Department for **Innovation, Universities** & **Skills**

Business Innovation Investment in the UK

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Executive summary

The theory of economic growth postulates that innovation is a primary source of a country's long run productivity growth. Innovation is the outcome of firms' efforts to produce new or improved products, introduce more efficient productive processes and implement organisational or managerial changes or new marketing and design processes. This paper introduces different types of business investment on innovation complementary to the more traditional R&D concept, such as investment in innovation-related training and design, investment in machinery, equipment and software and in marketing.

Despite R&D representing only a third of firms' investment in innovative activities, however, it is still an important part of innovation performance. A comparison of aggregate R&D trends in the UK and other major OECD economies shows the UK's performance somewhat lagging behind. Once industrial sector composition is taken into account, however, UK's position appears more in line with other developed economies.

Trying to understand the determinants of innovation gives insights on how a country's economic growth could be promoted using public policy and has long challenged researchers and policy makers. The existing evidence concludes that the decision to perform R&D activities is influenced by a firm's size, while the amount of R&D expenditure grows broadly proportionally with firm size. Other factors affecting R&D investment decisions are firm and industry characteristics such as concentration, market power and the firm's ability to appropriate the results of its research efforts. New evidence on factors associated with different forms of investment in innovation using the UK Innovation Survey data is presented in this paper and the conclusions are broadly in line with the recent empirical literature. It is found that larger firms are more likely to engage in all types of innovation activities but their size does not affect the intensity of their R&D investment. Firms that operate in international markets are more likely to engage in innovation and they engage in R&D more intensively. Firms in industries where greater use is made of formal or strategic methods to protect innovations invest a higher proportion of their sales in R&D.

The last chapter references recent published studies suggesting that adjusting for international differences in the cost and productivity of R&D also affects the international comparisons of R&D intensity.

To understand firms' incentives to innovate, it is also important to discuss the efficiency of the innovation process and quantify the impact of investment in innovation on productivity.

Most of the existing evidence on the returns to investment in innovation focuses on estimating the rate of return to R&D investment. Many studies also attempt to distinguish between private rate of return, which are the revenues that firms derive from their own investment in R&D, and social rate of returns, constituted by the sum of private returns and the so called "R&D spillovers", which are the benefits deriving from R&D investment of other firms.

Introduction

The theory of economic growth postulates that innovation is a primary source of a country's long run productivity growth. Trying to understand the determinants of innovation gives insights on how a country's economic growth could be promoted using public policy. Innovation is the outcome of firms' efforts to produce new or improved products, introduce more efficient productive processes and implement organisational or managerial changes or new marketing and design processes. Chapter 1 presents a discussion of these different sources of innovation using the latest available data from the UK Innovation Survey. It is clear that firms' investment in innovation activities is much broader than their effort in Research and Development (R&D) alone, which has traditionally been the focus of much of the economic literature, for a number of reasons. First, the most recent theoretical thinking has stressed the role of R&D activities as engine of economic growth: Romer (1990), Grossman and Helpman (1991), and Aghion and Howitt (1992) all presented theoretical models in which the long-run rate of economic growth is driven by the decision of firms to devote resources to R&D activities.

Second, the availability of relatively long and comparable cross-country time series on expenditure on research has also been a dominant factor in determining the attention of much empirical research on the determinants and impacts of R&D investment (see e.g. Guellec and Van Pottelsberghe de la Potterie, 2004). The reason for this richness in R&D data availability is that it is relatively easier to measure than other types of innovation-related expenditure, such as, for example, design. Chapter 2 presents a detailed analysis of long-run trends in R&D expenditure in the UK and other major economies. The variability of R&D investment across industrial sectors is discussed in the light of the apparent low ranking of the UK in terms of the ratio of R&D expenditure to Gross Domestic Product (GDP).

In an attempt to identify the main factors associated with different types of innovation expenditure, Chapter 3 presents the results of a modelling exercise that relates a firm's decision to invest in innovation to a series of firm and industry characteristics. It is found that, in line with the existing evidence, investment in innovation in the UK is associated with factors such as firm's size, market competition and other industry characteristics, and with the ability of the firm to appropriate the results of its research effort.

To understand firms' incentives to innovate, it is also important to discuss the efficiency of the innovation process and quantify the impact of investment in innovation on productivity. Chapter 4 references recent work on international differences in the cost and productivity of R&D and how these might further affect conclusions drawn from conventional R&D intensity measures. It then presents some existing evidence on the rates of return to R&D investment at different levels of aggregation: firm, industry and economy, distinguishing between the private rate of return - the revenues derived by firms from their own investment in R&D, and social rate of returns, constituted by the sum of private returns and the so called "R&D spillovers", which are the benefits derived from a firm's R&D investment by other economic agents.

Chapter 1 The characteristics of business investment in innovation

This chapter introduces the types of business investment on innovation complementary to the more traditional R&D concept, such as investment in innovation-related training and design, investment in machinery, equipment and software and in marketing. The main patterns of expenditure in these types of activities by UK firms are presented.

1.1 Characteristics of firms' investment in Innovation

A firm's innovation performance depends on the ability to bring together knowledge, ideas and market awareness into new or improved goods and services that better meet customer needs. Technologies on their own are not enough for this and essential complementary assets are likely to include some or all of individual creativity, business knowledge, design and innovation management.

These elements can be usefully brigaded into the idea of an innovation system model, which takes account of:

- Technology/knowledge dissemination (which is picked up in the innovation survey through equipment/software + external knowledge)
- Complementary organisational and management capabilities and change (not the main topic of this paper but cannot be left out of the picture)
- Management of the innovation process itself.

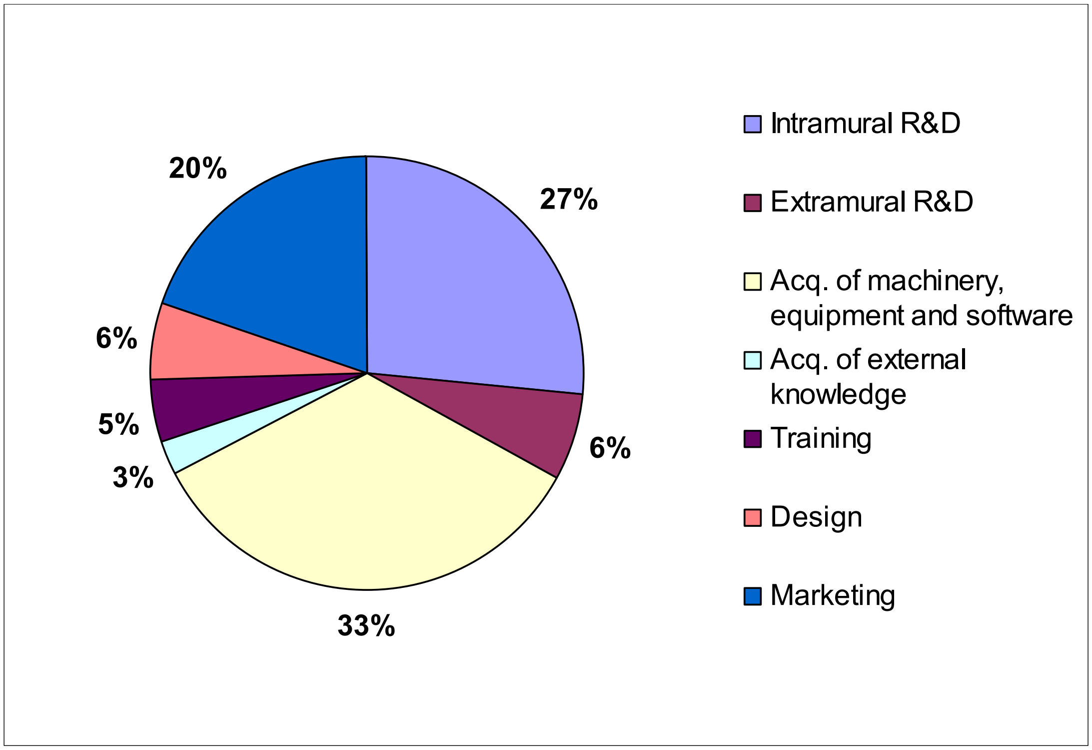
As a recent OECD (2005) report on the UK has pointed out, representing innovation using a small number of purely technology indicators, such as R&D and patents, underestimates the extent of innovation in the UK relative to other countries. One of UK's strength is in knowledge intensive services and creative industries, where innovation is less likely to be picked up by technology indicators. A recent review (DTI, 2005a) has highlighted how forms of investment complementary to traditional R&D and application of skills are crucial in determining business and economic performance.

UK business spends around £40 billion on innovation on these broader measures. Figure 1 shows the breakdown of this spending in UK businesses.[1] One third of all expenditure is investment in capital and IT, including software. Business R&D conducted internally or externally also constitutes approximately a third of the total. Marketing expenditure constitutes 20% of all innovation expenditure.

All innovating businesses pursue combinations of these forms of innovation activities, with the extent and balance between them depending on sector and size.

[1] The main data source for this Chapter and Chapter 3 is the UK Community Innovation Survey. This is conducted by EU member states every 2 years (since 2005, previously every 4). The most recent survey was conducted in 2007. More details are available at: http://www.berr.gov.uk/dius/innovation/innovation-statistics/cis/page10957.html

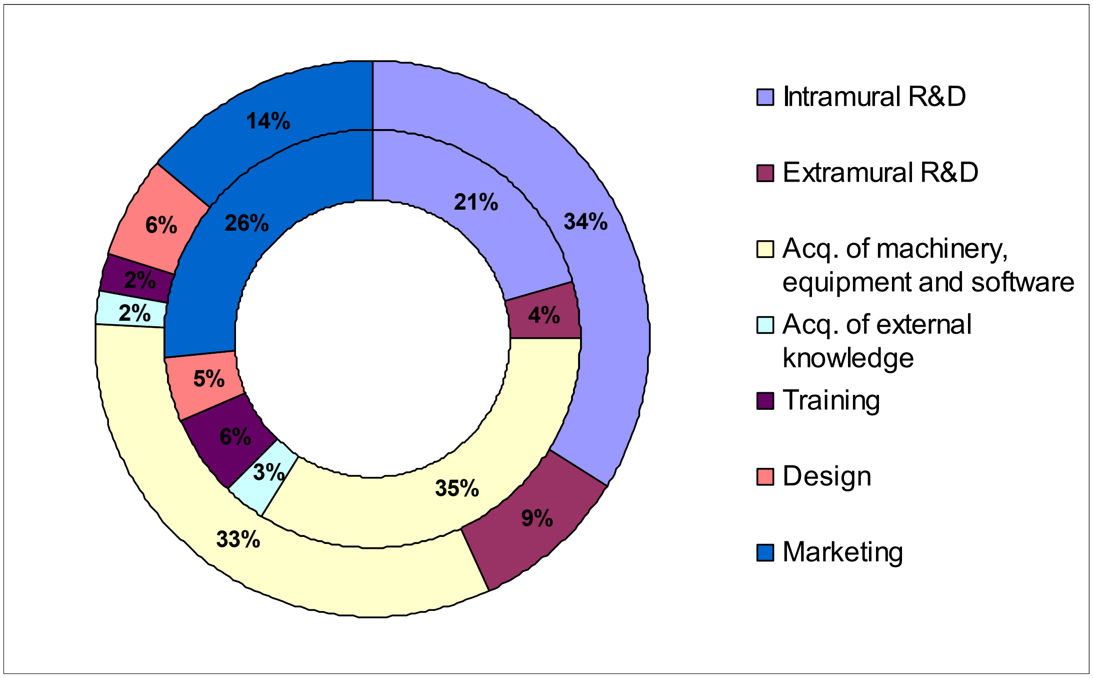
Figure 1: Expenditure on innovation by type, 2006



Source: UK Innovation Survey, 2007

The variation across the broad industrial sectors of manufacturing and services is shown in Figure 2.

Figure 2: Expenditure in innovation by type: manufacturing and services, 2006



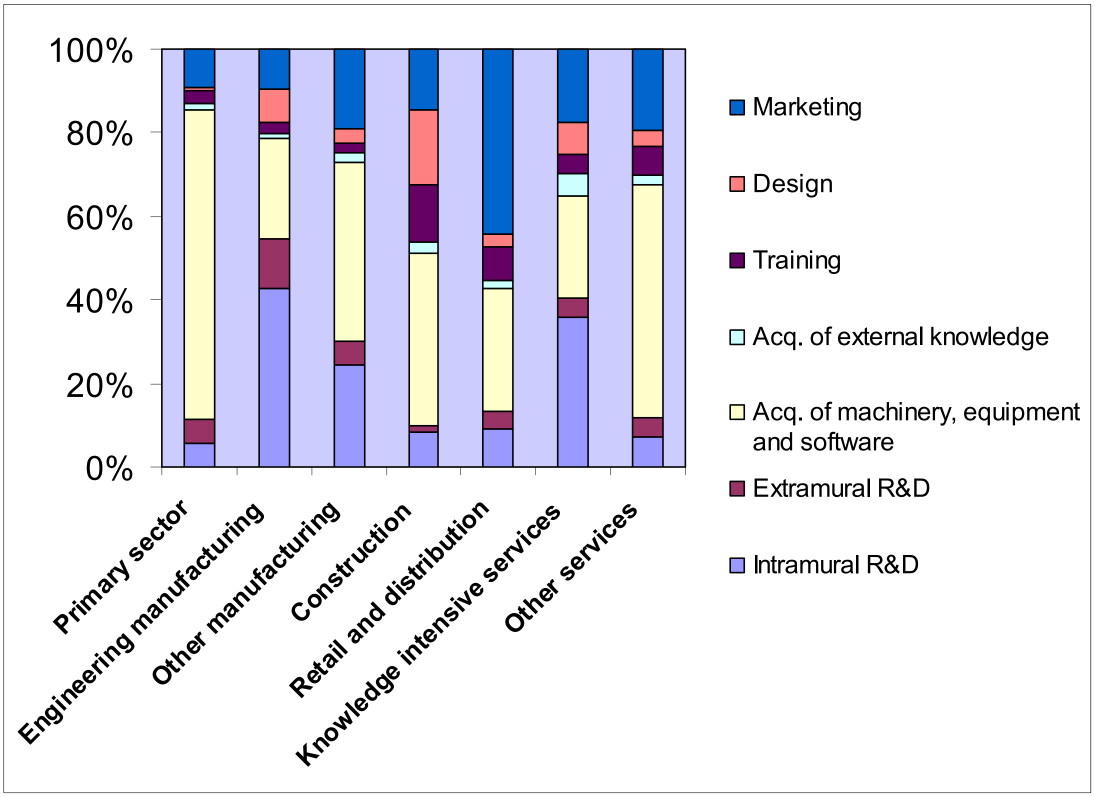
Source: UK Innovation Survey, 2007

Note: external circle: manufacturing; internal circle: services

In Figure 3, which compares expenditure across a more disaggregated industrial classification,[2] the difference in R&D intensity across sectors is particular evident, with Engineering based Manufacturing and Knowledge Intensive Services recording relatively high R&D intensity, while Construction, Retail and Other services exhibit much lower shares of their innovation investment in R&D.

[2] **Primary sector:** Mining and Quarrying and Electricity, gas & water supply
Engineering-based Manufacturing: Manufacturing of electrical and optical equipments, Manufacturing of transport equipments, Manufacturing of plastic metals & minerals.
Other Manufacturing: Manufacturing of food, clothing, wood, paper, publish & print, Manufacturing of fuels, chemicals, Manufacturing not elsewhere classified
Retail & distribution: Wholesale and Retail Trade
Knowledge-intensive services: Telecommunications, Financial intermediation, Computer and related activities, Research and experimental development, Architectural and engineering activities, Technical testing and analysis, Advertising
Other services: Hotels & restaurants, Transport, Post and courier activities, Real estate activities, Renting of machinery, equipment, personal, and household goods

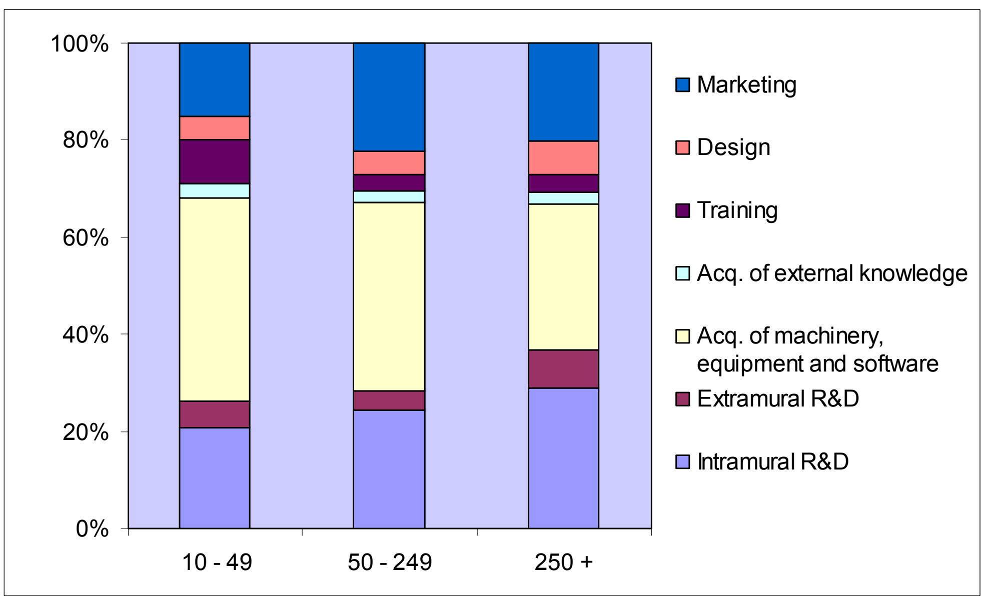
Figure 3: Innovation expenditure by industrial sector



Source: UK Innovation Survey, 2007

Expenditure patterns vary also with firm size, with formal R&D becoming more important the larger the firm, and smaller firms relying more on acquisition of capital goods and software and on training, as shown in Figure 4.

