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The Determinants of Investment in Industrial Research and Development in the United Kingdom and in Germany

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Executive summary

- Investment in R&D has long been recognised as being among the main determinants of economic growth and prosperity. Analysing the factors that affect R&D is, therefore, a crucial issue for the economic understanding of what affects growth and competitiveness, and for the provision of public incentives that could help to increase the stock of knowledge of the society.

- Research and development intensity has risen significantly and consistently in Germany in recent years, while declining in the UK. The aim of this project is to contribute to the understanding of the reasons behind the R&D intensity gap between the two countries and to suggest possible policies that may be employed in order to increase the amount of investment in R&D undertaken by business enterprises.

- Our analysis shows that output is an important determinant of R&D expenditure. An increase in industry output leads to an increase in R&D both in the short run and the long run. However, output movements are significant only in the high-tech industries and their impact is much stronger in the UK than in Germany, particularly in the long run.

- The larger output effect in the UK could be the outcome of different institutional settings in the two countries – i.e. more flexibility in the UK compared to Germany and, hence, greater ability to adapt R&D investments to final demand.

- Another, and perhaps more plausible, explanation for this result could be the different R&D strategies in the two countries. In Germany, there is more emphasis on generating new technologies and this objective is less likely to be determined by output movements. In the UK, the focus is on imitation and technology transfers, which are probably more responsive to changes in demand.

- Among the main factors behind the decrease in R&D expenditure in UK manufacturing are the concentration of R&D in a few key sectors, the decrease in military R&D after the Peace Dividend, the insufficient supply of skills and the slowdown in government R&D subsidies to business enterprises. The R&D carried out by foreign affiliates positively affects total R&D in the UK, compensating for the decline in other sources of R&D expenditure in the business sector.

- Additional measures are needed in order to improve the innovative capacity of the UK. Policies should aim at increasing the supply of skills, particularly at the intermediate skill level, and promoting direct government funding of high-tech/high-risk projects. Benefits could also be attained by more widespread investment in R&D across all manufacturing sectors.

1 Introduction

Understanding what factors may contribute to an increase in R&D expenditure in European countries is vital for achieving the European Union's ambitious goal of increasing Europe's investment in R&D from around 1.9% of GDP to 3% by 2010. This was added to the Lisbon Agenda of the European Union Summit in January 2002 in light of the evidence that Europe's expenditure on R&D was significantly lagging behind that of the US (2.6% of GDP, quickly rising) and Japan (2.9%).

The gap between business R&D intensity in Germany and the UK more than doubled from around 0.2 to 0.5 percentage points between 1993 and the end of the decade. While Germany's R&D intensity has risen significantly and consistently in recent years, the UK could not improve its overall performance over the same period after a more pronounced and longer-lasting decline in the earlier years of the decade.

Knowledge accumulation through R&D is a key determinant of technological change, and its importance for a country's long-run rate of economic growth has received increasing attention from researchers and policymakers over the past decade. There is an extensive body of empirical evidence that supports the theoretical prediction that investment in R&D has a positive effect on economic growth, and R&D investment is widely used as an indicator of innovative activity. Our research thus provides a valuable input to the current policy debate on R&D incentives in both Germany and the UK, as well as in Europe as a whole.

This study focuses on R&D expenditure in the manufacturing sector. For each country, we have collected data on R&D and its determinants for 11 industries over a 10-year period. The industry data set is complemented by several aggregate series, which are used to investigate the main macro economic trends in Germany and the UK.

The comparative analysis highlights the economies' relative strengths and weaknesses in providing incentives for R&D investment from which valuable implications for mutual policy learning can be inferred.

Our investigation will start with a short introduction to the literature on the determinants of R&D. We consider three broad categories of determinants of R&D expenditure – industry characteristics, public policies and product market competition – which will provide the background to our empirical analysis. We present a descriptive analysis of the data which highlights the major differences between the two countries. This first empirical analysis allows us to formulate initial hypotheses about the relative importance of the various factors that can affect R&D expenditure.

We then proceed to test the hypotheses econometrically and discuss the implications of our results. Finally, the main conclusions will be discussed.

