Fiscal Studies (2001) vol. 22, no. 3, pp. 337–355

The Internationalisation of UK R&D

NICHOLAS BLOOM AND RACHEL GRIFFITH[*]

Abstract

Policies to promote research and development (R&D) are high on the government's agenda. R&D and innovation are seen as key drivers of economic growth and important for raising UK productivity. This paper considers recent trends in UK R&D performance. We show that UK R&D is more internationalised than that of other G5 countries and is becoming increasingly so at a faster rate. A rising share of UK R&D is funded from abroad and UK firms are undertaking more of their R&D overseas. Using an international panel of countries, we show that R&D in one country responds to a change in the price in another 'competitor' country. This suggests that UK innovation policies could play an important role in determining whether increasingly footloose R&D locates in the UK or moves overseas.

JEL classification: F2, H3, O3.

I. INTRODUCTION

There has been long-standing concern that the UK has not been performing well in terms of its innovative output. Policy-makers and academics have increasingly emphasised the importance of research and development (R&D) and innovation as engines of growth.[1] In the UK, there is concern that its productivity gap with other G5 countries may be linked to its poor R&D track record.[2]

[*]Institute for Fiscal Studies.
The work was funded by the Economic and Social Research Council (ESRC) Centre for Microeconomic Analysis of Fiscal Policy at the Institute for Fiscal Studies. The authors would like to thank John Barber, Piers Bisson, Alex Klemm, Helen Simpson, Marc Thomas and John Van Reenen for helpful comments. Access to the BERD micro data was under contract to the Department of Trade and Industry. All errors and omissions remain the responsibility of the authors.
[1]See, *inter alia*, HM Treasury (2000), European Commission (2000) and Aghion and Howitt (1992).
[2]See O'Mahony and Vecchi (2000), O'Mahony (1999) and HM Treasury (2000).

Recent policy discussion in the UK has focused on the extension of tax credits for R&D expenditure to all firms as a means of encouraging more R&D.[3] The empirical evidence suggests that spillovers from R&D and innovation are localised,[4] so the UK will want to promote itself as a good location for 'footloose' R&D. One particular issue is how an R&D tax credit would interact with the European Union (EU) State Aids rules. These could prohibit a tax credit that explicitly targeted R&D performed in the UK.[5] The government therefore faces a balancing act between addressing EU competition concerns and promoting R&D in the UK.

The stakes in the R&D policy game appear to be rising, in part because UK R&D is becoming increasingly international, and so potentially more footloose. Before implementing any R&D policies, it is useful to gain some understanding of what lies behind recent trends in the UK's poor technological performance. This paper uses unique data sources to shed light on these issues. We show the following:

- Total business expenditure on R&D (BERD) as a proportion of gross domestic product (GDP) has increased in other countries but remained static in the UK.
- The UK has a larger share of R&D funded from abroad than any other G5 country. This share is also growing more rapidly than in other G5 countries.
- The share of R&D performed in the UK that is directly undertaken by foreign-owned firms has also risen from 1995 to 1999.
- Looking at the largest R&D-performing sector — pharmaceuticals — an increasing share of R&D by UK firms is being conducted abroad.

These trends point to increasing internationalisation of R&D. This appears to be happening in all G5 countries, but is more progressed in the UK, which appears to have started internationalising R&D earlier and has proceeded at a faster rate.

The next section outlines some of the main trends in the UK's innovative performance and compares them with those of the other G5 countries. Section III documents the increasing internationalisation of R&D. Section IV uses data on an international panel of countries and shows that R&D in one country responds to a change in the tax price of doing R&D in another 'competitor' country. The final section considers the policy implications of these trends for the UK. An appendix describes our data sources.

---

[3]Griffith (2000) discusses the rationale for government subsidisation of business R&D, and Bloom, Griffith and Klemm (2001) discuss the implementation of an R&D tax credit. Recent empirical evidence suggests that R&D tax credits are an effective instrument, although there are many remaining questions about their implementation and desirability.

[4]See, for example, Jaffe (1986) and Henderson, Jaffe and Trajtenberg (1993), who use evidence from US patent data that local patents (within the state) have a greater spillover benefit than other, out-of-state patents.

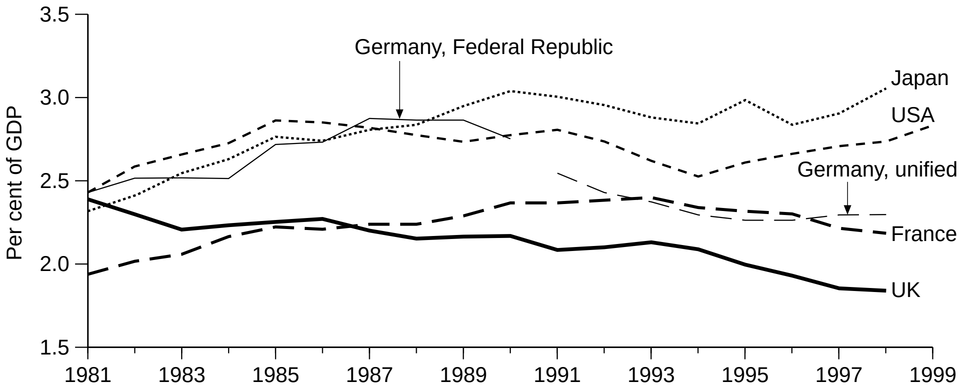
[5]See Besley and Seabright (1999) for a discussion of current State Aids rules and their implementation. These rules are currently under consideration by the EU and this may not continue to be an issue of concern.

II. TRENDS IN UK INNOVATIVE PERFORMANCE

Figure 1 shows trends in gross expenditure on R&D (GERD) as a share of GDP over time in the G5 countries.[6] In the UK, it has been falling in almost every year over the last two decades. This trend has continued into the late 1990s, with the share of GDP devoted to R&D falling every year from 1993 until 1998. This is in contrast to other G5 countries, whose R&D shares have, in general, shown an upward trend (see Table 1 for numbers for the most recent years).