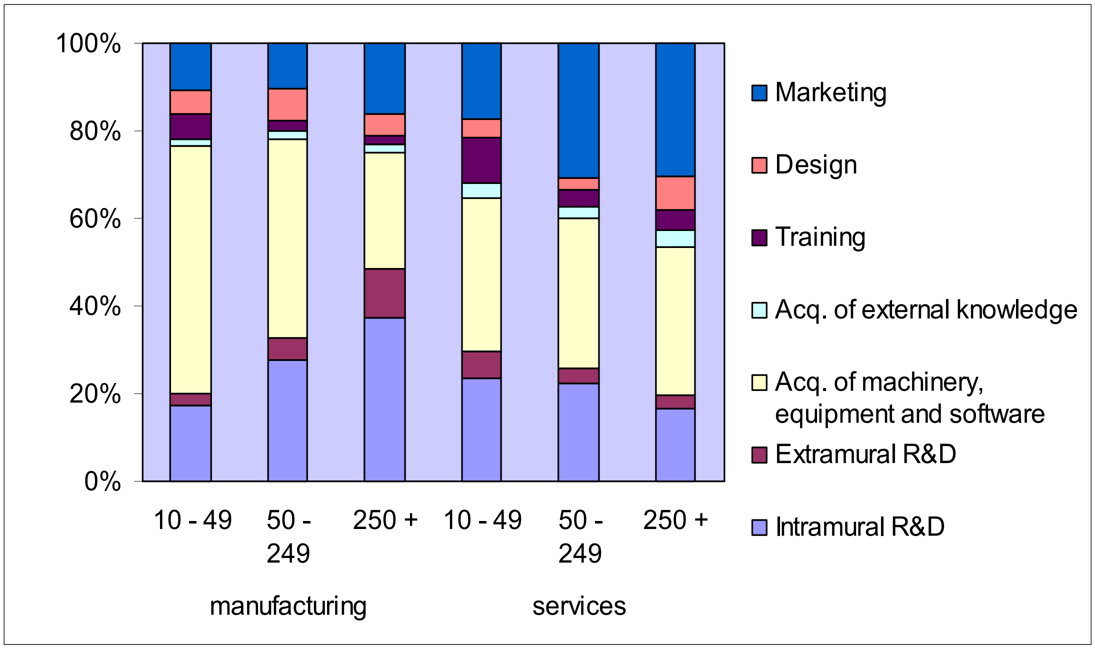
Figure 4: Innovation expenditure by firm size



Source: UK Innovation Survey, 2007

This pattern is predominant in the manufacturing sector, but less pronounced in the services sector. Here large firms invest proportionately less in formal R&D, while their marketing expenditure is higher (Figure 5).

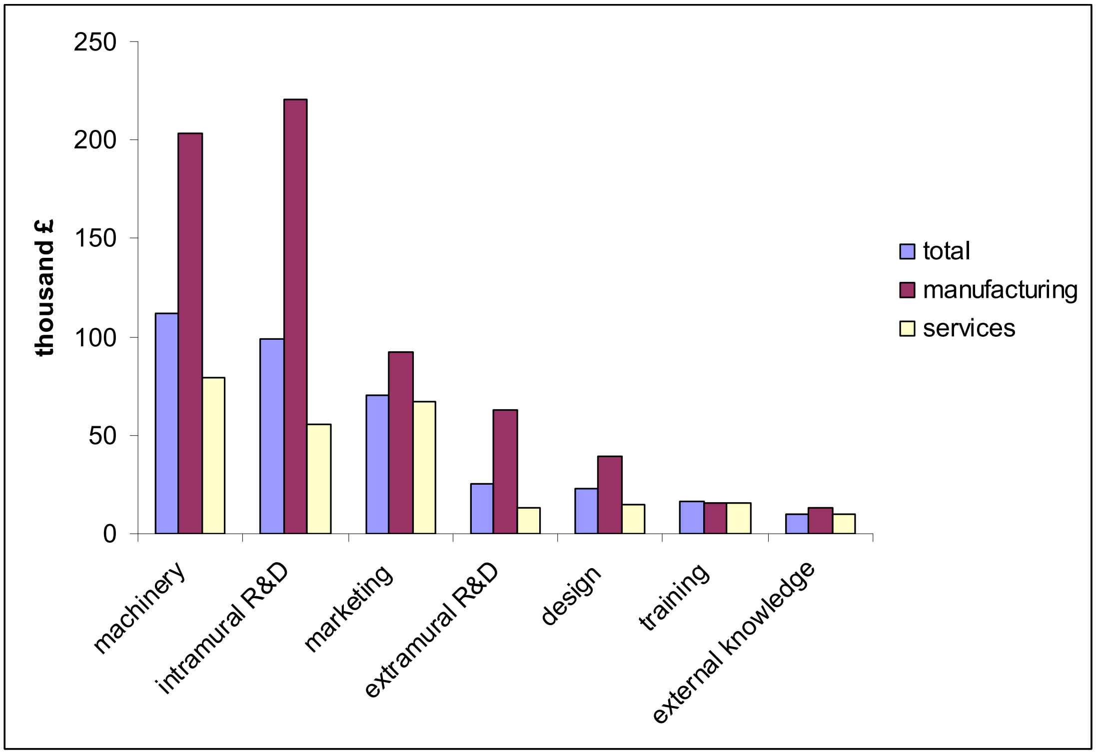
Figure 5: Innovation expenditure by firm size and industry



Source: UK Innovation Survey, 2007

Average expenditure across UK firms is represented in Figure 6: manufacturing firms spend on average more than twice than service sector firms on machinery, equipment and software, and four times as much on traditional (intramural and extramural) R&D. Differences across the two industrial sectors are less pronounced for expenditure on marketing and almost disappear for training, and acquisition of external knowledge.

Figure 6: Average expenditure on innovation in UK business



Source: UK Innovation Survey, 2007

Variability across industrial sectors is illustrated in Table 1: firms in the primary sector (mining and quarrying and utilities) invest heavily in machinery and equipment, as well as traditional R&D and marketing. Traditional R&D and design are comparatively high on average among engineering manufacturing firms. Design is also important in the construction industry and in the knowledge intensive services.

Table 1: Average expenditure on innovation across sectors

	Intramural R&D	Extramural R&D	Machinery	External knowledge	Training	Design	Marketing
Primary sector	229	233	2442	63	115	32	367
Engineering manufacturing	317	94	172	10	18	64	72
Other manufacturing	138	36	229	16	13	19	109
Construction	16	2	62	5	23	33	26
Retail and distribution	24	12	67	5	20	9	112
Knowledge intensive services	128	17	82	21	17	29	62
Other services	14	9	87	5	12	8	34

Source: UK Innovation Survey, 2007

1.2 Complementary investment in Innovation

Do firms that engage in one innovation activity also tend to engage in others? How are the different innovation activities related within firms? Swann (2007) explores a variety of different approaches to measuring complementarity amongst different innovation activities and finds that, according to one mathematical index of complementarity, intramural R&D, external knowledge and design are complementary to extramural R&D.

Another way of measuring the degree of association between pairs of variables is to compute a coefficient of correlation. Correlations between pairs of innovation activity are shown in Table 2, where large correlation coefficients are highlighted. A relatively high degree of positive correlation is observed across all types of expenditure, with stronger patterns for intramural R&D and design (0.50) or marketing (0.50), training and marketing (0.49) and design and marketing (0.47).

Table 2: (Sample) correlations between pairs of types of innovation activity

	Intramural R&D	Extramural R&D	Mach. eq. software	Ext. knowl.	Training	Design
Extramural R&D	**0.44**					
Mach. eq. software	0.29	0.20				
Ext. knowl.	0.33	**0.44**	0.24			
Training	**0.42**	0.31	**0.40**	0.37		
Design	**0.50**	0.36	0.26	0.35	**0.40**	
Marketing	**0.50**	0.32	**0.41**	0.33	**0.49**	**0.47**

Source: UK Innovation Survey, 2007

When considering innovation expenditure rather than activity, the associations are generally lower; these are reported in Table 3. Highest complementarities are observed for intra/extra mural R&D (0.68) between training and design (0.57), and between training and machinery, equipment and software (0.45).[3]

Table 3: (Sample) correlations between pairs of types of innovation expenditure

	Intramural R&D	Extramural R&D	Mach. eq. software	Ext. knowl.	Training	Design
Extramural R&D	**0.68**					
Mach. eq. software	0.19	0.15				
Ext. knowl.	0.11	0.16	**0.34**			
Training	0.12	0.09	**0.45**	**0.41**		
Design	0.21	0.04	0.27	0.13	**0.57**	
Marketing	0.17	0.10	0.20	0.08	0.30	0.22

Source: UK Innovation Survey, 2007

[3] The correlation coefficients were all significantly different from zero at 1% confidence level.

It also appears that training is highly correlated with external knowledge: this could be an indicator of firms' efforts to acquire what in the innovation literature is known as "absorptive capacity", i.e. the firm's ability to recognise and assimilate new external information and apply it to commercial end, which is crucial for innovation (Cohen and Levinthal, 1989).

From Table 3, it also appears that some complementarity exists between acquisition of external knowledge and machinery, equipment and software (correlation coefficient 0.34).

These patterns are dominant among firms in the manufacturing sector (Table 4), while for service sector firms more important links exist between acquisition of external knowledge and acquisition of extramural R&D and machinery and software (Table 5).

Table 4: (Sample) correlations between pairs of types of innovation expenditure, manufacturing

	Intramural R&D	Extramural R&D	Mach. eq. software	Ext. knowl.	Training	Design
Extramural R&D	**0.69**					
Mach. eq. software	0.21	0.18				
Ext. knowl.	0.12	0.15	0.08			
Training	**0.36**	0.11	**0.39**	0.22		
Design	0.32	0.06	0.13	0.08	0.23	
Marketing	0.29	0.17	0.16	0.10	0.21	0.25

Source: UK Innovation Survey, 2007

Important linkages also exist in service sector firms between external and internal (training) knowledge acquisition, between training and machinery and software acquisition and between training and marketing.

Table 5: (Sample) correlations between pairs of types of innovation expenditure, services

	Intramural R&D	Extramural R&D	Mach. eq. software	Ext. knowl.	Training	Design
Extramural R&D	0.20					
Mach. eq. software	0.21	0.09				
Ext. knowl.	0.12	**0.69**	**0.66**			
Training	0.26	0.28	**0.58**	**0.54**		
Design	0.22	0.08	0.11	0.28	0.20	
Marketing	0.02	0.08	0.16	0.08	**0.35**	0.04

Source: UK Innovation Survey, 2007

The breakdown by size reveals that this pattern is dominated by large firms (firms with over 250 employees) whereas for small and medium firms complementarities are much less evident.

Chapter 2 UK R&D expenditure

This chapter presents a detailed analysis of R&D expenditure in the UK and draws a comparison with other major OECD economies. The analysis is broken down by industrial sector, with emphasis on the role of sector composition in explaining the UK relative R&D performance. Size issues are also addressed.

A final section assesses the level of internationalisation of business R&D in the UK, both in terms of inflows and outflows.

2.1 Trends in total and business R&D in the UK

The analysis in the previous Chapter has shown that R&D expenditure by enterprises (both internal and external) represents one third of all innovation expenditure. Nevertheless, R&D remains an important indicator of innovative activity, not least for the richness, longevity and cross-country comparability of the R&D data available.

Table 6 presents the UK aggregate R&D expenditure in the UK by business enterprises (BERD) and by the whole economy (Gross domestic expenditure on R&D or GERD), including Government, Higher Education establishments, the Research Councils and non-profit and foreign private businesses.

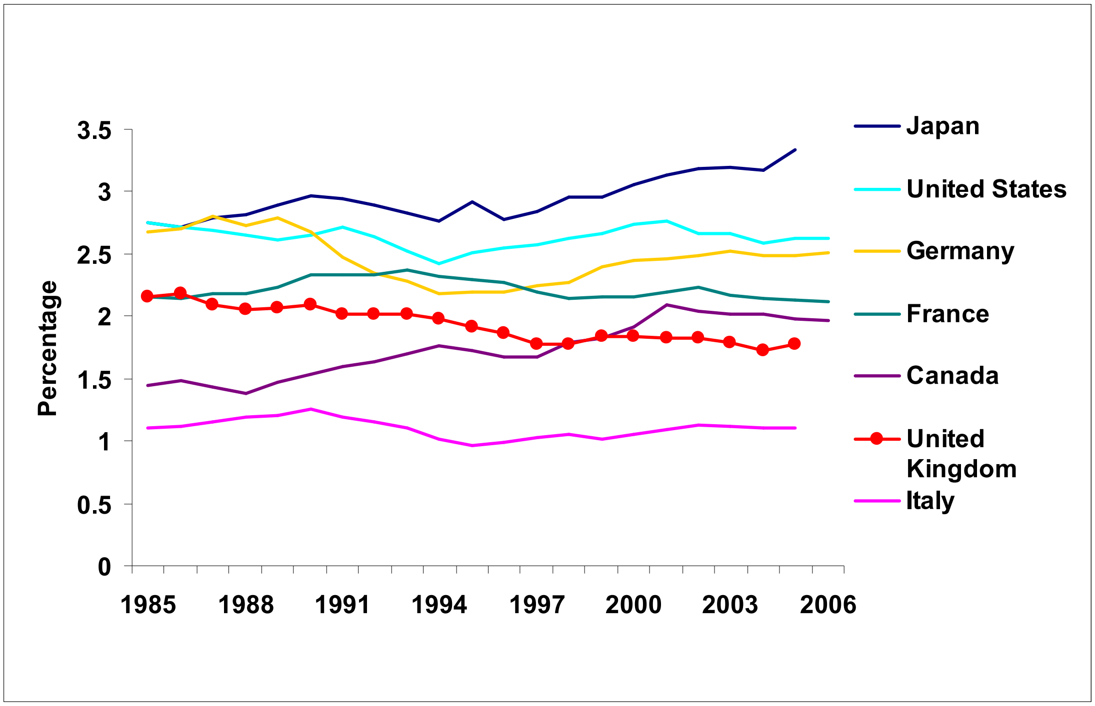
Table 6: UK R&D expenditure (£million)

Year		
2006	Business expenditure on R&D (BERD)	14,306
2005	Gross expenditure on R&D (GERD)	21,764

Source: ONS, latest available figures

An international comparison of GERD figures shows a stable R&D ratio is a common feature of other EU countries, as well as the US, in recent years (Figure 7).