2 The determinants of business expenditure on R&D: an introduction to the existing empirical evidence

Investment in R&D has long been recognised as being among the main determinants of economic growth and prosperity, and the analysis of the relationship between R&D and productivity has played a major role in providing the necessary theoretical and empirical evidence (Griliches, 1979; Griliches, 1988; Grossman and Helpman, 1991; Coe and Helpman, 1995). Following Becker and Pain (2003) and Becker (2006), we identify three main determinants of R&D: specific firm/industry characteristics, public policies and product market competition.[1] These are the factors that we will account for in our empirical analysis.

The importance of industry characteristics

Internal finance and sales are identified as the two key industry characteristics that affect innovation activities.[2] It is commonly argued that firms are not able to attract (sufficient) external funds to finance investment in R&D, given capital market imperfections. Consequently, they have to rely on internal funds. Going back at least to Schumpeter (1939, 1942), the theoretical argument for an impact of internal finance on R&D is long-standing. However, the empirical evidence has been less clear cut. While most of the studies surveyed by Cohen (1995) point to a positive relationship between internal finance and R&D, the earlier survey by Kamien and Schwartz (1982) concluded that the evidence of a significant influence appeared to be weak.

Following Schumpeter (1939, 1942), several arguments have been put forward to support the hypothesis that innovation will increase more than proportionately with respect to firm size, measured by sales or market power.[3] These include economies of scale in R&D technology, more efficient implementation, higher returns from R&D, and greater ability to secure finance for risky projects given capital market imperfections. Indeed, current sales are often found to have a significantly positive impact on R&D expenditures.

[1] Becker and Pain (2003) and Becker (2006) identify two additional determinants of R&D: resource endowments and location, such as the availability of human capital or the ability to locate close to universities or research centres.

[2] Detailed surveys of this literature are provided by Kamien and Schwartz (1982), Baldwin and Scott (1987), Cohen and Levin (1989), Acs and Audretsch (1990) and Cohen (1995).

[3] We consider the impact of market concentration in the category 'competition'.

The impact of public policies on R&D expenditure

Market failure can provide a rationale for government intervention to support private R&D. If the private rate of return is below the social rate of return, as might be expected if firms are unable to fully appropriate the rents from their innovations, then expenditure on R&D could be lower than socially optimal. Knowledge spillovers, financial market failures, skilled labour shortages and informational imperfections can all lead to fewer innovative activities than would be socially desirable (Jaumotte and Pain, 2005).

Governments can affect the decision to invest in R&D via two main tools:

1. favourable tax treatments, such as R&D tax credits; and
2. direct provision of funds for private R&D projects.

Governments may also support private R&D indirectly if there are spillovers from government-funded research at universities and publicly funded research centres.

While the empirical evidence regarding the effectiveness of public policies on R&D remains mixed, on balance it indicates that public policies can have important effects. Ultimately, other forms of public policy may also be important, such as general support to science base research and the strength of intellectual property protection (Kanwar and Evenson, 2003). Moreover, given that a large part of the cost related to an R&D project is the wage of highly skilled workers, measures directed to generate the necessary skills are crucial to an effective increase in R&D expenditure.

Product market competition

Product market competition may have two distinct effects on R&D expenditures. On the one hand, it could reduce the incentive to innovate because firms are less likely to extract the rents from innovation, as predicted by standard industrial organization theory and early Schumpeterian endogenous growth models.[4] On the other hand, a firm could invest in R&D as a strategic variable to face increased competition and defend its market share. R&D rivalry in this context has been analysed in models from both the trade and the industrial organisation literature.[5]

Increased competition may also have different effects depending on the intensity of the use of new technologies. Investment in product-related R&D may be smaller in low-tech than in high-tech industries due to a higher degree of product standardization in the former. Low-tech industries may also find it more profitable to imitate process-related R&D conducted by high-tech industries, rather than undertaking innovation themselves. In this case, increasing competition can raise R&D expenditure in high-tech but not in low-tech industries, as documented by Zietz and Fayissa (1992).

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[4] See, for instance, Dasgupta and Stiglitz (1980), Aghion and Howitt (1992) and Caballero and Jaffe (1993).

[5] For example, in Caves (1985) and Clemenz (1990).

On balance the existing evidence suggests that increased competition has a positive effect on R&D, consistent with theoretical models that emphasise the extent to which R&D might be used as a defensive strategy in response to greater competition.

Studies that investigate potential spillover effects from R&D investment by foreign firms are less conclusive and provide different results depending on the country being analysed. The difficulty in finding a clear answer can be caused by the foreign country's own objectives when launching a business venture abroad, and/or on the R&D environment in the host country. If the host country invests heavily in R&D, the stream of knowledge spillovers can go from the national to the foreign business and, hence, the direction of the relationship is reversed.

