. (1997). *Commercializing New Technologies*. Boston: Harvard Business School Press.
- Jones, G.K. and Davis, H.J. (2000). National culture and innovation: Implications for locating global R&D operations. *Management International Review*, 40, 11-39.
- Jones, G. K. and Teegan, H.J. (2003). Factors affecting foreign R&D location decisions: Management and host policy implications. *International Journal of Technology Management*, 25, 8.
- Kok, W. (Chair of High Level Group) (2004). *Facing the Challenges: The Lisbon strategy for growth and employment*. Luxembourg: Office for Official Publications of the European Communities.
- Kuznets, S. (1971). *Economic Growth of Nations: Total output and production structure*. Cambridge, MA: The Belknap Press of Harvard University.
- Le Bas, C. and Sierra, C. (2002). Location versus country advantages in R&D activities: Some further results on MNE's locational strategies. *Research Policy*, 31, 589-609.

Lee, C.Y. (2003). Industry R&D intensity distributions: Regularities and underlying determinants. *Journal of Evolutionary Economics*, 12, 307-341.

Lewis, G. (1991.) The scientific output of the EC's less favored regions. *Scientometrics*, 21, 383-402.

Lichtenberg, F. R. and Siegel, D. (1991). The impact of R&D investment on productivity: New evidence using linked R&D-LRD data. *NBER Working Paper No. W2901*.

Lin, B.-W. and Chen J.-S. (2005). Corporate technology portfolios and R&D performance measures: A study of technology intensive firms. *R&D Management*, 35, 2,157-170.

Lucey, M. (2005). The measurement of payments, licences and royalties for S&T activities. Presented at the Forum on the Internationalization of R&D. OECD-Belgian Science Policy. Brussels, 29-30 March.

Lucking, B. (2004). *International Comparisons of the Third Community Innovation Survey (CIS3)*. London: DTI.

Mairesse, J. and Mohnen, P. (2004). The importance of R&D for innovation: A reassessment using French survey data. *NBER Working Paper No. W10897*.

Maliar L. and Maliar S. (2004). Endogenous growth and endogenous business cycles. *Macroeconomic Dynamics*, 8, 559-581.

Marshall, A. (1890). *Principle of Economics*. London: Macmillan.

Martin, R. (1999). The new geographical turn in economics: Some critical reflections. *Cambridge Journal of Economics*, 23, 65-91.

Martin, T. (2001). Innovation in services and the knowledge economy: The interface between policymakers and enterprises. *Innovation and Productivity in Services*, 119-133. Paris: OECD.

Meister, C., and Verspagen, B. (2005). European productivity gaps: Is R&D the solution? *DRUID Working Paper No. 05-06*. Danish Research Unit for Industrial Dynamics Winter Conference, 27-29 January.

Melbourne Institute of Applied Economic and Social Research (2004). *R&D and Intellectual Property Scoreboard*. Australia: Author.

Meyer, M. (2004). Measuring the impact of technology on science in the knowledge-driven economy. International Workshop on 'Measuring the Impacts of Science on Society'. Montreal. 17-18 June.

Ministère de l'éducation nationale. (2004). Création ou rachat de centres de R&D : deux voies pour assurer la présence des groupes français à l'étranger. *Note d'information 01-26*.

Narula R. and Duysters G (2004). Globalisation and trends in international R&D alliances. *Journal of International Management*, 10(2), 199-218.

Narula, R. and Zanfei, A. (2004). Globalisation of innovation: The role of multinational enterprises. In J. Fagerberg, D.C. Mowery and R.R. Nelson (Eds.), *The Oxford Handbook of Innovation*. Oxford: OUP.

National Science Foundation (2004). *Science and Engineering Indicators: 2004*. Arlington, VA: National Science Foundation.

National Science Foundation (2005) *National Patterns of Research and Development Resources: 2003*. Arlington, VA: Division of Science Resources Statistics, Directorate for Social, Behavioral, and Economic Sciences, National Science Foundation.