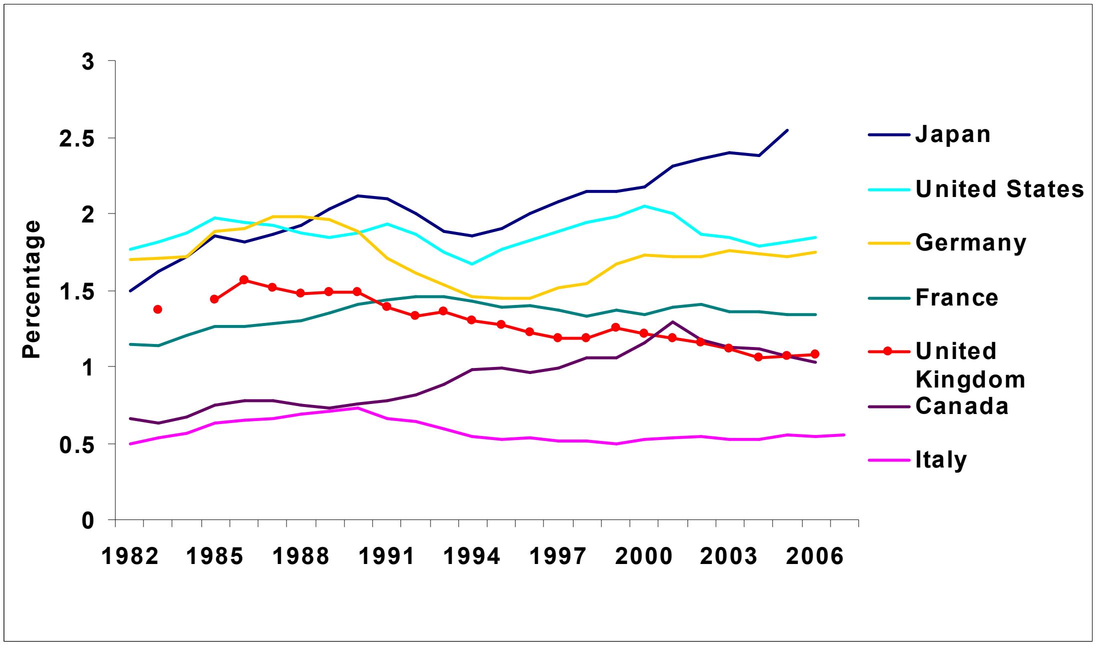
Figure 7: Gross expenditure on R&D as percentage of GDP, G7 countries



Source: OECD MSTI 2007-2

Business Enterprise R&D performed in the UK has shown a slight downward trend as a share of GDP since 1990. Most advanced economies, with the exception of Japan, have experienced fairly steady levels of R&D to GDP since the turn of the century. That is, in most leading economies, the level of BERD has grown in line with GDP over this period.

Figure 8: Business R&D as percentage of GDP, G7 countries

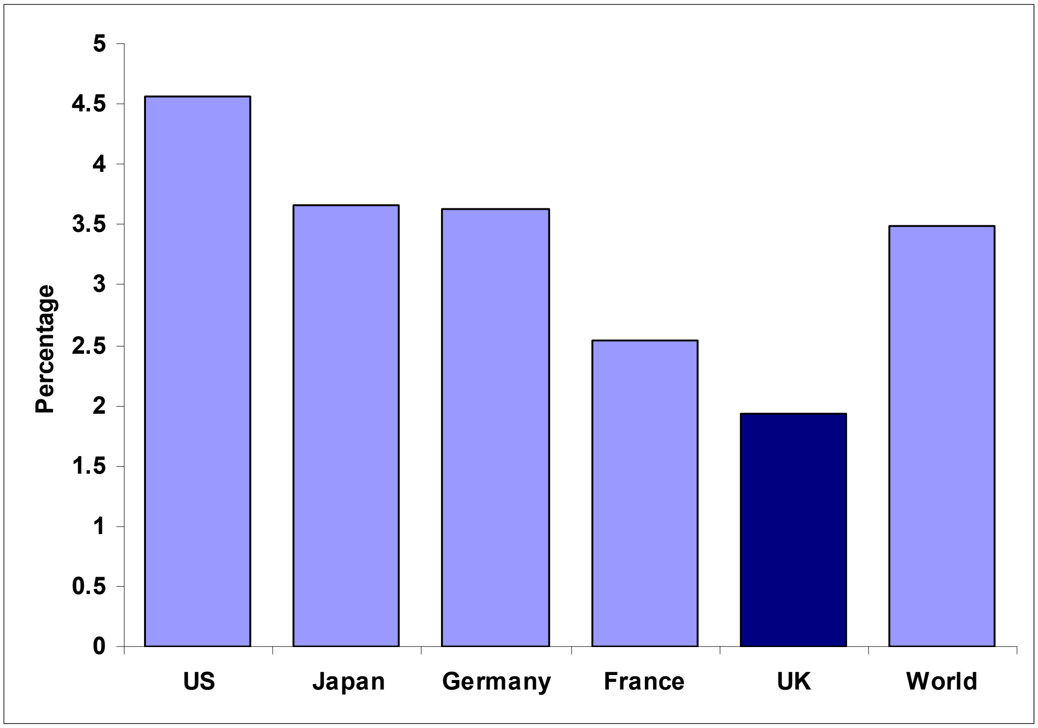


Source: OECD MSTI 2007-2

The UK's ratio of Business R&D expenditure to GDP is lower than most G7 countries. When considering the top R&D spending businesses represented in the UK R&D Scoreboard [4] (Figure 9), it appears that the ratio of R&D to sales is significantly below the world average for R&D intensive businesses.

[4] The R&D Scoreboard provides a snapshot of R&D activity by both the UK's most active 850 companies (UK 850), and the 1250 most active globally (International 1250). Information on the UK R&D Scoreboard can be found at: http://www.innovation.gov.uk/rd_scoreboard/default.asp

Figure 9: International comparison of R&D Intensity (R&D/Sales)

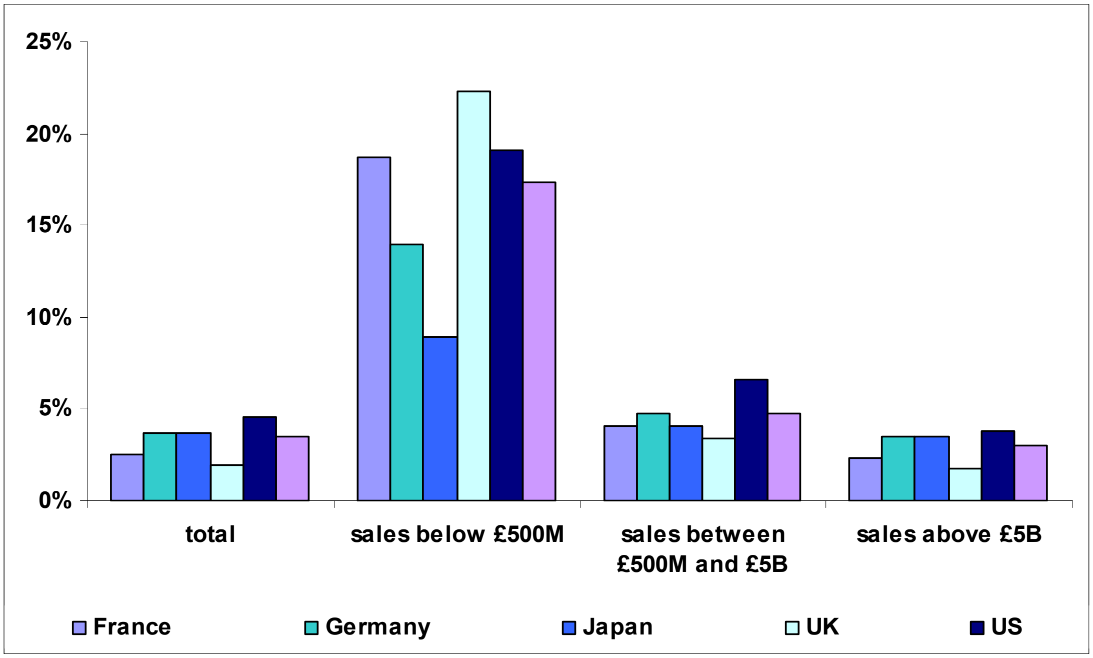


Source: The 2007 R&D Scoreboard (International 1250)

2.2 The role of size in explaining cross country differences

A possible explanation put forward for the lower UK R&D intensity compared to other major economies is that the UK lacks large firms, which are the major performers of business R&D. A comparison of R&D intensity by size band (Figure 10) seems to suggest that this is not the case in general. UK firms appear to have a lower R&D intensity that France, Germany, Japan and USA across all size bands, with the exception of small firms with sales below £500 million.

Figure 10: R&D intensity for different size bands



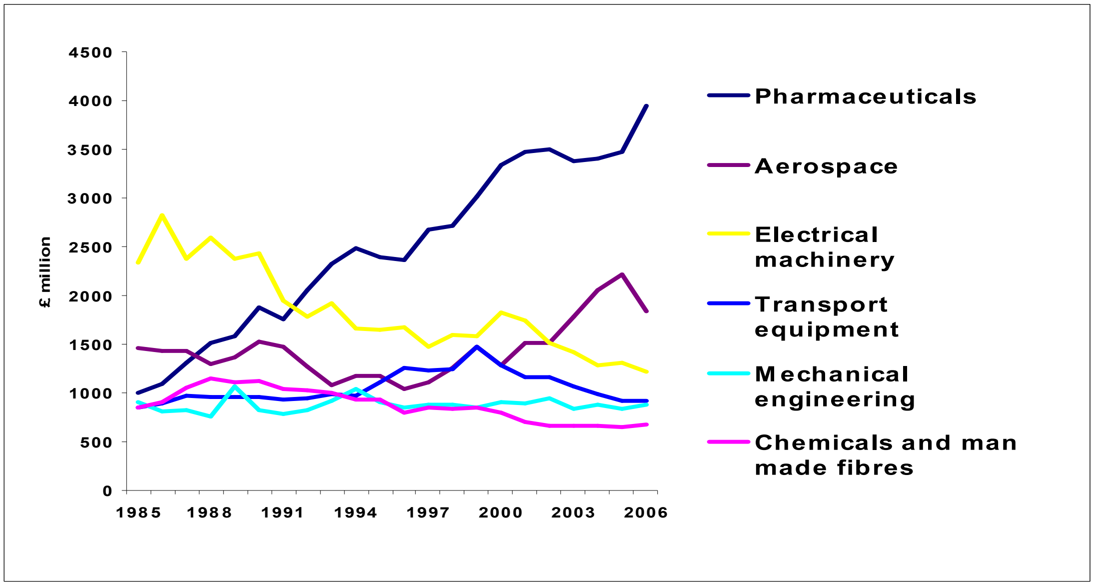
Source: The 2007 R&D Scoreboard (International 1250)

This, however, might reflect a different sector composition across countries and the next section examines the effects of the sectoral structure of the UK against other major economies.

2.3 The role of the industrial sector mix

R&D investment varies significantly across industrial sectors. Trends in UK business R&D expenditures across sectors are shown in Figure 11 for manufacturing and Figure 12 for services.

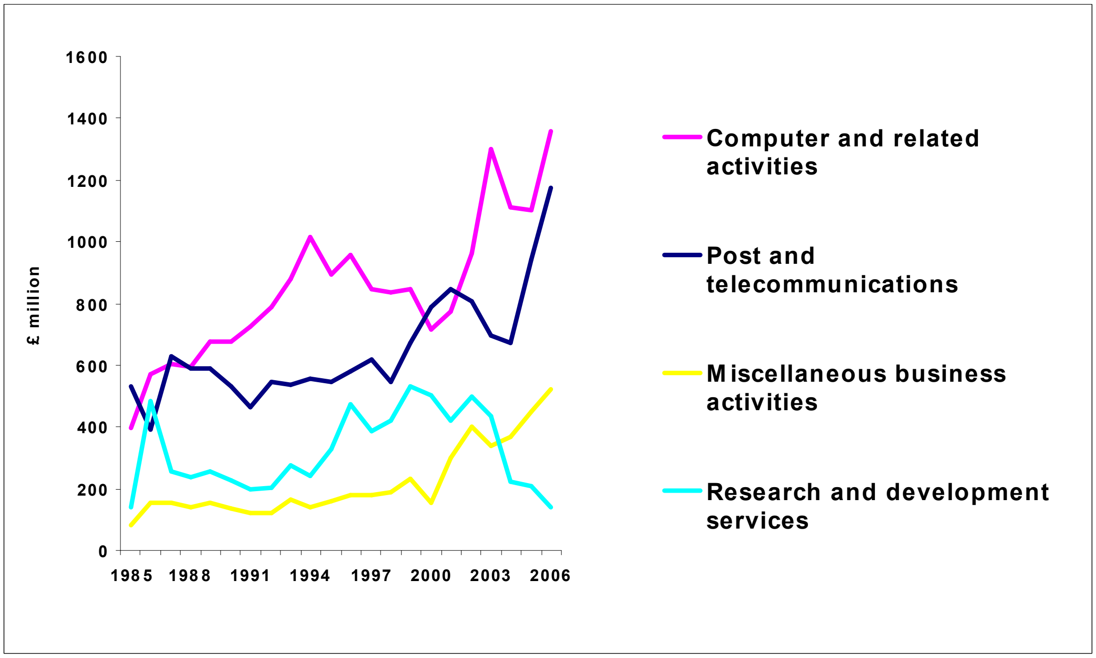
Figure 11: Real terms UK business R&D by selected product groups (manufacturing)



Source: ONS 2008

The most recent trends in BERD in real terms have been dominated by Pharmaceuticals and Aerospace in the manufacturing sector and by Computing activities and Telecommunications in the services sector.

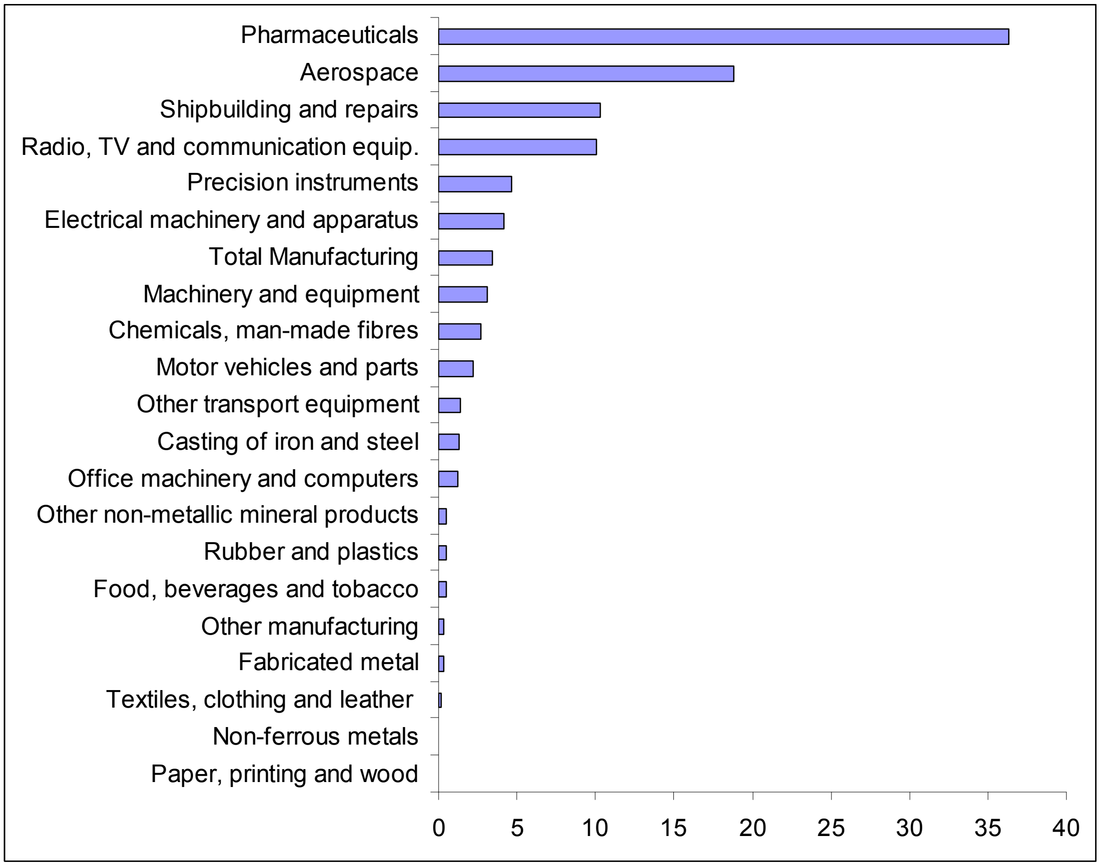
Figure 12: Real terms UK business R&D by selected product groups (services)



Source: ONS 2008

R&D intensity, defined as R&D expenditure as percentage of sales, also varies dramatically across industrial sectors: this is emphasised in Figure 13 for the manufacturing sector.

Figure 13: R&D Intensity (R&D expenditure as a proportion of sales) in UK manufacturing, 2006



Source: ONS 2008

Differences in R&D intensities across sectors can occur because of different technological opportunities, returns to R&D investment and scope and effectiveness of intellectual property protection in different industries. As a result of sector heterogeneity, it is possible that the cross-country differences observed in Figure 9 could be due differences in the industrial structures across these countries.