3 Main trends in R&D expenditure in Germany and the UK

The industry perspective

This project is based on the analysis of a new industry data set, including 11 manufacturing industries in each country. The industry list is presented in Table 1. The time series dimension of the data covers 11 years of observations, from 1990 to 2000. The German R&D series were provided by the Stifterverband für die deutsche Wissenschaft.[6] For the UK, we used ONS data (MA14).

In addition to data on business expenditure on R&D, several other data series were collected for the empirical analysis. These included data on value added at current prices and value added deflators; expenditure on R&D performed in businesses and funded by the government as a share of the total R&D (G_ratio); expenditure on R&D performed by foreign owned firms as a share of total R&D (F_ratio); number of scientists and engineers employed on R&D (SE_ratio); and import penetration (Mpen = value of imports over home demand).

Table 1
List of industries used in the analysis

Industry group	SIC 92/NACE Rev. 1
Food, Beverages and Tobacco	15–16
Textiles and Textile Products	17–19
Wood, Wood Products and Paper	20–22
Chemicals	24
Rubber and Plastic Products	25
Other non-Metallic Minerals	26
Basic Metals and Fabricated Metal Products	27–28
Machinery and Equipment	29
Electrical and Optical Equipment	30–33
Transport Equipment	34–35
Other Manufacturing, Recycling	36–37

[6] Given the change in industry classification from *SYPRO* to NACE Rev. 1 in 1995, the R&D series from 1990 to 1993 were converted into the NACE Rev. 1 classification. In Germany, the introduced NACE Rev. 1 classification was incorporated into WZ 93. The WZ 93 classification replaced the previously valid industry classification edition 79 (WZ 79), the version for the statistics of the manufacturing industries (Federal Statistical Office, 1995; Statistisches Bundesamt, German Classification of Economic Activities, 1993, Wiesbaden). The compilation of this conversion is described in the Appendix.

The data set also includes the following variables at the country level: real long-term interest rates, real effective exchange rates and the R&D performed by higher education institutions. A full description of the sources is provided in the Appendix.

Business expenditure on R&D is the largest component of the total R&D undertaken within a country (about 70%). The way this has performed over the last decade can provide an indication of the strengths and weaknesses of each country in achieving the ambitious European Union goals. How does each individual industry perform compared to the whole economy? Some trends are presented in Tables 2 and 3, which show for each country the average R&D over output ratio in the whole economy and in each industry.

Table 2
Business R&D as a percentage of GDP or value added (Germany)

	Average 1991–2000	Level 1991	Level 2000
BERD/GDP	1.59	1.75	1.75
Industry (BERD/VA)			
15–16	1.62	1.54	1.85
17–19	1.45	0.91	2.14
20–22	0.31	0.35	0.31
24	13.77	13.73	14.81
25	2.28	1.94	3.00
26	1.72	1.80	2.52
27–28	2.15	2.75	1.98
29	5.31	4.89	5.46
30–33	12.91	13.26	11.51
34–35	15.87	9.12	24.25
36–37	0.30	0.30	0.31

Table 3
Business R&D as a percentage of GDP or value added (United Kingdom)

	Average 1991–2000	Level 1991	Level 2000
BERD/GDP	1.27	1.39	1.21
Industry (BERD/VA)			
15–16	1.13	1.16	1.30
17–19	0.38	0.33	0.43
20–22	0.23	0.28	0.17
24	18.39	15.83	23.24
25	0.83	0.66	0.69
26	1.09	1.37	0.94
27–28	0.92	0.88	0.84
29	5.25	5.26	5.70
30–33	9.55	11.74	9.78
34–35	13.31	14.41	13.75
36–37	0.32	0.44	0.20

At the whole economy level, we can clearly see a lower R&D intensity in the UK compared to Germany across the 10-year period. In 2001, the R&D/GDP ratio in the UK is even below the 10 year average, indicating a decreasing trend. Germany experienced a slowdown in the 1990s which brings down the overall average, but the situation improves towards the end of the decade.