FIGURE 1

Total R&D (GERD) as a Percentage of GDP



Source: OECD, 1999a.

TABLE 1

Total R&D (GERD) as a Percentage of GDP

Per cent

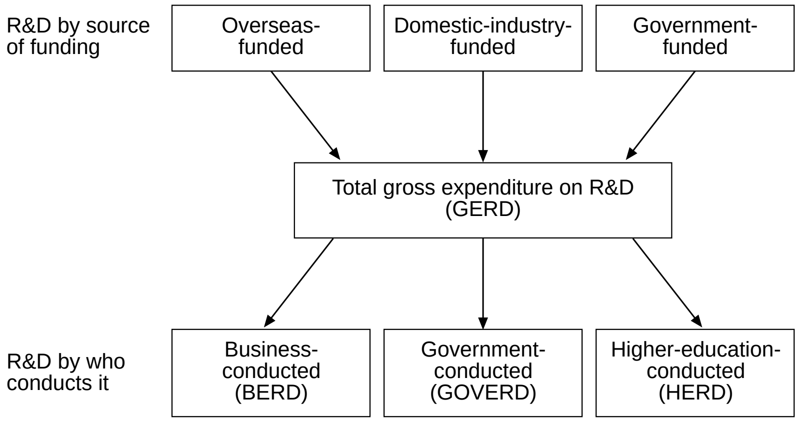
	1981	*1990*	*1995*	*1996*	*1997*	*1998*	*1999*
France	1.93	2.37	2.31	2.30	2.21	2.18	
Germany	2.43	2.75	2.26	2.26	2.29	2.29	
Japan	2.32	3.04	2.98	2.83	2.91	3.06	
UK	2.39	2.16	1.99	1.92	1.84	1.83	
USA	2.42	2.78	2.61	2.66	2.71	2.74	2.84

Source: OECD, 1999a.

[6]There is a break in the German R&D figures because of reunification in 1991. This makes it difficult to make comparisons over time. The figures reported in the tables refer to unified Germany after 1990 and to West Germany only for the earlier period. In the graphs, we show two separate series. Comparisons pre- and post-1990 should be made with caution.

FIGURE 2

Breakdown of R&D by Who Funds It and Who Conducts It



These GERD figures can be broken down in two ways — by who *conducts* the R&D and by who *funds* the R&D. These need not be the same agent, as, for example, the government will often fund R&D conducted by the business sector. Figure 2 depicts the relationship between total GERD, the three main groups that conduct it and the three main groups that fund it. The breakdown of GERD by who conducts it is shown in Table 2, averaged over the period 1981–98. In all countries, business conducts the bulk of R&D. The proportion conducted by higher education is highest in Japan, and the amount conducted by government varies somewhat, with France having a notably higher proportion.

Figure 3 shows that the proportion of GERD conducted by business enterprises has also shown a strong increase in France, Japan and the USA and a much slower increase in the UK.

TABLE 2

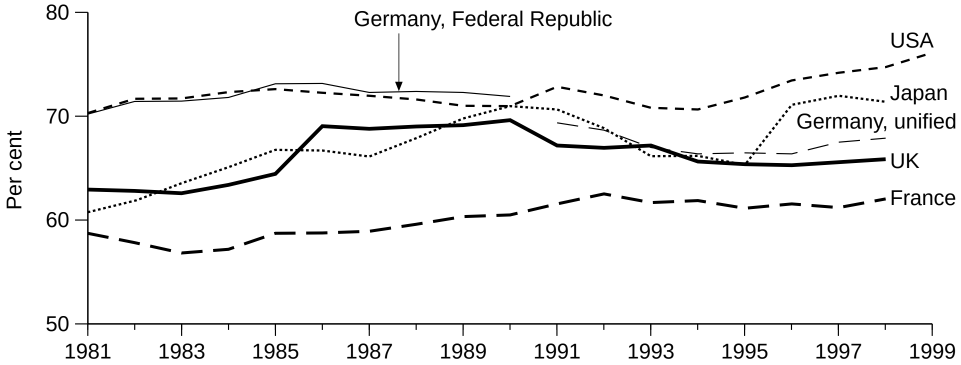
Breakdown of GERD by Who Conducts It, 1981–98

	Business enterprises	*Government*	*Higher education*[a]
France	60.0	23.2	16.8
Germany	69.9	13.8	16.5
Japan	67.2	9.1	23.6
UK	66.5	15.1	18.5
USA	72.3	10.3	17.5

[a]This also includes a small residual category called the 'private non-profit sector'.
Source: OECD, 1999a.

FIGURE 3

Percentage of GERD Undertaken by Business Enterprise



Source: OECD, 1999a.

The breakdown of GERD by who finances it is shown in Table 3. In all countries except France, domestic industry is the single largest source of R&D financing. It is noticeable that, in the UK, a larger share is funded from overseas than in the other G5 countries. In France and the USA, a larger share is funded by the government, and much of this is related to heavy defence R&D expenditure.

While all countries have experienced a cutback in government expenditure on R&D over the last 20 years (see Figure 4), this decline has been most dramatic in the UK, from 49 per cent in 1981 to 24 per cent in 1998. This reflects two major trends across all countries: there have been cutbacks in government-provided services, such as the military, and thus corresponding cuts in R&D expenditure; and there has been a move away from direct government spending towards more incentive-based mechanisms for funding R&D, such as tax credits.[7]