In order to analyse differences in R&D performance related to a country's industrial structure, it is helpful to classify industrial sectors into five broad groups according to their R&D intensity.[5] Figure 14 shows the proportion of R&D expenditure in each group for the

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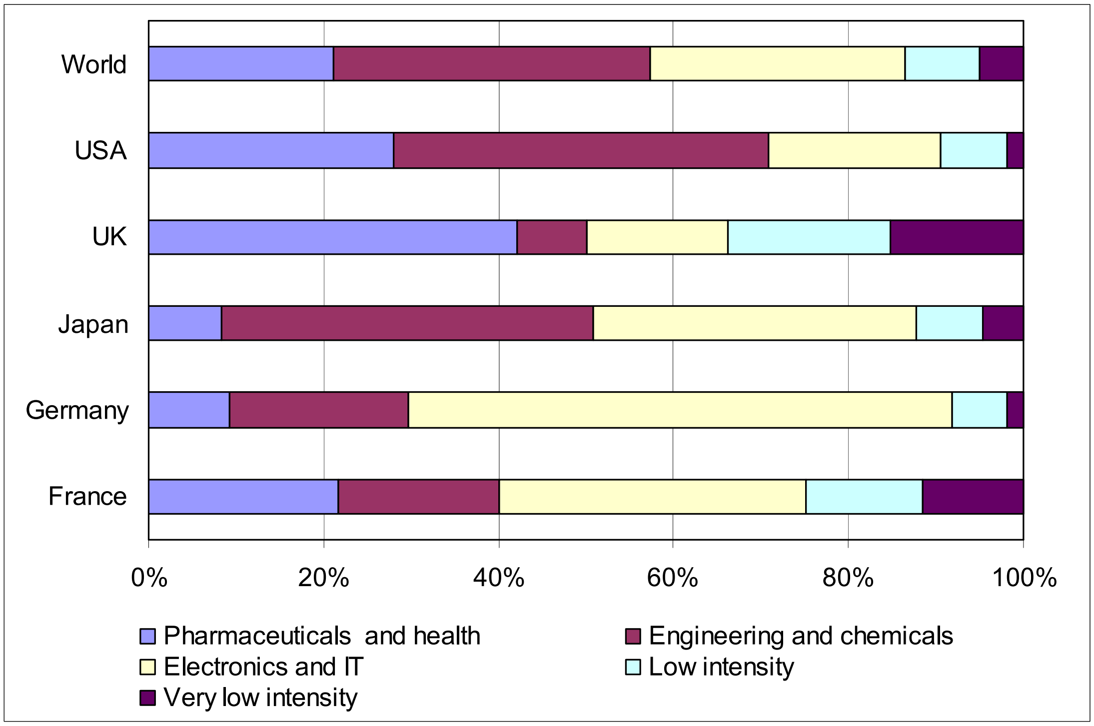
[5] The sector groups are defined as follows:
Pharmaceuticals and health: Pharmaceuticals & biotechnology, Health care equipment & services.
Electronics and IT: Electronic & electrical equipment, Technology hardware & equipment, Software & computer services.
Engineering and chemicals: Aerospace & defence, Automobiles & parts, Industrial engineering, Chemicals, Personal goods, General industrials, Household goods, Travel & leisure, Leisure goods, Media.

UK, US, Germany, France and Japan, as well as the world average. The largest proportion of UK R&D expenditure (over 40%) is in the high R&D intensive sectors Pharmaceuticals and Health. This proportion is higher than any other country. This sector, however, represents less than 10% of UK industry's sales, which are relatively concentrated in low R&D intensive sectors. These are dominated by oil and gas producers (40% of UK sales),[6] followed by banks (12%), a food retailer (Tesco, 6%), mining (5%) and mobile telecommunications (4%), (Figure 15).

Figure 14: Proportion of R&D expenditure in each sector

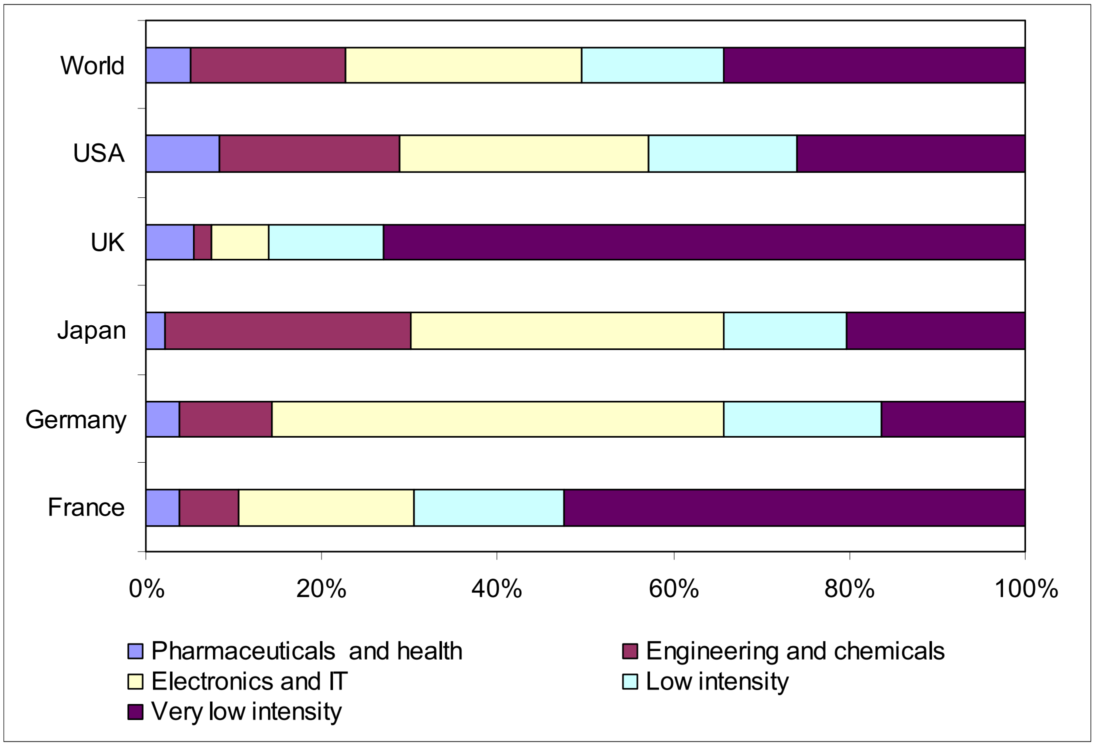


Source: The 2007 R&D Scoreboard (International 1250)

Low intensity: Beverages, Construction & materials, Food producers, General retailers, Industrial metals Mining, Support services, Fixed line telecommunications, Mobile telecommunications, Banks, Food & drug retailers, General financial, Life insurance, Non life insurance.
Very low intensity: Electricity, oil & gas producers, Oil equipment, services & distribution, Industrial transportation, Gas, water & multiutilities, Tobacco, Forestry & paper.

[6] Combined sales of BP and Shell are £300b, compared with total sales of companies represented in the R&D Scoreboard of £734b. The only other country where this sector is relevant is the US, where Oil company total sales of £1,260b, but only represent 17% of total sales in the Scoreboard (International 1250).

Figure 15: Proportion of sales in each sector



Source: The 2007 R&D Scoreboard (International 1250)

Table 7 presents R&D intensity by sector group across countries: all countries appear to have a similar R&D intensity within each group. This suggests that the sector mix must be responsible for the large differences observed between countries in overall R&D intensity. The table also highlights that UK owned firms have among the highest R&D to sales ratios in Pharmaceuticals and Health and the highest in Engineering and chemicals.

Table 7: R&D Intensity by sector

Group	US	Japan	Germany	France	UK	World
Pharmaceuticals and health	15.3%	14.2%	8.9%	14.7%	14.7%	14.4%
Electronics and IT	9.5%	5.5%	7.0%	6.8%	8.4%	7.2%
Engineering and chemicals	3.2%	3.8%	4.4%	4.5%	4.7%	3.8%
Low intensity	2.1%	2.0%	1.3%	2.0%	2.7%	1.8%
Very low intensity	0.3%	0.8%	0.4%	0.6%	0.4%	0.5%

Source: The 2007 R&D Scoreboard (International 1250)

The differences in R&D intensity between the UK and other countries can be decomposed into differences in industrial structure and differences in R&D intensity in each industry. This analysis (termed “shift-share”) shows that the difference in R&D to sales ratio between UK and each of the other countries in the table can be largely attributed to differences in the industrial mix of R&D performing businesses (Table 8).[7]

Table 8: Accounting for differences in R&D intensity across countries due to industry mix

Comparison	Difference in intensity	Explained by intensity levels within industries	Explained by differences industrial structure
UK vs France	-0.66%	0.15%	-0.82%
UK vs Germany	-1.76%	0.75%	-2.51%
UK vs Japan	-1.74%	1.15%	-2.89%
UK vs US	-2.67%	0.27%	-2.94%

Source: The 2007 R&D Scoreboard (International 1250)

2.4 The internationalisation of business R&D

International R&D flows and collaborations are increasingly important phenomena in shaping innovation systems, and the UK is well placed to gain from an increase in international R&D activity. Internationalisation of R&D has been happening in the UK for some time and is a gradually increasing trend (Bloom and Griffith, 2001).

In a report to the DTI, Arthur D. Little (2005) concluded that in the UK R&D is generally more highly internationalised than in comparable countries and this is also shown by an increased dependence on foreign funding for R&D.

The UK is unique amongst the G7 countries in the share of its business expenditure on R&D that is financed from abroad. Foreign firms in the UK appear to be relatively more R&D intensive than foreign firms based in other G7 countries. Existing data on foreign investment in UK R&D activity show that the UK has been an important location for MNEs and their associated knowledge investments.

The high degree of internationalisation is a source both of advantage and of risk to the UK. There are concerns that the internationalisation of R&D is reaching developing countries and this might result in a loss of R&D capabilities in the UK as research is transferred overseas.

The effects of internationalisation depends on

a) The mobility of human resources
b) The potential for major changes in location and funding of R&D facilities by UK and foreign firms
c) The ability of the UK economy to benefit from foreign investment in R&D (through the take up of “knowledge spillovers”). This is in turn related to investment in complementary assets, including skills, design and management.

Firms’ R&D location decisions

[7] This confirms previous results using the 2004 R&D Scoreboard (DTI, 2005b) and OECD data (OECD, 2005).

The decision to locate Research & Development facilities is complex and influenced by a variety of factors, of which and nationality of ownership is only one. Results from a recent EU survey (European Commission, 2006) showed that, within the EU, Germany, the United Kingdom and France are the three most favoured countries, followed by the Netherlands, Italy and Sweden. In more than 60% of the cases, firms stated their home country as one of the three most attractive locations. Underlying reasons for the preference for the home country may be geographic proximity to other company sites, familiarity with the national socioeconomic environment and of course language. It also seems that, while companies prefer to choose an R&D location within their country, this location is then subject to the overall R&D strategy, as is any other company site outside the home-country. The main factors are related to market conditions (i.e. characteristics of the goods-and-services market, the labour market and the market for R&D). This is the case of "market access", "high availability of researchers" and "access to specialised R&D knowledge and results". The surveyed companies also emphasise factors that fall under the category of framework conditions, and reflect the predictability and stability of government policy, of the R&D framework and of R&D cooperation opportunities.

To examine the determinants of R&D location decisions, McGuckin et al. (2005) carried out 42 in-depth interviews with large multinational R&D performers in four high-tech industries. They found that drivers for the location of "Research" and "Development" appear to differ. Research is more associated with academic centres of excellence and is carried out in proximity to universities and alliance partners.[8] Development activities, on the other hand, are carried out close to the target market, and to customers, manufacturing units and suppliers.

McGuckin et al. (2005) also find evidence of "home country bias", whereby research projects and teams are located in close proximity to the company's headquarters since this offers opportunities for collaboration and cooperation.

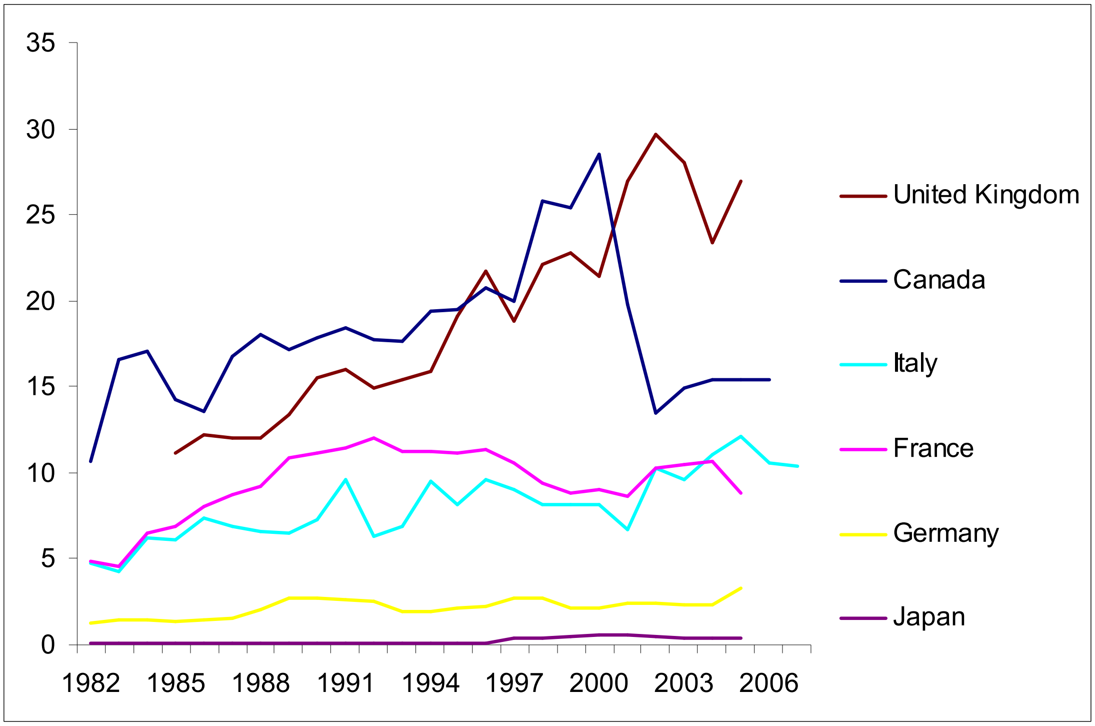
Thursby and Thursby (2006) present results from a survey of over 200 multinational companies across 15 industries regarding the factors that influence decisions on where to conduct R&D. Respondents were asked to rank the most important factors in the decision to locate R&D facilities outside the home country and within the home country separately. The interviews also distinguished between locations in developed or emerging economies. Results on the factors that influence R&D location showed that the issue is not why firms locate at home or not, but why they locate in a developed economy versus an emerging economy. Results show that regardless of where companies locate R&D, four factors stand out: output market potential, quality of R&D personnel, university collaboration, and intellectual property protection. How these factors influenced decisions, however, varied depending on whether sites were in developed or emerging economies.

R&D Inflows: UK performed but foreign funded R&D

The UK is an attractive place for foreign owned firms to do R&D, owing to a number of framework conditions such as macro-economic stability, light-touch regulation, a favourable corporation tax regime and the strength of its research base. Compared to other countries, a relatively high share of UK business R&D is funded from abroad (Figure 16). Although figures for the US are not available, it appears that the UK tops the list and has recently overtaken Canada.

[8] Abramovsky et al. (2007), however, find that co-location of business R&D with a relevant university research departments in the UK is not dictated by high quality (i.e. 5 or 5* rating by the RAE) except for the pharmaceuticals and chemicals industries. This appears true for foreign-owned establishments as well as domestic ones.