NIST Planning Report (2005). *Report 05-1 Measuring Service-Sector Research and Development*. National Science Foundation and National Institute of Standards & Technology.

NISTEP (2005). *Science and Technology Indicators, 2004: A systematic analysis of science and technology activities in Japan. NISTEP Report No. 73* (English version of the report published in March 2005).

OECD (2001). *Changing business strategies for R&D and their implications for science and technology policy. OECD Background and Issues Paper*. Paris: OECD.

OECD (2003). *The Sources of Economic Growth in OECD Countries*. Paris: OECD.

OECD (2004a). *Compendium of Patent Statistics, 2004*. Paris: OECD.

OECD (2004b) *Science, Technology and Industry Outlook, 2004*. Paris: OECD.

OECD (2004c). *Research and Development Expenditure in Industry*. Paris: OECD.

OECD (2005a). *Internationalisation of R&D: Trends, issues and implications for S&T policies. Background Report for the Forum on the Internationalization of R&D OECD-Belgian Science Policy*. Brussels, 29-30 March.

OECD (2005b). *Growth in Services: Fostering employment, productivity and innovation*. Paris: OECD.

OECD (2005c). *Compendium of Patent Statistics, 2005*. Paris: OECD.

OECD (2005d). *Promoting Innovation in Services*. Paris: OECD.

OECD (2005e). *Main Science and Technology Indicators, 2005*. Paris: OECD.

OECD (2006a). *OECD Indicators for OECD non-member countries*. Paris: OECD.

OECD (2006b). *Main Science and Technology Indicators, vol. 2006/1*. Paris: OECD.

OECD (2006c). *Research and Development Expenditure in Industry, 1987-2004*. Paris: OECD.

Office of National Statistics. (2004). *Research and Development in UK Businesses, 2002*. Newport: National Statistics.

Office of National Statistics. (2005). *Research and Development in UK Businesses, 2003*. Newport: National Statistics.

Papageorgiou, C., Savvides, A. and Zachariadis, M. (2004). International Medical R&D Spillovers. Working paper. Louisiana State University.

Papanastassiou, M. (1997). Firm strategies and the research intensity of US MNEs overseas operations: An analysis of host country determinants. In R. Pearce (Ed.), *Global Competition and Technology*. London: Macmillan.

Patel, P., and Vega, M. (1999). Patterns of internationalisation of corporate technology: location vs. home country advantage. *Research Policy*, 28, 145-155.

Pavitt, K. (1984). Sectoral patterns of technological change: Towards a taxonomy and a theory. *Research Policy*, 13(6), 313-373.

Rafferty M. (2003). Do business cycles alter the composition of research and development expenditure? *Contemporary Economic Policy*, 21, 394-405.

Rammer, C. (2004). FuE-Verhalten von jungen Unternehmen in Deutschland: Ein Panelanalyse für den Zeitraum 1998-2003. *Studien zum deutschen Innovationssystem* Nr. 8-2005. Mannheim: ZEW (Centre for European Economic Research) and BMBF (German Ministry of Education and Research).

Research Infosource Inc. (2004). *Canada's Top 100 Corporate R&D Spenders 2004*. Toronto, Canada.

Rey, S.J. (2001). Spatial empirics for economic growth and convergence. *Geographical Analysis*, 33, 195-214.

Rogers, E. (1996). *Diffusion of Innovations* (4th ed.), New York: Simon & Schuster Trade.

Romer, P.M. (2000) Should the government subsidize supply or demand in the market for scientists and engineers? *NBER Working Paper* No. 7723.

Rothwell R, (1992) Successful industrial innovation: Critical factors for 1990s. *R&D Management*, 22(3) p.221-239.

Ryan, H.E. and Wiggins, R.A. (2002). The interactions between R&D investment decisions and compensation policy. *Financial Management*, 31, 1.

Saloner, G. and Rotemberg, J.J. (2000). Visionaries, managers, and strategic direction. *RAND Journal of Economics*, 31, 693-716.