TABLE 3

Breakdown of GERD by Who Funds It, 1981–98

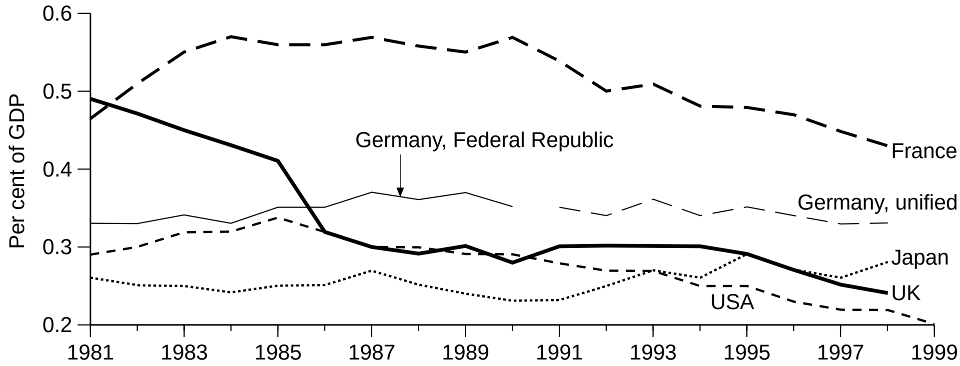
	Domestic industry	*Government*	*Overseas*
France	44.3	48.2	6.6
Germany	61.4	36.5	1.7
Japan	69.3	21.1	0.1
UK	48.3	36.9	11.2
USA	55.8	41.2	n.a.

Source: OECD, 1999a.

[7]See Stoneman (1999) for discussion of recent trends in UK government R&D expenditure.

FIGURE 4

Government Expenditure on R&D (GOVERD) as a Percentage of GDP

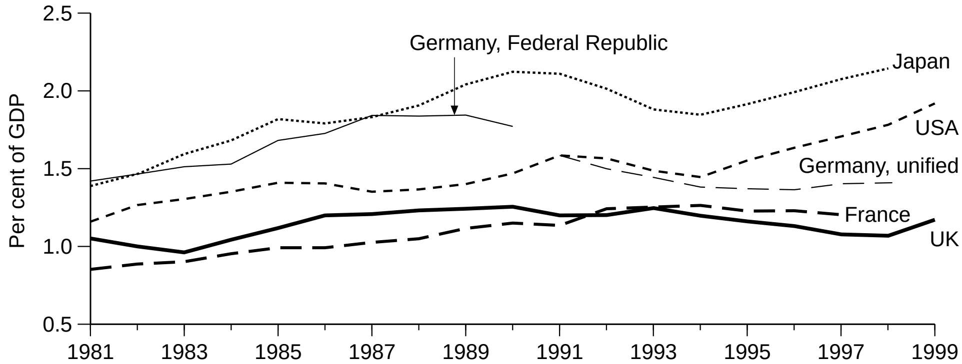


Source: OECD, 1999a.

As we saw above, a large share of R&D is both carried out and funded by business. This business-funded business-conducted R&D is often thought to be the main driver of economic growth in the short run. Governments' R&D programmes often pursue strategic objectives such as defence or environmental aims or more basic research. These may be riskier and have more long-run growth effects, as suggested in studies on the returns to government and business R&D expenditure.[8] As such, the intensity of business R&D to GDP is of central importance. It is also the part of GERD that would be directly affected by a tax

FIGURE 5

Business-Funded Business-Conducted R&D as a Percentage of GDP



Source: OECD, 1999a.

[8]See, for example, David, Hall and Toole (1999).

credit. Business-funded business-conducted R&D as a share of GDP has been approximately flat in the UK over the 1980s and 1990s, as shown in Figure 5. In comparison, other G5 countries have increased their shares of business-funded business-conducted R&D. Thus, even in the business component of R&D, the UK's intensity growth rate lags behind those of the other G5 countries.

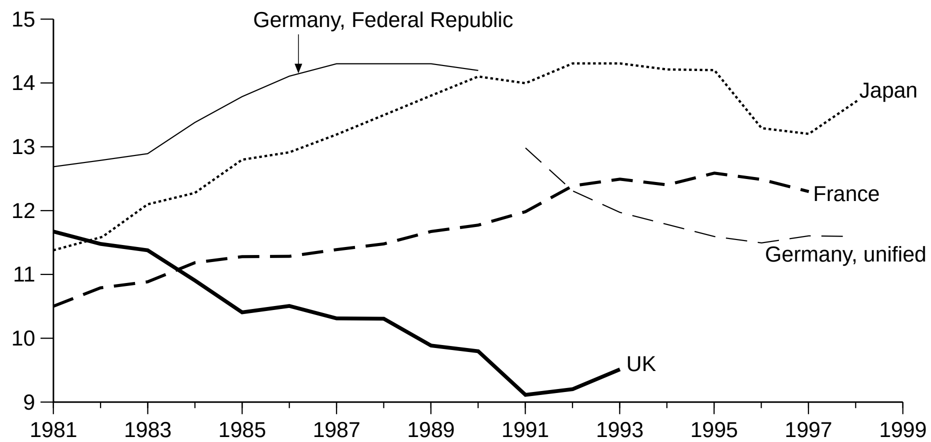
R&D expenditure is one indicator of innovative activity. It is a measure of the inputs to the innovative process. Do other indicators present a similar picture? Figure 6 shows that the number of R&D personnel per 1,000 members of the labour force has also declined over time in the UK in a way not seen in other G5 countries.

An indicator of innovative output is patent counts. These provide a similar picture. Table 4 shows the proportion of all patents taken out in the US Patent and Trademark Office by the nationality of the innovator. We use data from the US Patent and Trademark Office because it is the main international patenting office, with most patents of any value being patented there. The patents data give details of the firm that owns the patent and also the location of the inventor. We can use these to look at the origin of patents.

The proportion of patents originating in France declined by 26 per cent over the two decades and the proportion originating in Germany declined by 34 per cent. Japanese patenting activity in the USA has increased significantly over the time period, rising by 72 per cent. The proportion originating in the UK fell by the most, declining 39 per cent over the period. The USA still has the largest share, but it has declined as well, by 10 per cent over the period. The decline and subsequent levelling-out after 1994 in the UK are shown in Figure 7.

FIGURE 6

Number of R&D Personnel per 1,000 of the Labour Force



Note: Data are not available for the USA.
Source: OECD, 1999a.