Figure 16: Percentage of BERD financed by abroad, 1981-2006, G7 countries

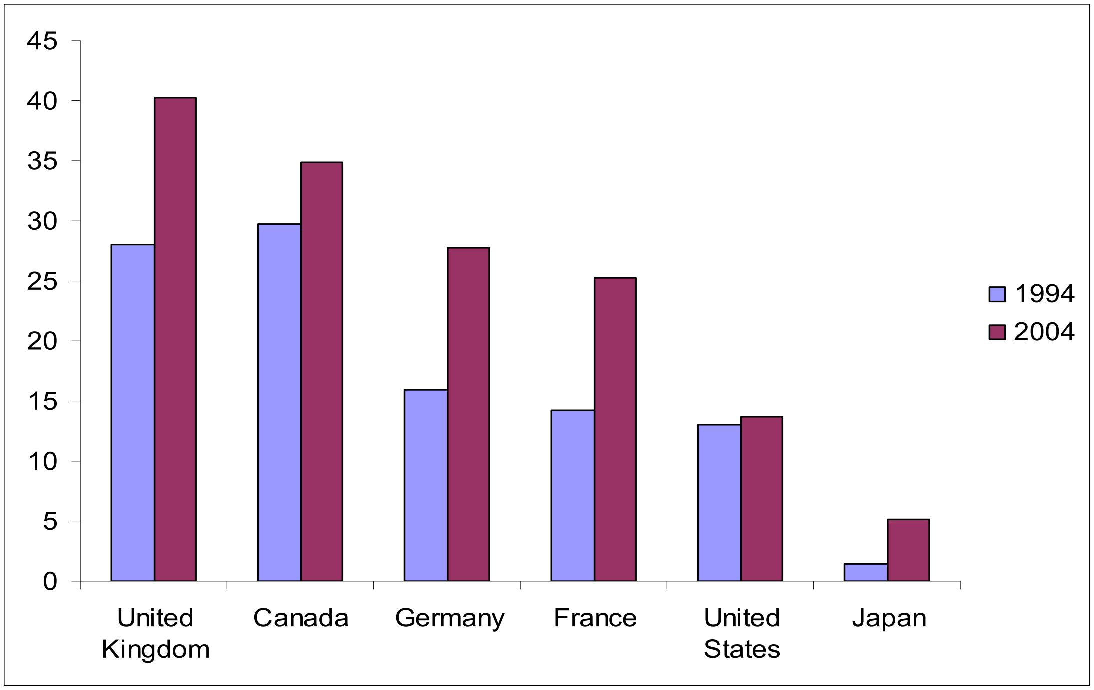


Source: OECD MSTI 2007-2; US data not available

According to the R&D Scoreboard, there are 297 foreign-owned R&D active companies among the top 850 R&D-performing companies in the UK, accounting for 23% of R&D. The ONS Business Enterprise R&D survey reports a higher proportion of UK R&D carried out by foreign owned affiliates – around 40%.[9] This proportion has increased from 30% during the last decade, following a process of R&D internationalisation common across European countries and Japan. In the US and Canada, the process has not been so marked recently (Figure 17). For the US, however, the percentage of R&D expenditure of foreign affiliates had more than doubled in the previous decade (1984-1994), from 6% to the current 13%.

[9] It is possible that this discrepancy is due to one of the characteristics of the R&D Scoreboard data in that it does not include the R&D of foreign owned firms if they do not disclose R&D expenditure in the accounts of the UK based subsidiary.

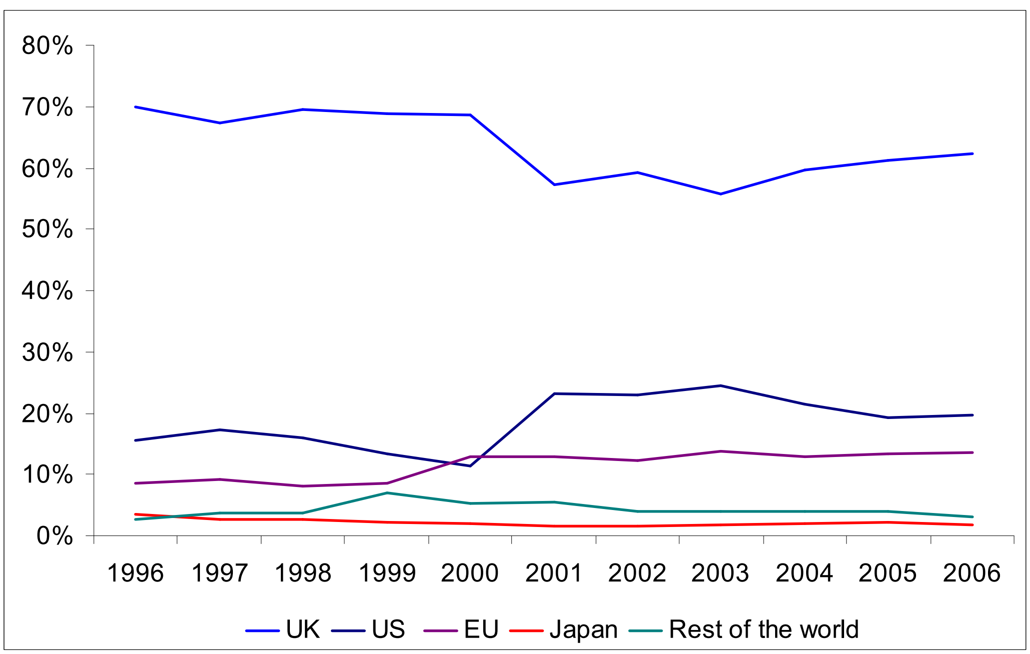
Figure 17: R&D expenditure of foreign affiliates as a percentage of R&D expenditures of enterprises.



Source: OECD MSTI 2007-2

Which country do these foreign affiliates belong to? As Figure 18 shows, foreign affiliates from the US represent approximately 20%, followed closely by European firms.

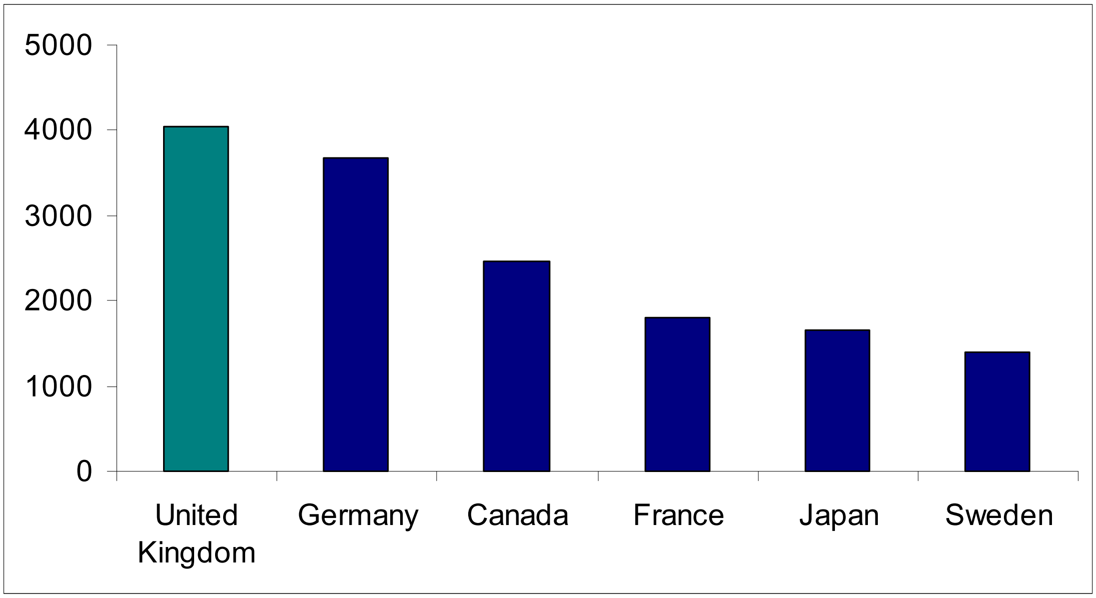
Figure 18: Expenditure on R&D performed in UK businesses by country of ownership of business (percentage of total)



Source: ONS 2008

The UK is also the most popular destination of US foreign direct investment in R&D, ahead of Germany, Canada and France (Figure 19).

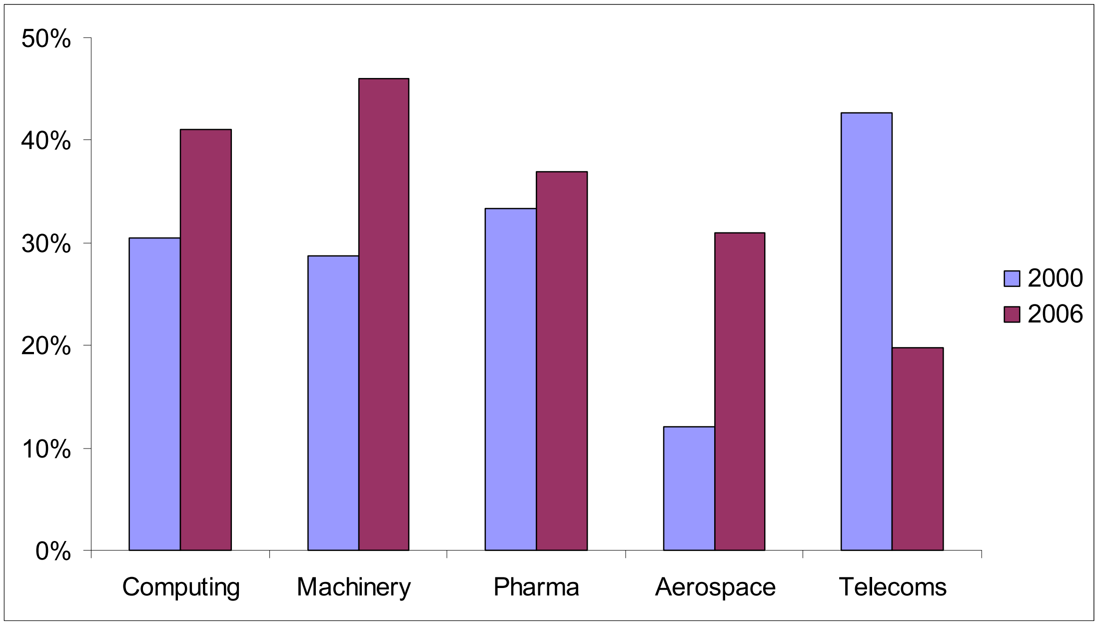
Figure 19: U.S. Direct Investment Abroad - Research and Development Expenditures (million US dollars, 2003)



Source: US Bureau of Economic Analysis

For all R&D intensive industries with the exception of the telecoms sector, foreign R&D as proportion of business R&D has increased between 2000 and 2005 (Figure 20).

Figure 20: R&D performed in the UK by foreign-owned firms as percentage of business R&D



Source: ONS 2008

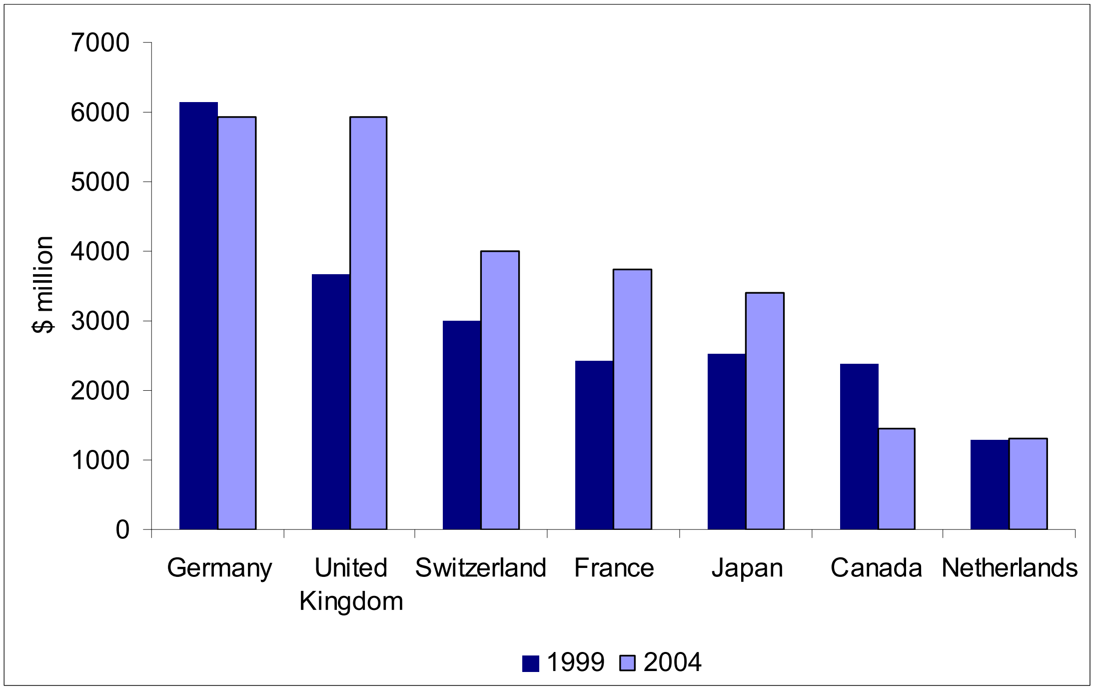
Note: 2006 data except for Telecoms 2005

R&D Outflows: UK funded but performed abroad

Another side of the internationalisation picture is R&D funded by UK firms but carried out overseas, in their own affiliates or externally. UK businesses are looking overseas to exploit sources of knowledge and they are major investors in R&D overseas. The UK has caught up with Germany as leading foreign R&D investor in the US (Figure 21). UK-owned affiliates' R&D in the US amounted to $6bn in 2004 i.e. around 20% of the value of business R&D spending in the UK. Even without taking into account UK funded R&D in other countries (which the technology balance of payments figures below suggest is substantial) this data suggests the deep embeddedness of UK business in the global R&D system and therefore the partial nature of the domestic R&D to GDP ratio as an indicator of technological innovation.

Some have argued that the UK benefits from R&D laboratories established in the US, since these new ideas are transferred back to the UK, through knowledge transfers within the enterprise and can result in significant gains in UK productivity (Griffith et al., 2004).

Figure 21: R&D Performed by majority-owned affiliates of foreign companies in the US, by country.

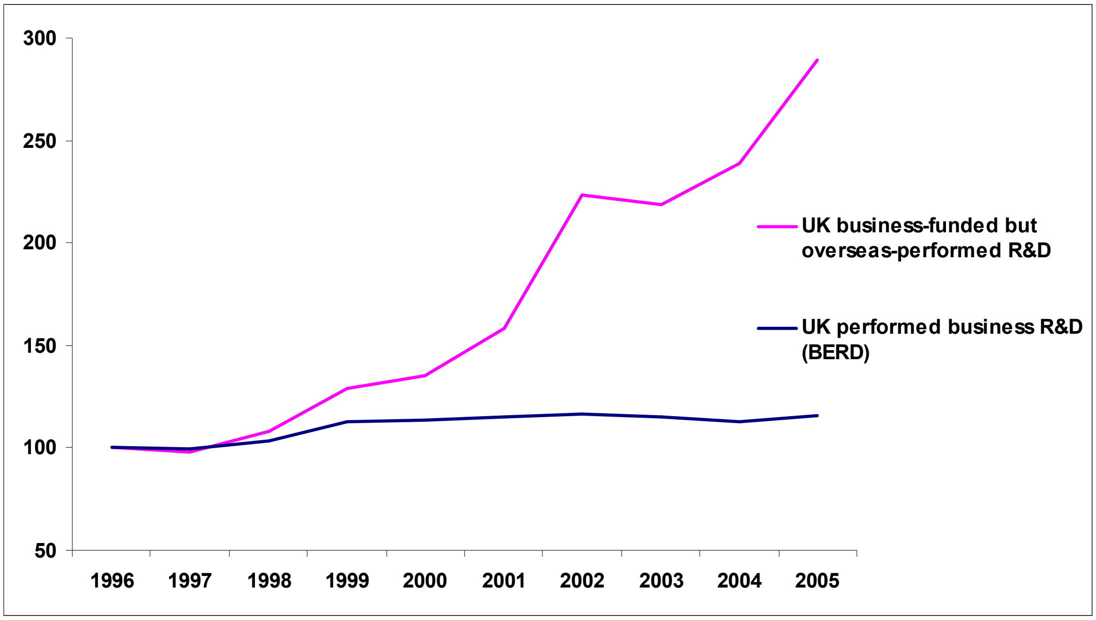


Source: NSF SEI 2008

There is also evidence that UK firms are outsourcing more of their R&D abroad. In the last decade UK business funded, but overseas performed, extra-mural R&D has increased at a much faster rate than business R&D performed in the UK. [10] While BERD has grown in real terms, from £11,550m to £13,410m between 1996 and 2005, extra-mural R&D performed abroad has nearly trebled over this period, from £606m to £1,757m. This striking difference in growth is depicted in Figure 22, where index numbers (equal to 100 in 1996) are used to highlight growth rates.

[10] This picture does not include R&D carried out by UK firms in their overseas affiliates, as this data is not currently collected in the Business R&D survey.