At the disaggregated level, R&D intensity displays considerable variation across industries and over time. In Germany, sectors that are traditionally R&D intensive (Chemicals, 24; Electrical and Optical Equipment, 30–33; Transport Equipment, 34–35) have generally been characterised by a rate of R&D intensity above 10%. The largest improvement over time can be observed in the Transport Equipment industry. This experienced a slowdown at the beginning of the 1990s but had a noticeable recovery by the year 2000, with R&D intensity growing from 9.12% in 1990 to 24.25% in 2000. On the other hand, Electrical and Optical Equipment (30–33) has been characterised by a decreasing amount of resources devoted to R&D, with R&D intensity going from 11.74% in 1990 to 9.78% in 2000.

The Wood and Paper industry (20–22) and the Basic Metals (27–28) have been characterised by a decreasing R&D intensity over time. In addition, there are industries, such as Textiles (17–19), that notoriously invest less in R&D. However, even in this industry, the R&D intensity has been growing over time. Overall performance has been quite positive, with most sectors showing an increase or remaining stable.

In the UK, 7 industries out of 11 experienced a decrease in R&D intensity, so there is a general downward trend confirming the aggregate figures. The Chemicals industry is the only one that outperforms the German equivalent in terms of R&D intensity. The overall average is approximately 5 percentage points higher than in Germany. However, in all other sectors, the UK is characterised by a lower R&D intensity compared to Germany. For example, in industry 25 (Rubber and Plastic Products), an average R&D intensity of 2.28% in Germany compares to a mere 0.83% in the UK. These trends are consistent not only with the previous aggregate analysis but also with existing evidence based on micro data.

A closer look at some key industries

In this section, we take a closer look at the data on R&D and its determinants that will be used in the empirical analysis. We particularly focus on four industries, two in the high-tech sector (Chemicals and Transport Equipment) and two in the low-tech sector (Rubber and Plastic Products, Textiles and Textile Products) – similar figures and tables for the other industries are presented in the Appendix. This comparison will provide not only a more detailed description of our data but also underline some interesting features of the determinants of R&D in the two countries.

Looking at Figure 1, we can see that in the high-tech industries the difference in R&D intensity in Germany and the UK is not particularly large. In the Chemicals industry, the UK is ahead of Germany throughout the whole sample, as observed earlier. The main difference between the two countries seems to be among the low-tech industries, where the gap in R&D intensity is particularly wide. The amount of resources devoted to R&D in the low-tech industries is understandably lower compared to the high-tech sector, but in Germany there is still considerable R&D activity being undertaken in, for example, the Rubber and Plastic industry, Textiles and Basic Metals (see Appendix, Figure A.4).