TABLE 4

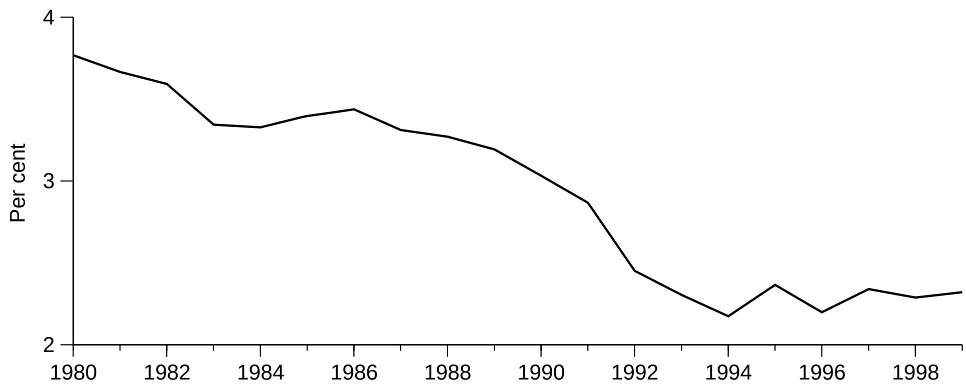
Percentage of Patents Taken Out in the US Patent and Trademark Office, by Nationality

	France	Germany	Japan	UK	USA
1980	3.25	8.90	11.18	3.77	61.57
1985	3.26	8.94	17.28	3.39	56.16
1990	3.12	7.92	20.90	3.04	53.39
1995	2.64	6.03	20.07	2.35	56.61
1996	2.48	5.85	19.75	2.20	56.99
1997	2.58	5.87	19.49	2.34	56.32
1998	2.45	5.87	19.68	2.28	55.57
1999	2.42	5.85	19.22	2.31	55.63
% change, 1980–99	–26%	–34%	+72%	–39%	–10%

Source: US Patent and Trademark Office (http://www.uspto.gov).

FIGURE 7

Percentage of Patents Taken Out by UK Firms in US Patent and Trademark Office



Source: Compiled from US Patent and Trademark Office data.

While none of these indicators is perfect, taken together they paint a picture of the UK lagging behind other G5 countries technologically. In the next section, we consider whether the internationalisation of R&D has played a role in explaining this decline in the UK.

III. INTERNATIONALISATION OF UK INNOVATIVE ACTIVITY

The analysis in the previous section described trends in the aggregate level of R&D and innovative activity by the geographic location of the activity. The first part of this section describes trends in the amount of UK R&D funded or conducted by foreign firms. UK firms also undertake innovative activity overseas. The second part of this section considers quantitative evidence from one industry — pharmaceuticals — on how important this is.

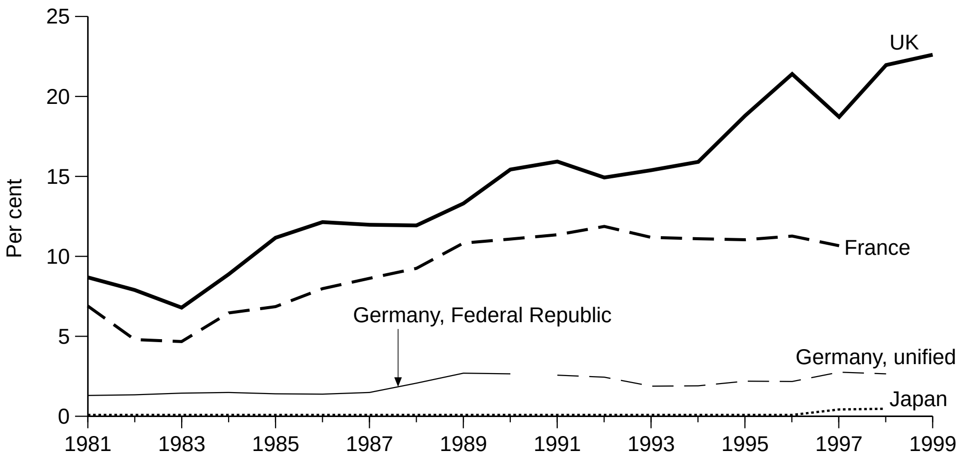
1. R&D by Foreign Firms in the UK

In this section, we use a unique data-set to look at business R&D undertaken in the UK. We use the micro data that underlie the annual Business Expenditure on Research and Development (BERD) survey undertaken by the Office for National Statistics (ONS) (see Data Appendix for details). This provides details of R&D expenditure in the UK at the firm level. We can break this down by its source of funding. In particular, we can examine whether R&D has been funded domestically or from abroad. We can also break the expenditure down by the nationality of the firm that does the R&D. The UK is notable amongst the G5 countries for having a high and rising share of foreign-funded R&D, as shown in Figure 8. By 1998, 22 per cent of UK business R&D was funded from abroad. This compares with 11 per cent in France, 0.4 per cent in Japan and 2.7 per cent in Germany.[9]

In Table 5, we show the breakdown of UK business expenditure on R&D by source of funding. Not surprisingly, a higher proportion of BERD is funded by industry than of GERD (gross expenditure on R&D) — see Table 3. This

FIGURE 8

Percentage of Business Expenditure on R&D (BERD) Financed from Abroad



Note: Data are not available for the USA.
Source: OECD, 1999a.

[9]The French figure is for 1997. Data are not available for the USA.

TABLE 5

Breakdown of UK BERD by Source of Funding

	Government	*EU*	*Own*	*Overseas*	*Other*
1994	13.5	0.9	62.2	16.7	6.7
1995	11.4	1.0	62.0	17.9	7.7
1996	9.8	1.0	62.0	19.8	7.4
1997	10.6	1.1	64.0	17.4	6.9
1998	12.0	1.5	59.9	20.0	6.6
1999	10.4	1.0	60.8	21.4	6.4

Source: Authors' calculations using BERD survey. Calculated from non-grossed-up sample; see Data Appendix for details.

proportion has remained fairly stable over the six-year period shown in Table 5. Government funding of BERD has fallen slightly, while overseas funding has risen from 16.7 per cent to 21.4 per cent.