Figure 22: Index of UK business R&D and business funded but overseas performed R&D: real terms (1996=100)



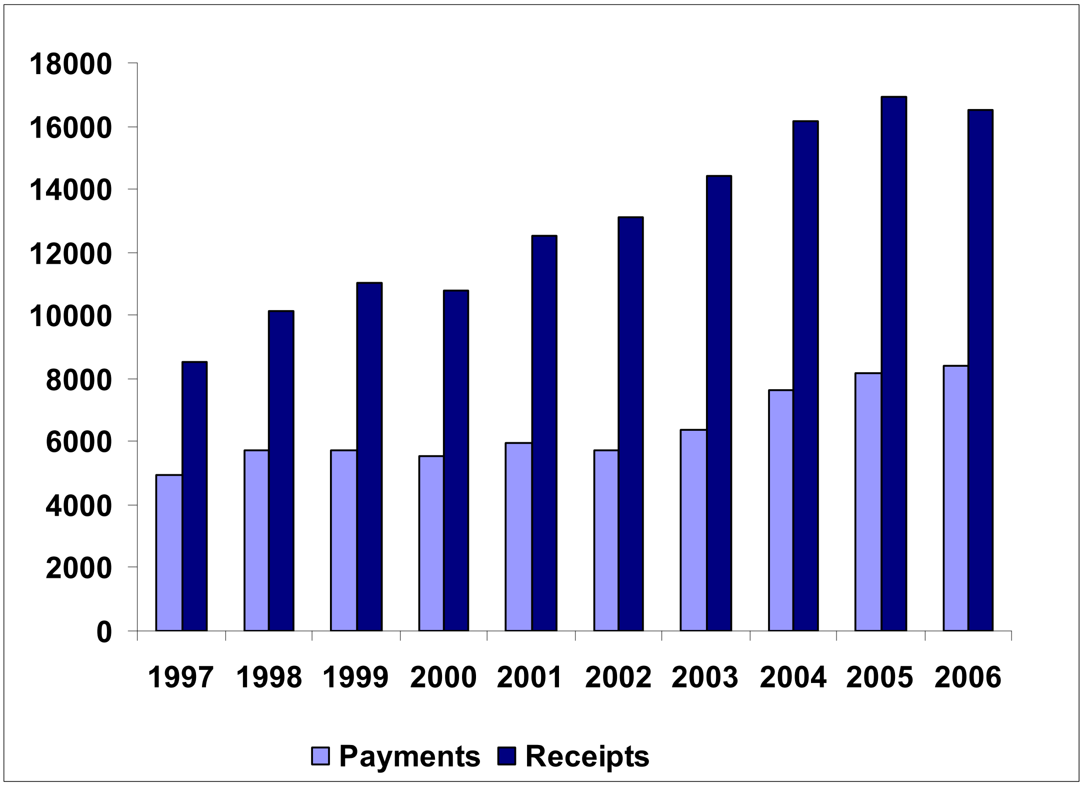
Source: ONS 2007

The technology balance of payments

Another tool to assess the degree of technological internationalisation of a country is the technology balance of payments. This measures international transfers of technology: licences, patents, know-how and research, technical assistance. Unlike R&D expenditure, these are payments for production-ready technologies, reflecting the accumulated value of past R&D and other innovation spending.[11] The majority of these transactions correspond to operations between parent companies and affiliates. The technology balance of payments reflects a country's ability to sell its technology abroad and its use of foreign technologies. The UK has shown a strongly positive balance in the last decade (Figure 23) second only to the US among OECD countries (Figure 24).

[11] Technology receipts and payments constitute the main form of disembodied technology diffusion. Trade in technology comprises four main categories:
– Transfer of techniques (through patents and licences, disclosure of know-how).
– Transfer (sale, licensing, franchising) of designs, trademarks and patterns.
– Services with a technical content, including technical and engineering studies, as well as technical assistance.
– Industrial R&D.
The main limitations of these data are the heterogeneity of their content at country level and the difficulty of dissociating the technological from the non-technological aspect of trade in services, which falls under the heading of pure industrial property.
Trade in services may be underestimated when a significant proportion does not give rise to any financial payments or when payments are not made in the form of technology payments.

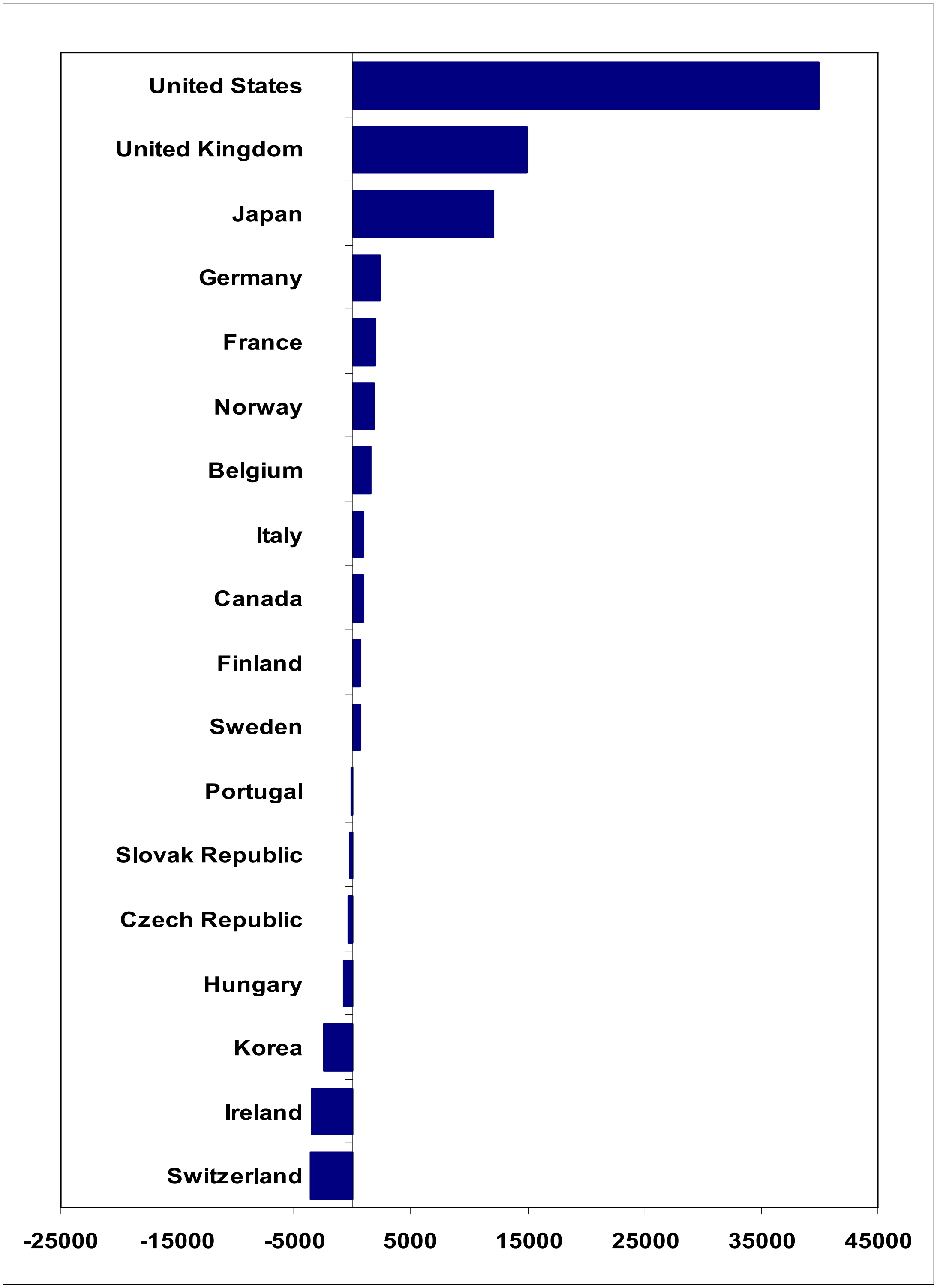
Figure 23: Technology balance of payments, UK (million £)



Source: OECD MSTI 2007-2

The positive balance implies that the UK businesses in multi-national corporations are significant sources of new technologies, at least within the corporations. But the absolute level of outflows might imply a history of significant R&D spending in overseas affiliates.

Figure 24: Technology balance of payments 2006(*), main OECD countries (million current US dollars)



Source: OECD MSTI 2007-2

(*) 2003 for Canada, France, Japan, Korea

Chapter 3 Why do firms invest in innovation activities?

Understanding the variables that influence innovative activity has long challenged researchers and policy makers. Measures of innovative activity can be classified as either innovative inputs or output. Measures of innovative output that have been used in the empirical literature include the number of patents, the number of significant innovations, and various indices of the market value of innovations.

Despite the evidence – discussed in Chapter 1 – that R&D expenditure only represents one third of business investment in innovation, this remains the most frequently used measure of input into the innovation process.

After a brief review of the existing evidence on the determinants of business R&D, this Chapter presents some analysis of the firm and industry characteristics that are associated with different forms of investment in innovation using recent UK Innovation Survey data.

3.1 The existing evidence

Schumpeter (1934) argued that the large firm operating in a concentrated market was the principal engine of technological progress: a large part of the industrial organization literature therefore attempted to empirically test this proposition by focusing on the effects of firm size and market concentration on innovation. These attempts to highlight the factors determining the level and rate of innovative activity were reviewed extensively in Cohen and Levin (1989) and Cohen (1995) and will be only briefly summarised in what follows.

It is now widely accepted that the relationship between market structure, firm size and innovation is more complex than what many studies have hypothesised. The recent theoretical literature has emphasised that both innovation and market structure are endogenous variables and must be seen as simultaneously determined.

Firm size as determinant of investment in innovative activities

Numerous empirical studies were conducted in the tradition of Schumpeter's work. Most of this empirical literature has interpreted Schumpeter's claim for a large firm advantage in innovation as a proposition that innovative activity increases more than proportionately with firm size. Several justifications were put forward: capital market imperfections that confer advantage to large firms in financing risky R&D projects; scale economies in the R&D function itself; higher returns when the innovator has a large volume of sales over which to spread fixed cost of innovation; complementarities between R&D and other non manufacturing activities and so on. Counter-arguments were also suggested: the efficiency in R&D can be undermined either through the loss of managerial control or because of excessive bureaucratic control; incentives for individual scientists and entrepreneurs may become attenuated as their ability to capture the benefits of innovation diminishes.

Over four decades of empirical research on the relationship between firm size and innovation have spawned a number of robust empirical patterns: overwhelming evidence exists that size positively affects the decision to engage in R&D activities. R&D expenditure rises monotonically with firm size and proportionately beyond some modest firm size threshold. Moreover, R&D was found to vary closely with firm size within industries, with size typically explaining over half of its variation (see, for example, Bound et al., 1984, Cohen et al., 1987, Cohen and Klepper, 1996).

These findings have been widely interpreted as indicating that, contrary to Schumpeter's idea, large size offered no advantage in the conduct of R&D. A problem common to almost all the studies of R&D and firms size is, however, the endogeneity of firm size: central to Schumpeter's notion of "creative destruction" – his other famous contribution to the theory of innovation, this issue has been neglected in this literature.[12]

Market power and innovation

Schumpeter suggested that firms require the expectation of some ex-post degree of market power to have the incentive to invest in R&D. He also argued that an ex-ante oligopolistic market structure and the possession of market power also favoured innovation.

The empirical literature has focused on the effects of ex-ante market concentration on innovative behaviour: the majority of studies that examine the relationship between market concentration and R&D have found a positive relationship between the two. A few have found evidence that concentration has a negative effect on R&D. Simple tests of the explanatory power of market concentration, however, find that it contributes little to an explanation of the variance in R&D intensity.[13]

Overall, the literature suggests that the direct influence of market concentration is small and it likely reflects the influence of other more fundamental determinants of technical advance, specifically technological opportunity and appropriability conditions.

Perhaps the most persistent finding on the effects of concentration on R&D intensity is that it depends on industry level variables: dummy variables representing technology classes are highly significant and explain considerably more variance than do concentration variables.

Other firm characteristics

Only modest progress has been made in explaining inter-firm differences in R&D intensity by other firm characteristics. Cash flow, a measure of internal financial capability, is the most thoroughly examined firm characteristic. Many, but not all, the studies that have included this explanatory variable have found that a firm's cash flow is associated with higher levels of R&D intensity (see Hall, 1990 and Himmelberg and Petersen, 1992).

The other widely studied corporate attribute is diversification: the diversified firm possesses more opportunities for exploiting the new knowledge because the outcome of research tends to be unpredictable. Diversified firms can also better exploit economies of

[12] Although it has been recognized in some studies on the relationship between innovation and market concentration, see below.

[13] Recognizing the potential simultaneity between innovation and concentration, some investigators have used instrumental variables for the concentration variable in regression studies of the effects of market structure on innovative activity. Others have used industry level data to estimate multi-equation models in which concentration and R&D are both treated as endogenous. Statistical tests suggest that such techniques are appropriate.

scope and complementarities among diverse activities. Results of this type of works have been mixed, however; moreover, measurement problems are pervasive in this literature.

Other Industry characteristics

Studies that address the importance of industry characteristics in explaining different R&D patterns have classified explanatory variables under three headings:

(a) product market demand,

(b) technological opportunities and

(c) appropriability conditions.

As far as the role of demand is concerned, Schmookler (1962) claimed that the rate of technological progress could essentially be explained as the outcome of demand incentives. His work sparked a lively debate among economists concerning whether "demand pull" or "technology push" were the primary force behind technological change. His proposition that demand almost alone determined the rate and direction of technical change has not, however, survived the empirical analysis. Dozen of case studies have documented examples in which a sequence of innovation were determined not by demand but by the state of knowledge in a particular industry. Econometric studies have shown that variables representing demand conditions were statistically significant but less important than the technology variables.

Studies on appropriability conditions are motivated by the existence of spillovers due to the limited ability of inventors and innovators to capture the entire benefits from their activity. Firms can and do use various methods to protect their inventions, including formal methods such as patents, copyright, trademarks, (registered) industrial designs, confidentiality agreements, and informal or "strategic" methods: secrecy, complexity of design, different forms of first-mover advantage (Levin et al., 1987; Cohen, Nelson, and Walsh, 1996). The decision to patent an invention rests on the relative costs and benefits of these alternative methods. These protection mechanisms offer one solution to the problem of imperfect appropriability.

The evidence shows that the patent system confers valuable property rights and provides a substantial incentive to R&D effort, but it does not appear to be the major source of private returns to inventive activity (Schankerman, 1998).

Industries differ widely in the extent to which patents are effective: the evidence suggests that patents are regarded as a necessary incentive for innovation in only a few industries. Also, there is evidence that patents are not perfectly enforced and also that many technologies are imitated very rapidly.[14]

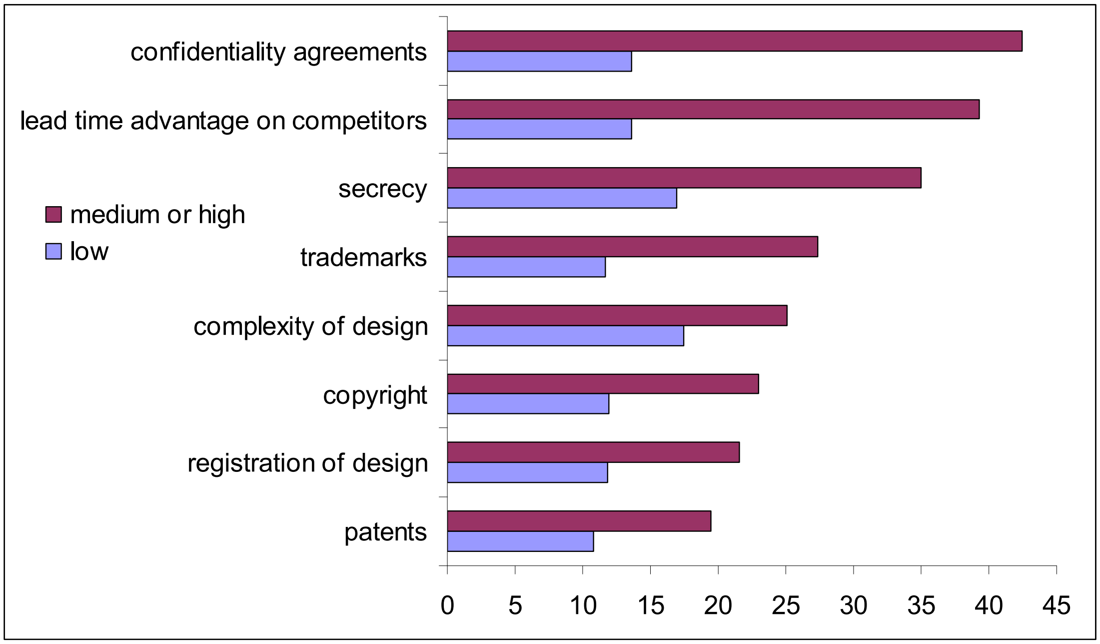
This confirms survey evidence that firms rely on a variety of mechanisms other than patents to protect inventions. The Levin at al. (1987) survey, for example, revealed that firms in many industries tend to regard other mechanisms, such as the costs of imitation and the necessary investments in complementary assets, as quite effective in appropriating the returns from innovation. Head start and the ability to move quickly down the learning curve were also often considered more effective means of appropriation than patents. Secrecy was viewed as more effective than patents in protecting process innovations. Recent UK data confirm that a higher share of innovative firms use other methods of protection rather than patents (Figure 25).[15]

[14] Mansfield, Schwartz and Wagner (1981), for example, estimate that about 60% of patented innovations are imitated within four years (by "innovating around" the patented product). This might explain the more aggressive IP exploitation activities by major firms in recent years.