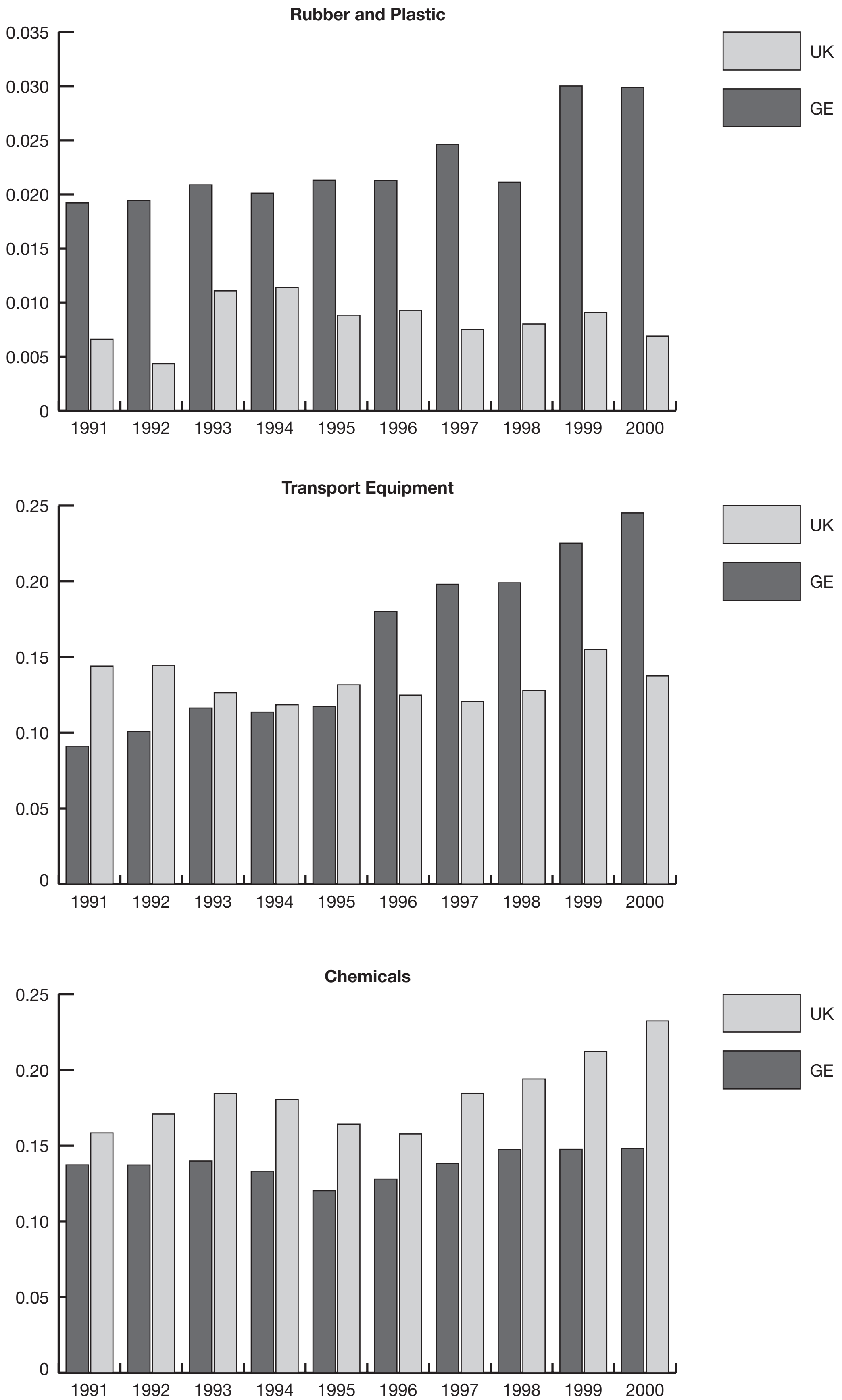

Figure 1
R&D intensity (R&D over value added) in selected industries

Table 4
Summary statistics of the determinants of R&D in selected industries

Chemicals					**Transport Equipment**				
	Mean	**St Dev**	**Min**	**Max**		**Mean**	**St Dev**	**Min**	**Max**
Germany					**Germany**				
F_ratio	0.013	0.010	0.002	0.030	F_ratio	0.001	0.000	0.000	0.001
G_ratio	0.011	0.002	0.007	0.014	G_ratio	0.003	0.001	0.001	0.005
SE_ratio	91.463	5.506	80.656	100.000	SE_ratio	8.776	0.815	7.534	9.860
Mpen	30.416	3.392	25.397	34.572	Mpen	28.44	0.022	0.244	0.316
Britain					**Britain**				
F_ratio	0.304	0.053	0.242	0.382	F_ratio	0.319	0.057	0.221	0.382
G_ratio	0.015	0.019	0.001	0.049	G_ratio	0.152	0.046	0.099	0.223
SE_ratio	56.296	7.383	45.830	68.826	SE_ratio	30.099	3.831	23.725	37.406
Mpen	41.731	4.226	35.129	46.160	Mpen	47.834	2.036	45.225	50.589

Rubber and Plastic					**Textiles and Textile Products**				
	Mean	**St Dev**	**Min**	**Max**		**Mean**	**St Dev**	**Min**	**Max**
Germany					**Germany**				
F_ratio	0.005	0.004	0.000	0.012	F_ratio	0.001	0.001	0.000	0.004
G_ratio	0.013	0.010	0.002	0.033	G_ratio	0.022	0.015	0.009	0.061
SE_ratio	14.68	1.635	12.840	18.396	SE_ratio	6.042	1.321	4.140	8.160
Mpen	20.67	1.378	18.101	22.370	Mpen	63.924	4.255	57.037	68.899
Britain					**Britain**				
F_ratio	0.447	0.163	0.283	0.851	F_ratio	0.213	0.131	0.091	0.432
G_ratio	0.010	0.015	0.011	0.041	G_ratio	0.066	0.056	0.000	0.179
SE_ratio	3.998	0.212	3.691	4.333	SE_ratio	0.000	0.000	0.000	0.000
Mpen	22.830	0.653	21.975	23.941	Mpen	46.949	4.687	40.575	54.599

Focusing on these selected industries, Table 4 illustrates summary statistics for some of the determinants of R&D that will form part of the empirical analysis. (Appendix Tables A.1–A.7 present the results for the remaining industries.)