As we saw in the previous section, R&D can be broken down by who funds it or by who conducts it. In the BERD survey, we also have information on the nationality of the firm that conducts the R&D. Therefore we can break down business R&D by the nationality of the firm conducting the R&D and by the source of funding. In the first column of Table 6, we show the proportion of BERD in the UK that is *conducted* by foreign-owned firms. This has increased from 29 per cent in 1994 to almost 35 per cent in 1999. The second column shows that between 23 and 34 per cent of BERD conducted by foreign-owned firms was funded from overseas. The final column shows the proportion of BERD conducted by domestic-owned firms that is funded from overseas. This has increased over the period 1994–99.

We can break the BERD conducted by foreign-owned firms down by nationality. In Table 7, we do this for 1996. In the first column, we see that 68.5

TABLE 6

Relationship between Nationality of Firm and BERD Funding

	Percentage of BERD conducted by foreign firms	*Percentage of BERD conducted by foreign firms funded from overseas*	*Percentage of BERD conducted by domestic firms funded from overseas*
1994	29.3	23.3	11.7
1995	28.3	30.5	10.2
1996	31.4	34.3	10.4
1997	31.9	29.6	10.9
1998	31.2	31.1	14.9
1999	34.5	33.5	14.2

Source: Authors' calculations using BERD survey. Calculated from non-grossed-up sample; see Data Appendix for details.

TABLE 7

Percentage of Activities Undertaken by Nationality of Owner, 1996

	R&D	Manufacturing		
		Employment	*Value-added*	*Investment*
British	68.5	73.1	65.6	60.7
North American	17.1	13.3	20.6	20.3
European Union	7.5	7.7	7.7	11.1
Other European	2.0	3.2	3.1	3.4
Japanese	3.6	2.0	1.9	4.0
Other foreign	2.3	0.7	1.0	1.3

Notes: Employment, value added and investment percentages are calculated from a sample of the selected Annual Census of Production (ACOP) Respondents Database (ARD) data. European Union countries are Belgium, Denmark, France, Germany, Greece, Ireland, Italy, Luxembourg, the Netherlands, Portugal and Spain.
Sources: Employment, value added and investment — Griffith and Simpson (2001); R&D — authors' calculations using BERD survey.

per cent of BERD is conducted by British-owned firms. North-American-owned conduct around 17 per cent, EU-owned around 7.5 per cent, other European around 2 per cent, Japanese around 3.6 per cent and other foreign-owned around 2.3 per cent. The final three columns compare these shares with the shares of these same nationalities in manufacturing employment, value added and investment.[10] We see that the distribution of R&D is similar to the distribution of employment, value added and investment between the nationalities of plant owners in the UK. One reason could be that R&D undertaken by foreign firms in the UK is usually associated with their production processes and plants, rather than as a stand-alone R&D laboratory.

Looking at patenting activity, we also see that the high share of foreign-funded and foreign-conducted R&D in the UK is mirrored by a high share of patents taken out in the US Patent and Trademark Office by foreign firms that state the UK as the location of the inventor. As an indicator of this, we tabulate in Table 8 the total number of patents over the period 1995–99 for the five largest UK-based patenting firms. Three of these — Kodak, US Philips Co. and IBM — are subsidiaries of US multinationals with research bases in the UK.

To look at this further, we took the 50 largest patenting firms that are located in the UK and separated them into those that were UK-owned and those where the owner was a foreign firm. These two lines are plotted in Figure 9. Mirroring the story of R&D, we see a high and rising share of the patenting of UK

[10]We are not able to break BERD down between manufacturing and non-manufacturing since many R&D facilities are labelled as research labs, which fall outside this classification. But since about 80 per cent of UK business R&D is undertaken in the manufacturing sector, comparing total R&D with the manufacturing sector figures seems appropriate.

innovative activity accounted for by foreign firms. Overall, this suggests that the UK research base is strongly multinational in nature and becoming increasingly so over recent years.

R&D can also be broken down by the industry that undertakes it. To investigate this internationalisation issue further, we look in greater detail at the UK pharmaceuticals industry, which is one of the UK's fastest-growing industries. By 1998, it carried out over 20 per cent of total business R&D in the UK, which is a larger share than in all other G5 countries, as shown in Figure 10. In common with the aggregate figures, Figure 11 shows that the proportion of UK-based R&D in the pharmaceuticals industry being funded by foreign firms is also increasing. Their share rose from 18 per cent in 1994 to 29 per cent in 1998.

TABLE 8

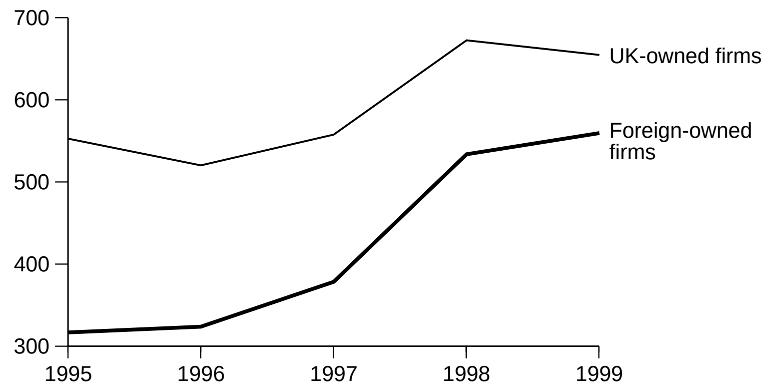
The Top Five UK-Based Patenting Firms during 1995–99

Rank	*Firm*	*Number of patents*
1st	Zeneca	374
2nd	BT	285
3rd	Kodak	236
4th	US Philips Co.	233
5th	IBM	224

Source: US Patent and Trademark Office (http://www.uspto.gov).