[15] This does not indicate whether the rents from different methods of protection are as high as those from patents.

Most empirical work in this area has focused on the mechanisms facilitating and constraining the ability of firms to capture the returns from new technology. There is no clear empirical consensus about whether grater appropriability encourages innovative activity. This reflects, in part, the difficulties of finding suitable data and formulating precise tests to distinguish among competing hypotheses on the effects of appropriability.

Figure 25: Importance to UK businesses of different methods to protect innovation



Source: UK Innovation Survey, 2007

3.2 Recent evidence for UK firms

In this section, we report new results from the analysis of the UK Innovation Survey data. We first try to understand the decision of firms to participate in various forms of innovative activity, and attempt to uncover the factors that affect that decision, on the basis of the theoretical arguments and the existing evidence discussed in the previous section, as well as taking into account the complementarities described in Section 1.1 .

We then focus our attention more specifically on R&D expenditure as a fraction of a company's total turnover (R&D intensity) and we attempt to identify those factors that are associated with different levels of this quantum across firms.

The decision to innovate

Firms are very likely to decide simultaneously whether to engage in a portfolio of innovative activities, including intramural and extramural R&D, design and marketing, acquisition of external knowledge, training and machinery. Ideally, we would like to model this as one decision empirically. Computationally, however, this would be very burdensome, thus instead we employ an empirical approach that permits the joint analysis of the decision to engage in different pairs of innovative activity. The choice of which pairs of activity to model jointly is based on theoretical motivations as well as on the evidence presented in the previous section.

First, we examine the decision to perform R&D internally and externally, then model two more sets of investment decision: the pattern of joint investment in marketing and design and the choice of simultaneously invest in training and acquire machinery, equipment and software. This approach models the firms' decision to engage in pairs of innovative activities as a function of a number of explanatory factors, including, following the arguments in Section 3.1 , firm-related as well as industry-related characteristics. Size has traditionally been considered an important factor in the analysis of R&D investment and is included here, measured by the logarithm of a firm's turnover.[16]

We also cover exposure to market competition by including among the explanatory variables the share of exports in a firm's turnover as an indicator of this exposure.

Other characteristics of the industrial sector in which the firm operates are also considered to be a significant factor in affecting the decision to innovate. These include the strength of demand conditions (demand pull), the degree of appropriability of intellectual property, the availability of technological opportunities (technology push), and the degree of market concentration. We attempt to control for some of these factors by using firm-specific variables constructed from the available survey data. The survey includes an explicit question on the firm's reasons for engaging in innovative activity. From the answers to this question, we build two variables to proxy for "demand pull" as well as "cost push" decisions. [17]

We attempt to control for all other omitted factors by including a series of industry control variables.

We also control for regional characteristics. Recent economic research has recognized the potential importance of "regional systems of innovation", defined as "the localized network of actors and institutions in the public and private sectors whose activities and interactions generate, import, modify and diffuse new technologies" (Evangelista et al., 2002). To control for regional effects reflecting different technological opportunities available to firms in their geographical area, dummy variables for the English regions and the Devolved Administrations have been included.

The results give an indication of the impact of the explanatory variables on the likelihood of the firms to engage in each of the innovation activities examined, in terms of percentage change in this likelihood for a 1% change in the explanatory variable, keeping everything else constant.

In all models, diagnostic tests also support the approach to analyse pairs of investment activities rather than the activities in isolation, as this would not give the same degree of accuracy in the results.[18]

Internal and external R&D activities

The decision to enter an external R&D relationship is very likely related to the decision to carry out R&D internally. The correlation coefficient reported in Table 2 supports this hypothesis and Table 3 shows that expenditure on these two types of activity is also highly correlated. Although Table 9 shows that the majority of firms do not engage in either activity, it also appears that less than 2% of firms engage in extra-mural R&D exclusively.

[16] The analysis was also replicated using the logarithm of employment as measure of size, with similar results.

[17] "Demand Pull" if the reasons to innovate are to increase the range of goods or services or to enter new markets or increase market size, "Cost pull" if the reason to innovate is to reduce costs.

[18] Detailed results of the modelling exercise are contained in a technical annex available upon request.

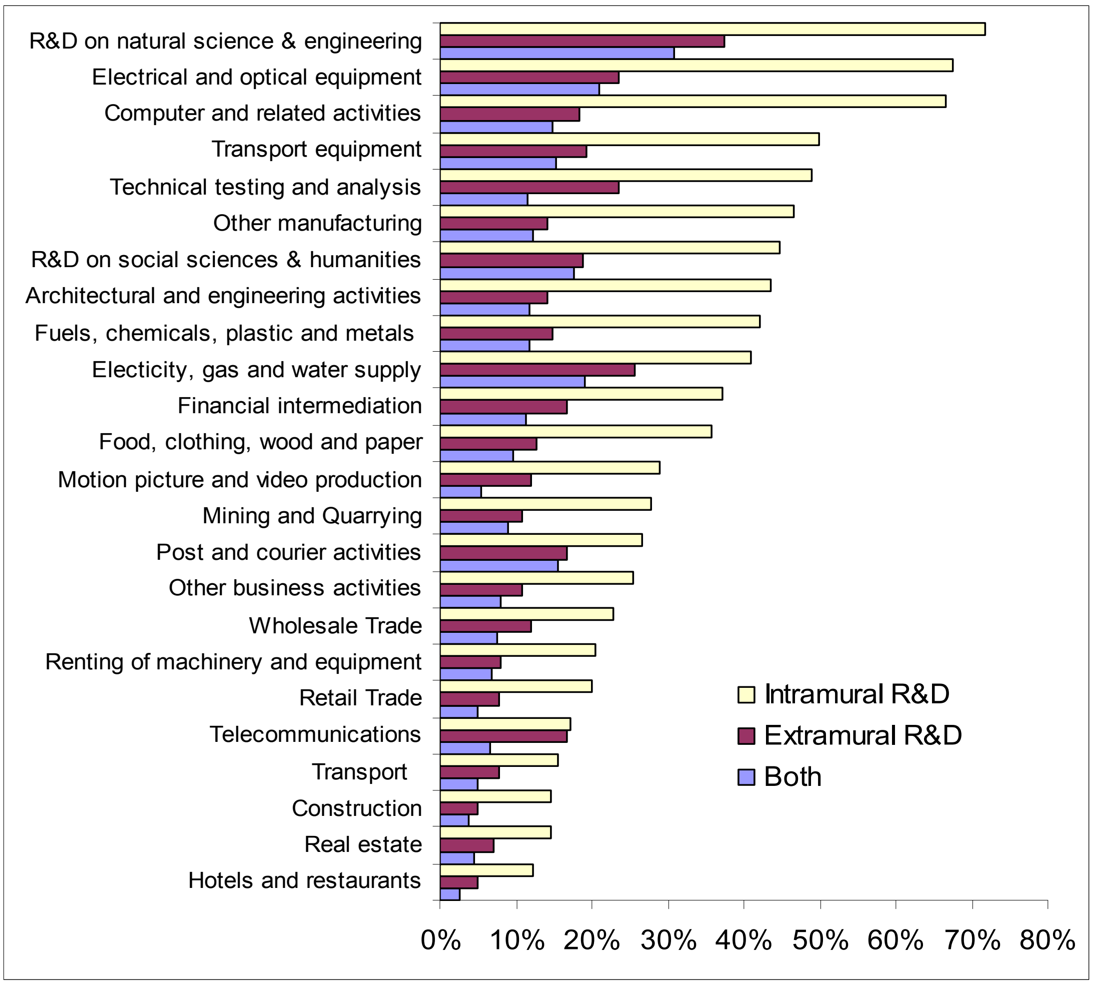
Table 9: Percentage of firms engaging in Intra or Extra-mural R&D or both

		Extramural R&D		
		No	Yes	Total
Intramural R&D	No	64.9%	1.9%	66.9%
	Yes	21.5%	11.7%	33.1%
Total		86.4%	13.6%	100%

Source: UK Innovation Survey, 2007

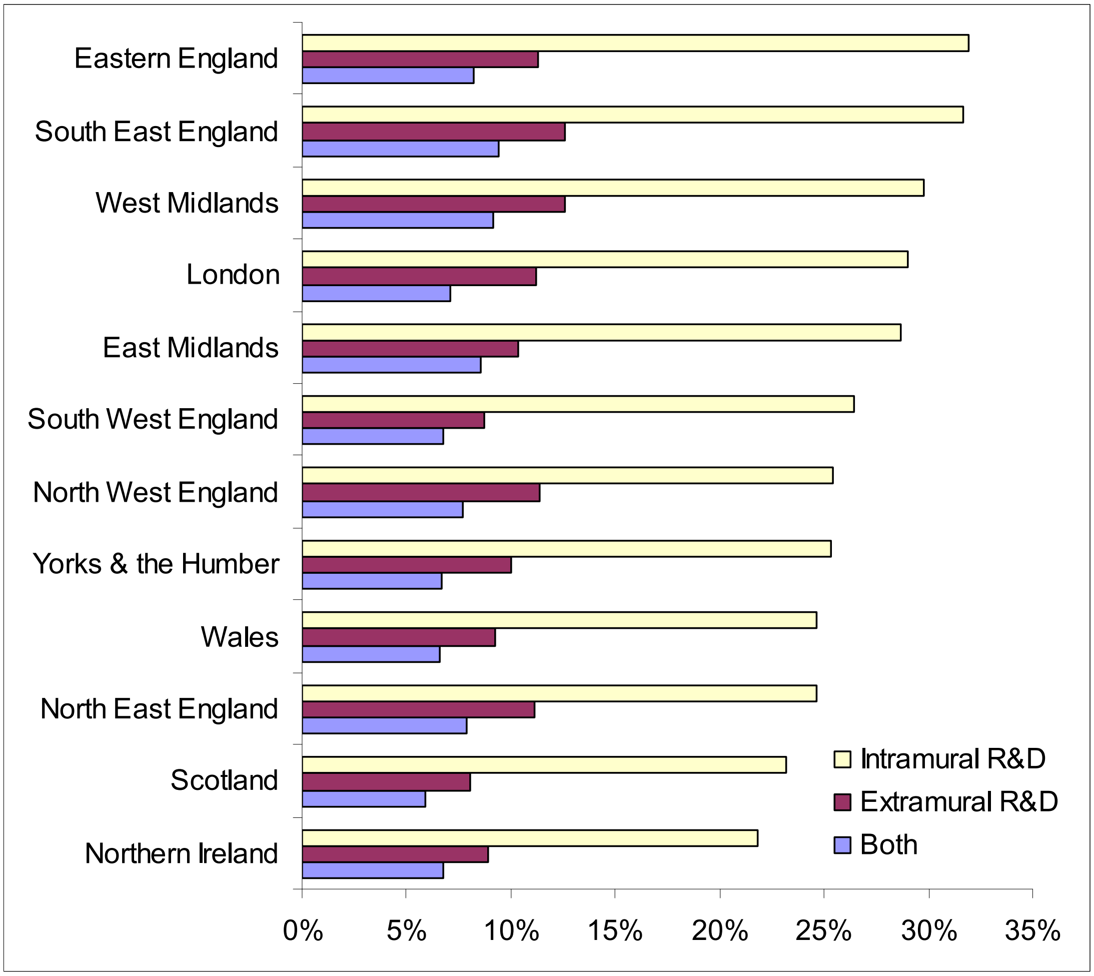
Industry variability in these two activities is very high, as Figure 26 shows, and the models reveal that industry controls are clearly important in explaining variability of participation across UK firms. Regional variation is not as pronounced (Figure 27) but the regional controls still appear to have some joint explanatory power in the model.

Figure 26: Percentage of firms performing intramural and extramural R&D by industrial sector



Source: UK Innovation Survey, 2007

Figure 27: Percentage of firms performing intramural and extramural R&D, by region



Source: UK Innovation Survey, 2007

We now turn to the firm-specific variables that might be associated with intramural or extramural R&D. Consistently with the existing evidence, we find that larger firms are significantly more likely to be engaged in R&D activities than smaller firms. A firm whose turnover is 1% higher than its competitors is 3% more likely to carry out both intra- and extra-mural R&D.

Investment in R&D is also associated with exposure to international competition, as measured by the firm's share of exports in its turnover: firms whose share of exports is 1% higher are 2% more likely to engage in intramural R&D activities than their competitors and 1% more likely to invest in extramural R&D. This could indicate that a more competitive environment is more conducive to innovation.[19]

Firms declaring that demand factors were important in the decision to engage in innovation (including R&D activities) were almost 40% more likely to invest in internal R&D and 19% more likely to invest in external R&D. Cost factors did not appear as important (16% impact on intramural and 9% impact on extramural R&D).

[19] The dataset, however, does not allow estimating precisely the direction of causality among the variables examined. This result could therefore also indicate that more innovative firms are more competitive on international markets and are able to sell a larger share of their output abroad.

These results seem consistent across broad industrial sectors: when we estimated the model separately for the manufacturing and services sectors we found no significant differences in the magnitude and sign of these effects.

Training and Machinery, equipment and software

The decision to upgrade the firms' physical capital and machinery is closely linked with training of staff associated with innovation. Thus modelling these two activities together is intuitively meaningful. Diagnostic tests, as well as the correlation coefficients presented in Table 2 support this decision. In our sample, only 5% of firms invest in training without at the same time acquiring machinery or software, compared with 35% who invest in both.

Table 10: Percentage of firms engaging in Training or Machinery, Equipment and Software of both

		Machinery, equipment and software		
		No	Yes	Total
Training	No	30.4%	28.8%	59.2%
	Yes	5.0%	35.8%	40.8%
Total		35.4%	64.6%	100%

Source: UK Innovation Survey, 2007

Results from the models show that industry characteristics are important in explaining differences in these two activities across firms, while regional variables are not overall a significant factor.

As in the previous models, a 1% increase in size is associated with a 3% increase in the likelihood to engage in training, and a 2% increase in the likelihood of investing in equipment and software. Demand and cost factors are equally important (around 20% for training and 14% for machinery) while international exposure was not a significant factor in training, and it even appears to be negatively related to investment in equipment and software.

Some differences were found when estimating the two models separately for manufacturing and services. For training, size appears more important in manufacturing (4%) than services (2%). For machinery, cost factors are twice as important in the manufacturing sector (15%) than in services (7%).

Marketing and design

In our sample, only 3% of firms report invest in design without innovation related marketing, while 18% invest in both (Table 11). These two activities are also highly correlated in the sample.

The decision to model these two activities together does however have a strong theoretical justification as the decision to introduce new or improved design is clearly related to the ability of the firm to promote this innovation among its customers and market it as improvement in the goods or services it provides.

Table 11: Percentage of firms engaging in Marketing or Design or both

		Marketing		
		No	Yes	Total
Design	No	55.7%	23.7%	79.4%
	Yes	2.7%	17.9%	20.6%
Total		58.4%	41.6%	100%

Source: UK Innovation Survey, 2007

Once again, the modelling results indicate that size has a role in the decision to invest in design for innovation (3% impact) although it is less important for marketing (1%).

Demand factors are more than twice as important as cost factors for marketing and about twice as important for design. Foreign exposure does not appear closely associated with investment in marketing, but it does appear to positively and proportionately affect the decision to invest in design.

We correctly controlled for industrial structure (Industry dummies were jointly significant), but the variability across regions appears much lower and regional dummies did not appear jointly significant in our models.

When comparing manufacturing and services, we found that for both training and design, size effects were more important in manufacturing than services, and cost factors were more important for service sector firms compared with manufacturing.

How much R&D?

As well as choosing whether to participate in innovative activities, firms also need to decide what amount of resources to devote to these activities. These decisions are typically taken together, thus any attempt to analyse differences in expenditure intensity across firms cannot be separated from the analysis of the factors associated with this participation.

In this section we model the process by which firms decide how much effort to put into innovation. Following the bulk of the existing studies, we limit the analysis to intramural R&D. The decision to engage in R&D and the decision of how much to invest are taken simultaneously by the firm. For this reason the model in this section is formalized in two equations (see also Hall and Mairesse, 1995, Crepon, Duguet and Mairesse, 1998, Moen and Mairesse, 2005 and Griffith, Huergo, Mairesse and Peter, 2006): (i) the firm's decision to engage in R&D activity (ii) the intensity with which the firm undertakes R&D.

As in the previous section, we model the firms' decision to participate in R&D activities as a function of their size, their foreign exposure, demand pull and cost push as reasons for innovating. We also control for industry and regional characteristics.