The data show that the proportion of R&D by foreign companies is on average much larger in the UK compared to Germany in all industries. This is consistent with the particular importance of foreign direct investment as a means to boost R&D and productivity in the UK. There is in fact evidence that foreign companies operating in the UK are characterised by a higher level of productivity compared to UK companies, and that they are generally more innovative (Barrel and Pain, 1997; Driffield 2001).

The level of business R&D financed by the government does not differ much across the two countries, with the exception of Transport Equipment where the UK share (15%) is larger than the German share (0.3%). Much more heterogeneous is the distribution of scientists and engineers employed in R&D across the different industries. For example, in

Germany nearly all R&D related employees in the Chemicals industry belong to this category, while in the UK they account for approximately half the employment in the same industry. In all industries except Transport Equipment, the share of scientists and engineers is higher in Germany than in the UK, particularly in the low-tech sectors. Finally, import penetration is generally higher in the UK than in Germany, particularly in some industries such as Transport Equipment.

4 Econometric analysis

Several factors can contribute to R&D expenditure in business enterprises. We look at three main groups of determinants, which have been identified in the literature review. These are industry characteristics, government policies and market competition. The latter also includes the R&D performed by foreign affiliates. This has been more of a policy issue in the UK than in Germany. The need to have a common specification in the two countries implies that some simplifying assumptions are adopted in modelling the relationship between R&D expenditure and its determinants.

The impact of industry characteristics on R&D expenditure: results

The analysis will be carried out in sequential steps, starting from the *core specification*, where only industry characteristics are taken into account, and then extending the analysis to the inclusion of public policy variables and the impact of product market competition.

Our core specification is given by the following model[7]:

$$\Delta\ln(R_{it}) = a_0 + \beta_1\Delta\ln(R_{i,t-1}) + \beta_2\Delta\ln(Y_{it}) + \beta_3\ln(R_{i,t-1}) + \beta_4\ln(Y_{i,t-1}) + \beta_5(SE\_ratio_{i,t-1}) + \beta_6\Delta\ln(\pi_{it}) + \sum_{i=1}^{11}\delta_i * ind_i + \sum_{t=1}^{9}\tau_t * year_t + \varepsilon_{it} \quad (1)$$

where $\Delta\ln(R_{it})$ is the rate of growth of real business expenditure on R&D in industry *i* at time *t*, $\Delta\ln(Y_{it})$ is the rate of growth of real value added at the industry level, $SE\_ratio_{i,t-1}$ is the number of scientists and engineers employed in R&D as a ratio of total employment, and $\Delta\ln(\pi_{it})$ is the rate of growth of average profit in the industry. Equation (1) also includes the lagged levels of value added, $\ln(Y_{i,t-1})$ and R&D, $\ln(R_{i,t-1})$, as well as industry and time dummies defined as ind_i and $year_t$ respectively. ε_{it} is assumed to be a white noise error. The results are presented in Table 5 for Germany and Table 6 for the UK.

In Germany, we obtain no positive effects from output and a negative and significant coefficient on the ratio of scientists and engineers over total employment. The latter is somewhat inconsistent with the widespread knowledge of the importance of skilled workers for undertaking R&D and developing innovations. This result is very sensitive to changes in the specification. Once we drop the year dummies, this variable becomes insignificant, while the rate of growth of profits is significantly different from zero at the 10% level of significance (column 2). The inclusion of the rate of growth of profits sensibly affects the coefficient on output growth. The latter becomes significant when the rate of growth of profits is dropped from the estimation (column 4). On the other hand,

[7] Compared to the model illustrated in Becker and Pain (2003), we have included a short-run lagged R&D term. This specification makes the results for Germany much more robust, while it does not significantly affect the UK estimates.