FIGURE 9

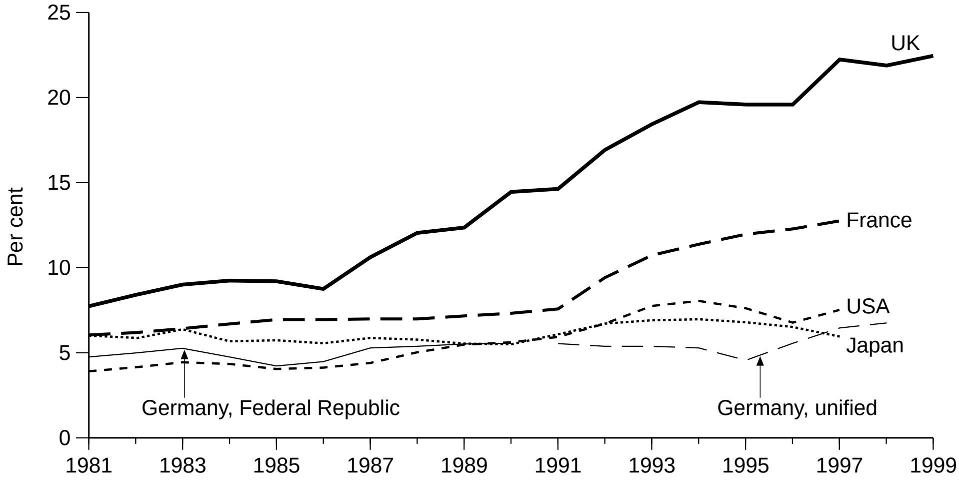
UK-Based Patenting by UK Firms and Foreign Firms[a]



[a]Number of patents taken out by foreign- and UK-owned companies in the top 50 patenting firms.
Source: Compiled from US Patent and Trademark Office data.

FIGURE 10

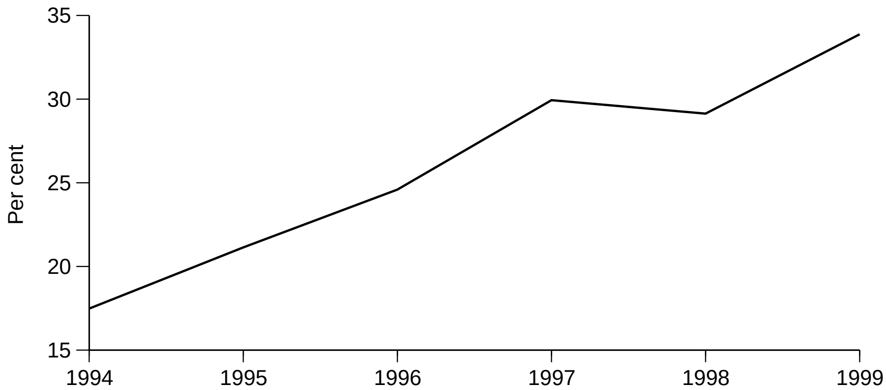
Percentage of Business Expenditure on R&D (BERD) in Pharmaceuticals Sector



Source: OECD, 1999a.

FIGURE 11

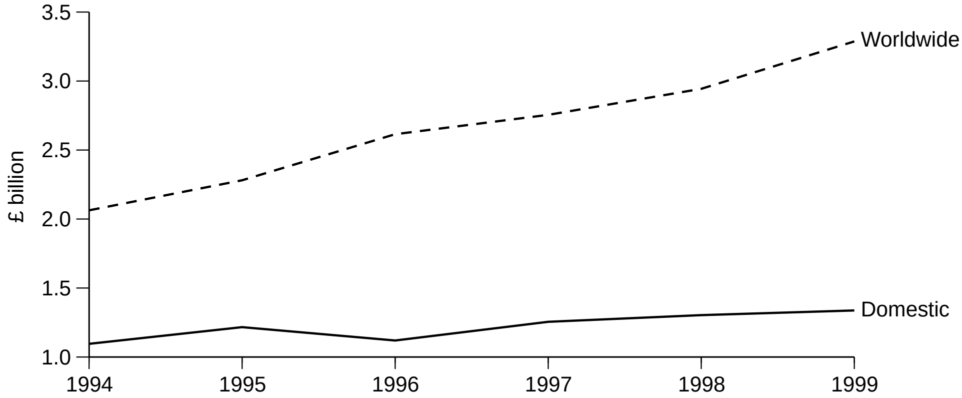
Percentage of R&D Spending in the UK by Foreign Pharmaceuticals Firms



Source: UK BERD survey.

FIGURE 12

Total R&D Spending by UK FTSE-Listed Pharmaceuticals Firms



Sources: UK BERD survey; Datastream.

2. UK Firms' R&D Abroad

Parallel to the increasing share of UK-*based* R&D funded by overseas firms, there is an increasing share of R&D *funded by* UK firms taking place abroad in the pharmaceuticals industry. Figure 12 shows the total amount of worldwide spending by UK pharmaceuticals firms[11] and the amount spent in the UK. Total spending has increased from just over £2 billion in 1994 to £2.9 billion in 1998 and nearly £3.3 billion in 1999. However, spending on R&D in the UK by the same firms has increased far less, moving from £1.1 billion in 1994 to only £1.3 billion in 1999.[12] This suggests that these firms are increasing their R&D spending in their overseas research labs at a faster pace than in the UK. This trend is corroborated in a recent paper by Serapio and Dalton (1999), which suggests that the share of foreign firms in US R&D is increasing.

So, overall, the UK pharmaceuticals R&D is rapidly internationalising in both directions. UK firms are increasing their overseas research expenditures while foreign firms are increasing their R&D activities in the UK.

IV. FOOTLOOSE R&D

One possible explanation for R&D moving abroad is to take advantage of favourable tax breaks. Bloom, Griffith and Van Reenen (2001) show that R&D responds to changes in its own tax price, using data on a panel of countries. However, in a world where multinationals can choose amongst alternative

[11]This group is the 15 largest UK-based pharmaceuticals firms.
[12]The definition of R&D in company accounts differs somewhat from the GERD and BERD definitions.

locations in which to conduct their R&D, it is not only the domestic user cost of R&D capital but also the user cost of R&D in other locations that may affect firms' investment behaviour. As shown above, multinationals conduct R&D in several locations and may be able to shift R&D between these locations at low cost. One important question then becomes whether tax credits are leading to an increase in R&D conducted worldwide, or whether they signal a form of tax competition between countries for 'footloose' R&D. Is their main impact to increase total levels of R&D or just to change its location?