R&D intensity (intramural R&D as a proportion of sales) is a function of the same variables that determine R&D participation, excluding size.[20] But we use a larger set of variables to explain the level of R&D intensity, since we also include measures of the appropriability conditions faced by the firm — the extent of formal and strategic protection of intellectual property. Effective appropriability conditions are important in that they allow innovators the potential to gain supernormal returns on their innovation activities, thus, in principle they increase the incentives for and number of innovation activities (Spence, 1984).

[20] This is a necessary for the different impacts in the model to be identified. Even when included in the R&D equation, size is not a significant explanatory variable, so the restriction we impose is valid. This is a common finding in the literature presented earlier in the paper.

The estimated results indicate that firms with higher international exposure (1% higher share of export in sales) have marginally higher (0.3%) R&D intensities.

Firms that decide to innovate for reasons related to demand condition have R&D intensities on average 2% higher than firms that do not — conditional on the mean values of all of the other variables. Cost factors do not appear significant in the decision of how much to invest in R&D.

Both appropriability with strategic means (lead time, complexity of design and secrecy) and legal means of IP protection are associated with higher R&D intensities for firms who consider these instruments to be important in their innovative activity.

Conclusions

In this section we have attempted to identify the business factors that are associated with firms' participation in and intensity of innovation activity. With reference to R&D, we found that larger firms are more likely to engage in R&D but their size does not affect the intensity of their R&D investment. Firms that operate mainly in international markets are more likely to engage in formal R&D and they engage in R&D more intensively.

Firms in industries where greater use is made of formal or strategic methods to protect innovations invest a higher proportion of their sales in R&D.

A characteristic of the Innovation Survey data used is that it is a cross section and we are able to uncover correlations, but not necessarily causal relationships. This means that care needs to be taken in interpreting these results.

Chapter 4 The returns to investment in R&D and innovation

This chapter references recent work on international differences in the cost and productivity of R&D and how these might further affect conclusions drawn from conventional R&D intensity measures.

Most of the existing evidence on the returns to investment in innovation focuses on estimating the rate of return to R&D investment. Many studies also attempt to distinguish between private rate of return, which are the revenues to R&D performing firms, and social rate of returns, constituted by the sum of private returns and the so called "R&D spillovers", which are the benefits available to other firms or industries. This chapter also summarises the existing economic evidence on the impact of R&D on performance at different levels of aggregation.

4.1 International differences in the price of R&D

Dougherty et al. (2007) have observed that nominal R&D intensity is not informative about the real resources devoted to R&D because it does not take into account differences in relative prices of R&D inputs across countries. Since R&D outputs cannot be directly measured, one must focus on the prices of R&D inputs. Most studies and statistics use aggregate proxies such as purchasing power parity (PPP) to reflect factor price differences for GDP across countries, but this reflects relative prices of primary inputs – capital and labour- in GDP, not in R&D. Moreover, GDP is based on expenditure on final goods and services, rather than the intermediate goods and services that make up a large part of R&D expenditure. Finally, use of GDP PPPs does not capture differences in the industrial composition of R&D across countries.

Dougherty et al. derive an R&D PPP, which measures the price of an R&D unit in a particular country relative to the price in the US. This is computed for 19 manufacturing industries in six OECD countries – France, Germany, Japan, the Netherlands, the United Kingdom and the United States, with the U.S. as the base country, for two benchmark years, 1987 and 1997. The R&D PPP measure is derived from an aggregation of relative R&D input prices, using corresponding R&D expenditure shares as weights. Four main categories of R&D inputs are identified: labour, materials, other current costs ("overheads") and capital. Weights for each category are based on each input's representation in R&D expenditure (Table 12).

Table 12: R&D expenditure shares of total manufacturing R&D expenditure, 1997

Category	France	Germany	Japan	Netherlands	UK	US
Labour compensation	52.8%	61.7%	42.7%	52.1%	37.0%	46.5%
Materials and supplies	16.9%	13.9%	20.3%	14.7%	26.1%	15.8%
Other current costs	23.2%	17.5%	27.3%	23.7%	24.8%	29.3%
Capital Expenditure	7.1%	6.9%	9.5%	9.5%	12.1%	8.4%
Total R&D cost	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

Source: Dougherty et al. (2007)

Labour is the largest component of R&D cost, averaging about half of total expenditures. The price of R&D labour for intramural R&D is given by the average R&D compensation per R&D employee. This procedure assumes R&D personnel in different countries are equally productive, ascribing any differences in wages to higher labour costs, not to higher productivity.[21]

Materials and supplies represent about 20% of R&D expenditure and the majority of expenditure in this category consists of prototypes of new products. Thus own-industry output PPPs are appropriate in this case.

It is more difficult is to identify prices for the other current costs which represent on average 24% of R&D expenditure and are typically described as “overheads”, including communications services, rent, utilities, non-capital computers and instruments. Where possible, industry-of-origin and final expenditure price parities were matched to these categories.

Capital expenditures are the smallest category of R&D expenditure (9%) and a similar approach to calculating other current costs was used.

The price levels for each input category are summarised in Table 13. The R&D labour cost varies considerably across countries: it is lower in all countries compared to the US, and lowest in the UK.

Table 13: R&D input price level (cost relative to the U.S.) total manufacturing, 1997

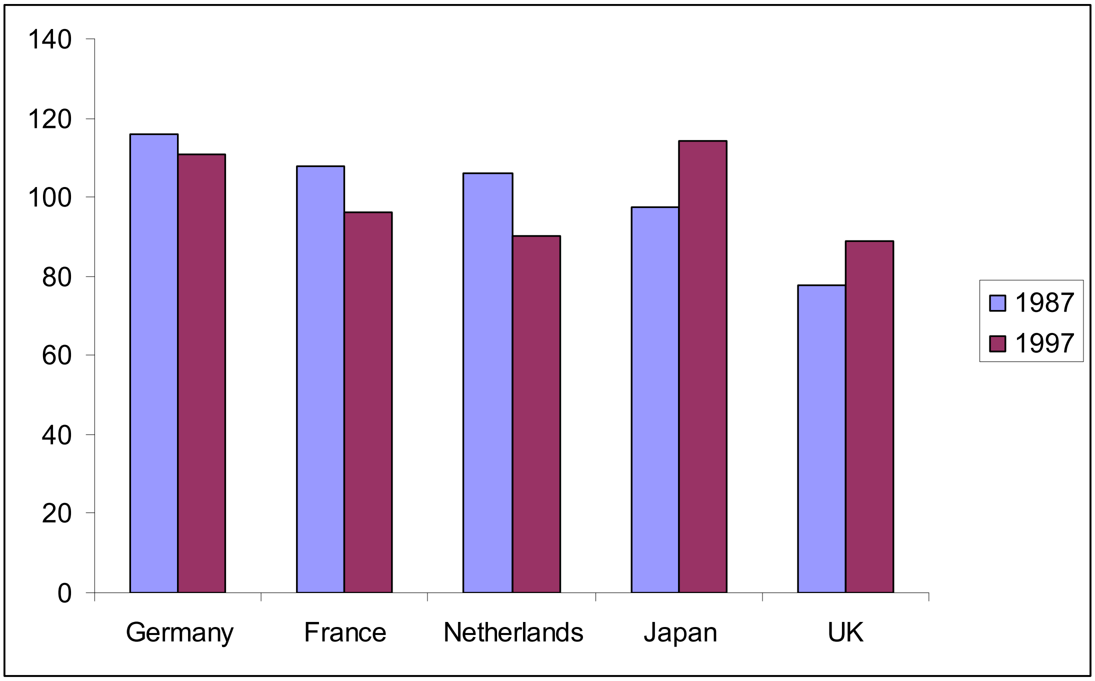
Category	France	Germany	Japan	Netherlands	UK	US
Labour compensation	84.9	97.6	93.9	76.4	58.9	100.0
Materials and supplies	118.1	129.9	101.0	117.5	149.3	100.0
Other current costs	102.0	133.2	161.3	95.0	107.1	100.0
Capital Expenditure	108.8	119.1	103.3	118.4	105.2	100.0

Source: Dougherty et al. (2007)

The R&D price levels, which express the relative cost of a unit of R&D input in each country compared with the United States, are presented in Figure 28. Based on R&D PPP measures, it appears that manufacturing R&D in 1997 was over 10% more expensive in Germany and almost 15% more expensive in Japan than in the US. Conversely, it was up to 10% cheaper to perform R&D in France, the Netherlands or the UK compared to the US.

[21] Interviews indicate, however, that biggest differences in compensation are across technical fields, and that the skills of R&D personnel in routine development work are quite similar across countries, thus making this assumption realistic at least for the group of developed economies examined in the study.

Figure 28: Relative R&D price levels (US=100), total manufacturing, 1987 and 1997



Source: Dougherty et al. (2007)

The ratios of R&D expenditure to GDP are a key focus of policy discussion across the world, and are often used as comparative measures of the intensity of the efforts devoted to innovative activities. Such comparisons or R&D intensities often rely on nominal figures: the effects on R&D intensities of adjusting for differences in R&D prices as well as output prices for total manufacturing in 1987 and 1997 are shown in Table 14. The nominal R&D intensity is defined as manufacturing R&D expenditure divided by manufacturing gross output. The real R&D intensity is calculated by using R&D PPPs to deflate nominal R&D expenditure (the numerator) and using output PPPs to convert manufacturing gross output (the denominator). The US R&D intensity is highest in both cases. But the real R&D intensity is considerably higher in each of the other countries and closer to the US level than under current practice of comparing nominal intensities. In particular, while the nominal R&D intensity in the UK is lower than the two other major European economies - France and Germany - once adjusted for the differences in the cost of performing R&D, its R&D intensity in the manufacturing sector is higher than in France or Germany.

The table suggests that the efforts devoted to R&D in each country are more similar across countries than is apparent from the standard approach of comparing nominal R&D intensities.

Table 14: Nominal and real R&D intensity for total manufacturing, 1987 and 1997

Country	R&D / GDP nominal	R&D / GDP real (PPP adjusted)
	Year 1987	
France	2.06	2.47
Germany	2.71	2.87
Japan	2.24	2.75
Netherlands	2.04	2.21
UK	2.07	3.09
US	3.44	3.44
	Year 1997	
France	2.22	2.40
Germany	2.50	2.47
Japan	2.89	2.95
Netherlands	1.59	1.74
UK	1.92	2.49
US	3.12	3.12

Source: Dougherty et al. (2007)

Although the table seems to suggest a fall in real UK R&D intensity between 1987 and 1997, in common with most of the other countries, caution should be used when interpreting the results of this exercise to compare the change in relative price levels over time.[22]

4.2 The returns to investment in innovation

Is there a significant relationship between investment in innovation, output growth and productivity? And what is the rate of return on innovation investment at the firm and industry levels? The empirical studies in this area focus predominantly on returns to investment in R&D,[23] despite the fact that there are other big categories of non R&D spend (where therefore the evidence is very limited).

The analytical tool employed to link productivity growth with research effort is a Cobb-Douglas production function where output is a function of conventional inputs and the stock of R&D. Thus, in this framework, R&D investment is simply considered an alternative capital investment in a standard neoclassical model:

$$\log Y = a(t) + \beta \log X + \gamma \log K + u$$

where *Y* is output at the firm, industry of national level, *X* is a vector of standard economic inputs such as man hours, structures and equipment, energy use and *K* is a measure of cumulated research effort or “capital”[24], *a(t)* represents other forces which affect output and change systematically over time, and *u* includes all other unsystematic random fluctuations in output. Estimated versions of this equation gave values for the elasticity of output with respect to R&D capital between 6% and 10% (Griliches, 1995).

[22] Two weighting issues make the time comparison of PPPs problematic. For details see Dougherty et al. (2007).

[23] Nadiri (1993) and Griliches (1995) provide surveys.

[24] R&D stock is computed as cumulative R&D expenditure, allowing for depreciation of the previously accumulated stock.

In an alternative formulation, levels are replaced by growth rates and the above equation becomes: [25]

$$\frac{d\log Y}{dt} = a + \beta\frac{d\log X}{dt} + \rho\frac{R}{Y} + \frac{du}{dt}$$

where *R* is the net investment in *K* (that is R&D net of the depreciation of the previously accumulated R&D capital), and ρ is the rate of return to investment in *K*. In this form, the rate of growth of output or productivity is related to the intensity *R/Y* of the investment in R&D. Versions of this equation were estimated by many authors (for example by Griliches and Lichteberg, 1984, Scherer, 1982 and Terleckyj, 1980, using industry aggregates), who report estimated rates of return between 20% and 50%, with more recent estimates falling in the lower part of this range.

In conclusion, the empirical evidence supports the existence of strong correlation between R&D and productivity performance.

4.3 The evidence for R&D spillovers

It has long been recognized that externalities arise in the innovation process because of the inability of firms to capture all the benefits of their invention. More specifically, patent legislation, trade secrecy or other methods allow the firm to appropriate a sizable proportion of the benefits of inventions. Even if some form of property rights protects inventors' ability, however, appropriability is, in most cases, not perfect. In modelling the spillovers phenomenon it is thus assumed that the level of productivity achieved by one firm or industry depends not only on its own research efforts but also on the level of the pool of general knowledge accessible to it.

Griliches (1992) identifies two types of spillover effects:

a) knowledge spillovers, which refer to the effect of research performed in one industry in improving technology in a second industry;

b) inputs effects, by which inputs purchased by one industry from another industry embody quality improvements that are not fully appropriated by the selling industry.

According to Griliches, true spillovers are ideas borrowed by research teams of a given industry from the research results of another industry, thus those of type (a). It is not clear that this kind of borrowing is particularly related to input purchase flows. In practice, it is very difficult to distinguish between the two.

The econometric methodologies employed in the search for spillover effects are essentially of two types: the *technology flow* approach and the *cost function* approach. The *technology flow* approach is based on input-output or "technology matrices": patent data are used to position the firms or industries in a matrix of technological linkages. Spillover effects of R&D undertaken by one firm or industry on the remaining firms or industries are thus examined.

Regressing the total factor productivity of the industry on its own R&D and borrowed R&D, Terleckyj (1980) reported a 45% rate of return for borrowed R&D and about 28% for own R&D in the manufacturing sector. Other studies confirmed similar patterns, i.e. the rate of return on borrowed R&D was about twice that of own R&D.

Much of the literature has used patent data to develop measures of the direction of spillovers. Scherer (1982) has classified a large sample of patents both by the industry

[25] The term *dlogK/dt* was "simplified" by using the definition $\rho = dY/dK = \gamma\, Y/K$ and *dlogK/dt* was approximated by *R/K*.

where they originated and the industry where they were expected to have a major impact. He thus obtained a technology flows table by which he re-weighted the available R&D data into measures of both origin and imported R&D. He then showed that the transmitted R&D variable had a higher coefficient and was often more significant that the own R&D variable.

Jaffe (1986, 1988) come closest in looking for the second- disembodied- type of spillovers. He used patent classification to position a firm in a technological space and included the proximity variable in the production function and in patent equations. His results show evidence of a technological spillover effect based on geographic proximity.

Jaffe (1989) has also studied the effects of geographic proximity to university-based research on the patenting of closely located firms with similar research objectives. His results suggest positive and strong spillover effects from university research. Jaffe, Trajtenberg and Henderson (1993) have used patent citation frequencies to university based patents to assess the contribution of universities to industrial productivity.

Knowledge spillovers from universities are also documented in Adams (1990), Mansfield (1991), Acs, Audretsch and Feldman (1992), who have all found that university research has substantial effects on innovative activity and performance.

The *cost function* approach (see Bernstein and Nadiri, 1989, 1991) estimates the effects of spillovers on the costs and structure of production of the receiving firms or industries. The basic econometric framework is to formulate a cost function which depends on output, relative factor prices for the variable inputs and quasi-fixed inputs such as stock of own physical capital and R&D capital but also the stock of R&D of other firms or industries. The latter variable captures the spillover of the research input of other firms or industries.

In summary, there have been a significant number of studies all pointing in the same direction: R&D spillovers are present, their magnitude may be quite large, and social rates of return remain significantly above private rates. The estimated elasticity of output with respect to aggregate outside R&D (μ) is between a half and double that of the elasticity of output with respect to own R&D (γ).

As Jones and Williams (1998) point out, the theoretical literature has emphasized the importance of market failures, such as imperfect competition and externalities in determining the outcomes in the market for new goods and ideas. Because there are incentives to both over- and under-invest in R&D, however, theory alone is unable to provide an unambiguous answer to the sign of the net distortion to R&D. This is why the empirical literature has attempted to resolve this ambiguity by estimating directly the rate of return to R&D. The empirical approach does not, however, indicate by how much R&D investment needs to be increased.

The theory thus provides some reason to question the findings of the empirical productivity literature: the empirical estimates are all based on a neoclassical theory of growth where R&D is simply an alternative form of capital investment. Distortions such as monopoly pricing, inter temporal knowledge spillovers, congestion externalities and creative destruction are ignored.

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