Table 5
Industry characteristics as R&D determinants (Germany)

	(1)	(2)	(3)	(4)
$\Delta\ln(R_{i,t-1})$	–0.076 (0.127)	0.016 (0.148)	0.015 (0.149)	0.031 (0.156)
$\Delta\ln(Y_{it})$	–0.072 (0.274)	0.076 (0.265)	0.081 (0.266)	0.457* (0.194)
$\ln(R_{i,t-1})$	–0.316* (0.110)	–0.192† (0.103)	–0.194† (0.102)	–0.206* (0.104)
$\ln(Y_{i,t-1})$	0.099 (0.225)	0.160 (0.266)	0.149 (0.260)	0.129 (0.261)
$SE\_ratio_{i,t-1}$	–0.005* (0.002)	–0.001 (0.002)		
$\Delta\ln(\pi_{it})$	0.136 (0.204)	0.251† (0.137)	0.233† (0.125)	
Industry dummies	Yes	Yes	Yes	Yes
Year dummies	Yes	No	No	No
Wald 1 (P values)	0.393	0.910	0.870	0.779

Note: standard errors in brackets. A '*' indicate that the coefficient is significant at the 5% level, a '†' indicates that the coefficient is significant at the 10% level. Wald 1 is a test of the hypothesis that the long-run R&D-output elasticity equals 1.

Table 6
Industry characteristics as R&D determinants (United Kingdom)

	(1)	(2)	(3)	(4)
$\Delta\ln(R_{i,t-1})$	–0.077 (0.151)	–0.067 (0.160)	–0.075 (0.151)	–0.067 (0.160)
$\Delta\ln(Y_{it})$	0.056 (0.759)	0.491† (0.281)	–0.218 (0.703)	0.404† (0.215)
$\ln(R_{i,t-1})$	–0.852* (0.157)	–0.797* (0.198)	–0.860* (0.158)	–0.804* (0.194)
$\ln(Y_{i,t-1})$	0.858* (0.236)	0.740* (0.197)	0.896* (0.224)	0.766* (0.177)
$SE\_ratio_{i,t-1}$	0.013* (0.006)	0.014* (0.005)	0.014* (0.006)	0.015* (0.005)
$\Delta\ln(\pi_{it})$	–0.157 (0.187)	–0.095 (0.180)		
Industry dummies	Yes	Yes	Yes	Yes
Year dummies	Yes	Yes	Yes	Yes
Wald 1 (P values)	0.980	0.730	0.876	0.806

Note: standard errors in brackets. A '*' indicates that the coefficient is significant at the 5% level, a '†' indicates that the coefficient is significant at the 10% level. Wald 1 is a test of the hypothesis that the long-run R&D-output elasticity equals 1.

the lagged level of output is never significant at conventional significance levels. This implies that the relationship between R&D and output is not precisely defined in the German data. This result is consistent with existing evidence – for example, Bond et al. (2003).

The results for the UK are more robust to changes in the specification. They show a strong effect from lagged output and a significant effect from the ratio of scientists and engineers that is consistent across all specifications.

The significance of the ratio of scientists and engineers over total employment in the UK, but not in Germany, appears at first to be quite puzzling. However, this result can partly be explained by the higher cost of labour at the upper end of the skill distribution in the UK, and partly by the different system of education in the two countries and, hence, the different supply of skills. German workers are generally characterised by a higher qualification at the intermediate level, achieved through an effective vocational apprentice scheme. The UK apprenticeship programmes have not gained the same status as in Germany, and they have gradually decreased in importance.

The impact of public policies

The importance of R&D for a country's economic performance and prosperity, together with the need to alleviate several forms of market failures that might lead to an underinvestment in R&D, are at the basis of various government measures to foster R&D expenditure. Such measures can take several forms – for example, tax credits or the funding of public research organizations. In our empirical analysis, we account for the impact of government direct financing of R&D performed in businesses. Additionally, we account for the R&D performed by the higher education sector, which is in large part financed by the government.

We also consider the impact of the interest rate on R&D expenditure. The interest rate is not a direct policy measure as far as R&D is concerned. Its level does not depend on particular consideration concerning R&D expenditure. It is also likely to affect investment in tangible capital more than investment in intangibles, such as R&D, as it is argued that the main source of funding for R&D is the firm's internal resources (Schumpeter 1939, 1942). However, the interest rate can be seen as an indicator of both the tightness of the financial market and future output movements and can, therefore, affect R&D decisions.