One way to investigate this issue is to include a measure of the user cost of R&D in foreign locations (ρ_{it}^{f}) as well as domestic ones (ρ_{it}^{d}). The user cost of R&D is the minimum rate of return a firm needs to earn on its R&D to satisfy its shareholders. This is also commonly known as a firm's investment hurdle rate. If there is an effect from the tax treatment of R&D in other countries on relocation decisions, one would expect the coefficient on ρ_{it}^{f} to be greater than zero.

Consider a model where firms have the option of conducting R&D domestically or in a foreign location. We can derive an empirical specification to represent this as follows:[13]

$$r_{it}^{d} = \beta_0 y_{it} + \beta_1 \rho_{it}^{d} + \beta_2 \rho_{it}^{f} + f_i + t_t + e_{it} \,,$$

where r_{it}^{d} is logged domestic real R&D, y_{it} is logged domestic real output, f_i are country-specific fixed effects and t_t are a full set of time dummies.

If a fall in the domestic user cost of R&D increases domestic R&D, then we would expect to see $\beta_1 < 0$. If a reduction in the user cost of R&D in the foreign country has a significant impact on relocating R&D from the domestic location to the foreign location, then we would expect $\beta_2 > 0$. As the cost of doing R&D in the foreign location falls, firms would shift R&D there and do less R&D domestically.

Constructing the relevant foreign R&D user cost is clearly a problem. In the results below, we have used a weighted average of the user cost of investing in R&D in the other countries, where the weights are the average amount of foreign direct investment (FDI) going to each country over the 11-year period 1982–92. The use of FDI as an indicator is theoretically appealing since, in most countries, firms can only benefit from R&D tax credits if they have taxable profits in that country against which they can offset the credit.

[13]This empirical specification can be derived by generalising the first-order conditions from a one-factor CES (constant elasticity of substitution) production function — see Bloom, Griffith and Van Reenen (2001) for more details. Alternatively, given the presence of time dummies and a specification in logs, this could represent the second stage of a two-stage R&D budgeting decision.

We are concerned about the possible endogeneity of this user cost variable. That is, we are concerned that there might be an omitted variable, such as the interest rate, that affects R&D, which is our explanatory variable. If there is, it would mean that we were finding a spurious relationship between the two variables. To get around this problem, we use an instrumental variables (IV) estimator. We use the tax component of the R&D user cost as an instrument, arguing that this is predetermined. These IV equations pass a Wald test on their overidentifying moment restrictions.[14]

In Table 9, we regress the amount of R&D done in one country on its own domestic user cost and the foreign user cost using a within-groups IV estimator. In the static model in column 1, the domestic user cost is significant and negatively signed, while the foreign user cost is significant and positively signed. This suggests that domestic R&D and foreign R&D are substitutes and there may be some relocation in response to R&D tax incentives. One concern we might have about the specification in column 1 is that it does not include dynamics. Empirical work has shown that R&D is a very persistent series. The omitted

TABLE 9

Relocation of R&D for Tax Reasons

Dependent variable: ln(R&D)	*(1)*	*(2)*	*(3)*
Lagged ln(R&D)	—	0.885	0.854
		0.044	*0.052*
Ln(domestic user cost)	–0.429	–0.135	–0.153
	0.133	*0.059*	*0.067*
Ln(foreign user cost)	1.054	0.364	0.775
	0.524	*0.223*	*0.330*
Ln(output)	1.213	0.016	–0.016
	0.337	*0.162*	*0.174*
Long-run elasticity — domestic user cost		–1.180	–1.050
(P value from Wald test)		(0.057)	(0.029)
Long-run elasticity — foreign user cost		3.176	5.300
(P value from Wald test)		(0.161)	(0.023)
Country dummies	Yes	Yes	Yes
Year dummies	Yes	Yes	Yes
Number of observations	139	139	122

Notes: Countries included in sample are Australia, Canada, France, Germany, Italy, Japan, the UK and the USA; the USA is excluded in column 3. The data run from 1979 to 1997. Instruments are current and lagged tax price of domestic R&D, current and lagged foreign user cost of R&D and once- and twice-lagged output; columns 2 and 3 use once- and twice-lagged R&D in addition.

[14]See Bloom, Griffith and Van Reenen (2001) for further discussion of the econometrics.

dynamics may be affecting our results. However, it should be noted that, with very persistent series, it can be difficult to obtain consistent estimates of the coefficients in a dynamic specification.

We include a lagged dependent variable in column 2. The domestic user cost remains negative and significant, with an impact elasticity of around 0.14 and a long-run elasticity of 1.18. The foreign user cost remains positive but is now imprecisely estimated so is no longer significant. An additional concern we might have is that countries vary in their openness and thus in the extent to which changes in the foreign tax price will affect domestic R&D. In particular, the USA is a relatively closed economy,[15] so that one would expect its response to the foreign user cost to be much lower. In column 3, we have dropped the USA and we see an increased and significant long-run foreign user cost coefficient. We did not find this result when we dropped any other individual country.

Overall, we interpret these results as suggesting that there is a positive relationship between the amount of R&D conducted in one country and the tax price of conducting R&D in its major FDI partners. This suggests that at least part of the explanation for the mobility of R&D could be the increasing generosity of tax subsidies to R&D that are on offer in many countries.

V. SUMMARY AND POLICY IMPLICATIONS

This paper has examined recent trends in R&D in the UK and compared them with those in other G5 countries. Overall, we see that there has been a worrying decline in the UK in the proportion of GDP that goes into R&D and innovation, as measured by a number of indicators. This decline is in part attributable to the decline in government spending. However, even focusing on business-conducted business-funded R&D, we still see a decline. There has also been an increasing tendency for R&D in the UK to be carried out by foreign firms. Mirroring this, UK firms in the highest-R&D-growth industry — pharmaceuticals — have been doing an increasing amount of their R&D abroad.