Salter A.J. and Martin B.R. (2001). The economic benefits of publicly funded basic research: A critical review. *Research Policy*, 30, 509-532.

Sandven, T. and Smith, K. (2005). Structural change, growth and innovation: The roles of medium and low tech industries. In H. Kreinsen, D. Jacobson and S. Laestadius (Eds.), *Low-tech Innovation in the Knowledge Economy*. Frankfurt: Peter Lang.

Sachwald F., (2005). The impact of EU enlargement on the location of production in Europe. *Les Études de l'Ifri*, No. 4, Paris.

Schaaper, M. (2004). An emerging knowledge based economy in China. Indicators from OECD databases. *STI Working Paper 2004/4*. Paris: Statistical Analysis of Science, Technology and Industry, Directorate for Science and Industry, OECD.

Sheehan, J. (2004). Globalisation of R&D: An OECD perspective. GUIRR Meeting on Globalization, Competitiveness and Workforce. Washington, DC, 3-4 February.

Shefer D. and Frenkel A. (2005). R&D, firm size and innovation: An empirical analysis. *Technovation*, 25(1), 25-32.

Scherer, F. and Ross, D. (1990). *Industrial Market Structure and Economic Performance*. Boston, MA: Houghton Mifflin.

Steen, E.J. van den (2005). Organizational beliefs and managerial vision. *Journal of Law, Economics and Organization*, 21, 256-283.

Stifterverband für die Deutsche Wissenschaft. (2004). *FuE-Info 1/2004*. Essen, Germany: Wissenschaftsstatistik gGmbH.

TÁRKI (2004). Az Európai Kutatási Térség (European Research Area - ERA) és Magyarország helyzetének összehasonlító vizsgálata. IFM Humán Erőforrás Háttér tanulmányok. Innováció és Információs Társadalom Szakmai Munkacsoport. 2004/6261. Budapest.

Tether, B. (2004). Do services innovate (differently)? *CRIC Discussion Paper No. 66*, Manchester: CRIC, University of Manchester.

Ulku, H. (2004). R&D, innovation, and economic growth: An empirical analysis. *IMF Working Paper WP/04/185*. International Monetary Fund.

UNCTAD (2005). *Transnational Corporations and the Internationalization of R&D. World Investment Report*. New York and Geneva: United Nations.

Vence-Deza, X. (1996). Innovation, regional development and technology policy: New spatial trends in industrialization of technology policy. In X. Vence-Deza and J.S. Metcalfe (Eds.), *Wealth from Diversity: Innovation, structural change and finance for regional development in Europe*, 145-197. Dordrecht: Kluwer.

Verspagen, B. (1997). European 'regional clubs': Do they exist, and where are they heading? *MERIT Working Paper 2/97-010*. Maastricht: MERIT.

Voelker, R. and Stead, R. (1999). New technologies and international locational choice for research and development units: Evidence from Europe. *Technology Analysis and Strategic Management*, 11, 199-209.

Walsh, K. (2003). Foreign High-Tech R&D in China: Risks, rewards and implications for US-China relations. Washington: The Henry L. Stimson Center.

Zanfei, A. (2000). Transnational firms and the changing organisation of innovative activities. *Cambridge Journal of Economics*, 24, 515-542.

Zedtwitz, M. von, and Gassmann, O. (2002). Market versus technology drive in R&D internationalisation: Four different patterns of managing research and development. *Research Policy*, 31, 569-588.

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Abstract

The Annual Digest of Industrial R&D highlights the most significant findings on industrial R&D based on a screening of recent publicly-available sources including official reports and relevant professional and academic literature. A detailed report of this screening is available in the Annex, the Background Document, while the Digest itself is much more synthetic and intended for a wide audience. In its first edition, it focuses on the impact of industrial R&D, levels and patterns of industrial R&D investment, the factors that influence those investments, and the internationalisation of industrial R&D.



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