Why do we see this internationalisation of R&D? Two reasons are commonly given. First, it may be that the incentives for R&D introduced by other countries (such as the USA, France and Canada) are changing the international allocation of R&D and that the UK is losing out. The empirical evidence given above on the effect of the R&D tax credit suggests some of the internationalisation of UK R&D abroad could be in response to the more generous treatment of R&D in the USA and other OECD countries. Hall and Van Reenen (1999) survey the evidence on the impact of R&D tax credits and conclude that their effect is significant.

---

[15]The USA is a relatively closed economy in the sense that exports and imports account for only about 10 per cent of GDP.

A second explanation is that agglomeration economies and other externalities are becoming increasingly important. Firms choose to do R&D where it is most productive. The paper by Serapio and Dalton (1999) suggests that technology sourcing is a large part of the reason why firms are moving their R&D to the UK.

What does all of this imply for policy? If increasing internationalisation is an indicator that R&D is becoming more footloose, then the response of firms to fiscal incentives, such as R&D tax credits, could be higher than previously estimated and increasing over time. If, on the other hand, R&D is becoming geographically more concentrated in a few key markets (mainly the USA), then this suggests policy should focus on promoting the early location of technological clusters in the UK.

DATA APPENDIX

The aggregate figures on R&D and R&D employment used in Section II come from the MSTI data-set (OECD, 1999a).

The patenting figures come from the US Patent and Trademark Office (http://www.uspto.gov); see also Bloom and Van Reenen (2000).

The breakdowns by nationality of owner come from the micro data underlying the BERD survey collected by the Office for National Statistics (ONS). Ownership data are sometimes missing; we do not include these observations.

The data used in the econometric analysis in Section IV come from the ANBERD data-set, which contains business enterprise R&D at the industry level (OECD, 1999b). This corresponds to the Frascati definition and is drawn from surveys by member states. Output is taken from the STAN data-set, also produced by the OECD (1999c), which can be matched into the ANBERD data. The separation of R&D by source of finance is achieved by using the figures from the MSTI data-set (OECD, 1999a). Output and other non-R&D variables are deflated using the GDP deflators (OECD, 1999c). R&D expenditure is deflated by a weighted average composed of 50 per cent wages and 50 per cent GDP deflator to reflect its strongly wage-related input costs. See Bloom, Griffith and Van Reenen (2001) for more details.

REFERENCES

Aghion, P. and Howitt, P. (1992), ‘A model of growth through creative destruction’, *Econometrica*, vol. 60, pp. 323–51.

BERD, Business Expenditure on Research and Development micro data collected by the UK Office for National Statistics, 1994–99.

Besley, T. and Seabright, P. (1999), ‘State Aids: making EU policy properly reflect geography and subsidiarity’, *Economic Policy*, vol. 28, April, pp. 16–53.

Bloom, N., Griffith, R. and Klemm, A. (2001), *Issues in the Design and Implementation of an R&D Tax Credit for UK Firms*, Briefing Note no. 15, London: Institute for Fiscal Studies (http://www.ifs.org.uk/innovation/bn15.pdf).

—, — and Van Reenen, J. (2001), 'Do R&D tax credits work? Evidence from an international panel of countries 1979–96', *Journal of Public Economics*, forthcoming.

— and Van Reenen, J. (2000), 'Patents, productivity and market value in a panel of British firms', Institute for Fiscal Studies, Working Paper no. 00/21.

David, P., Hall, B. and Toole, A. (1999), 'Is public R&D a complement or substitute for private R&D? A review of the econometric evidence', National Bureau of Economic Research, Working Paper no. 7373.

European Commission (2000), 'Innovation in a knowledge-driven economy', *Communication from the Commission to the Council and the European Parliament*, COM(2000) 567 final, Brussels.

Griffith, R. (2000), *How Important Is Business R&D for Economic Growth and Should the Government Subsidise It?*, Briefing Note no. 12, Institute for Fiscal Studies (http://www.ifs.org.uk/innovation/randdcredit.pdf).

— and Simpson, H. (2001), 'Characteristics of foreign-owned establishments', in R. Blundell, D. Card and R. Freeman (eds), *Creating a Premier League Economy*, Chicago: University of Chicago Press, forthcoming.

Hall, B. and Van Reenen, J. (1999), 'How effective are fiscal incentives for R&D? A review of the evidence', *Research Policy*, vol. 29, pp. 449–69.

Henderson, R., Jaffe, A. and Trajtenberg, M. (1993), 'Geographic localisation of knowledge spillovers as evidenced by patent citations', *Quarterly Journal of Economics*, vol. 108, pp. 577–98.

HM Treasury (2000), *Productivity in the UK: The Evidence and the Government's Approach*, London: The Stationery Office (http://www.hm-treasury.gov.uk).

Jaffe, A. (1986), 'Technological opportunity and spillovers of R&D: evidence from firms' patents, profits and market value', *American Economic Review*, vol. 75, pp. 984–1002.

OECD (1999a), Main Science and Technology Indicators (MSTI) database.

— (1999b), Analytic Business Expenditure on Research and Development (ANBERD) database.

— (1999c), Standard Industrial (STAN) database.

O'Mahony, M. (1999), *Britain's Productivity Performance 1950–1996*, London: National Institute of Economic and Social Research.

— and Vecchi, M. (2000), 'A closer look at the relationship between intangible investment and productivity', National Institute of Economic and Social Research, mimeo.

Serapio, M. and Dalton, D. (1999), 'Globalization of industrial R&D: an examination of foreign direct investments in R&D in the United States', *Research Policy*, vol. 28, pp. 303–16.

Stoneman, P. (1999), 'Government spending on research and development in the UK', *Fiscal Studies*, vol. 20, pp. 223–59.