To account for the impact of public policies, we re-write equation (1) as follows:

$$\Delta \ln(R_{it}) = a_0 + \gamma_1 G\_ratio_{i,t-1} + \gamma_2 \Delta \ln(HE_t) + \gamma_3 r_t + \beta X + \sum_{i=1}^{11} \delta_i * ind_i + \sum_{t=1}^{9} \tau_t * year + \varepsilon_{it} \qquad (2)$$

where G_ratio is the share of R&D financed by the government, $\Delta\ln(HE_t)$ is the change in the R&D performed by the higher education sector and r is the interest rate. X is a matrix containing all the variables representing industry characteristics, analysed in the previous section. Only those industry characteristics that were significant in the previous section are included in the estimation of equation (2). The R&D performed in the higher education sector is included at the whole country level because it is not available at the industry level of aggregation. This is related to the nature of the variable itself. It mainly refers to base research, which does not have an industry classification, but its results can spread across the whole economy. For this reason, the coefficient on this variable can be interpreted as a spillover effect of basic research on the R&D expenditure carried out at the industry level. Equation (2) is estimated for each country. A first set of results is presented in columns (1) and (2) of Table 7. In both countries the hypothesis of a unit R&D-output elasticity cannot be rejected (Wald 1). Hence we re-estimate equation (2) imposing this homogeneity restriction. The results are presented in columns 3 and 4.

Table 7
Public policy and R&D (Germany[8] and the UK)

	GER (1)	UK (2)	GER (3)	UK (4)
$\Delta\ln(R_{i,t-1})$	0.022 (0.138)	–0.030 (0.146)	–0.003 (0.129)	–0.086 (0.126)
$\Delta\ln(Y_{it})$	0.252 (0.179)	–0.750 (0.498)	0.333* (0.164)	–0.560 (0.444)
$\ln(R_{i,t-1})$	–0.293* (0.093)	–0.905* (0.166)		
$\ln(Y_{i,t-1})$	0.045 (0.234)	0.745* (0.165)		
$\ln(R_{i,t-1} - Y_{i,t-1})$			–0.223* (0.095)	–0.837* (0.148)
$SE\_ratio_{i,t-1}$		0.011* (0.005)		0.010* (0.005)
r	–0.032* (0.013)	Non significant	–0.026* (0.013)	
$G\_ratio_{i,t-1}$	0.077* (0.010)	Non significant	0.078* (0.010)	
$\Delta\ln(HE_t)$	2.231* (0.860)	1.319* (0.509)	2.082* (0.815)	1.149* (0.478)
Industry dummies	Yes	Yes	Yes	Yes
Wald 1 (P values)	0.330	0.316		

Note: standard errors in brackets. A '*' indicates that the coefficient is significant at the 5% level, a '†' indicates that the coefficient is significant at the 10% level. Wald 1 is a test of the hypothesis that the long-run R&D-output elasticity equals 1.

The results presented in Table 7 show a positive long-run impact of government funding on business R&D expenditure in Germany but not in the UK, where the coefficient is not significantly different from zero. The interest rate has the expected negative sign but it is only significantly different from zero in Germany. This implies that the cost of borrowing money affects the decision to invest in R&D in Germany but not in the UK. The long-run relationship between output and R&D is significant in both countries and it is particularly strong in the UK. Highly qualified workers employed in research departments still have a positive and significant impact on R&D expenditure in the UK.

Our results suggest that there is a substantial difference between the factors affecting R&D in the two countries. In Germany, government funding and the research carried out in higher education institutions have a very strong impact on R&D expenditure. In the UK, the R&D carried out in the higher education sector also plays a substantial role, although the impact is not as strong as in Germany. Given that the impact of this variable can be interpreted as a potential spillover, our results provide evidence for a weaker spillover effect in the UK compared to Germany. Also, in view of the fact that the amount of R&D in higher education in the two countries is very similar, the weaker spillover effect in the UK suggests a lower ability of UK businesses to internalise the knowledge created elsewhere. It is possible that the lower skill level of the intermediate workers in the UK reduces the potential for exploiting knowledge spillovers. On the other hand, highly qualified workers employed in R&D departments do play an important role in the UK, being consistently significant in all specifications.

[8] We also tried to include the change in profits using the specification presented in Table 1, column (3). However, the coefficient estimates were never statistically significant.

The impact of product market competition on R&D expenditure

Product market competition may have two distinct effects on R&D expenditure. For incumbent firms, greater competition might reduce market share and the incentive to innovate because they are less able to extract the rents from innovation. Alternatively, R&D may be used as a strategic variable to face the increased competition. Following Blundell et al. (1999), we use import penetration to proxy for product market competition, as well as the real effective exchange rate (Zietz and Fayssa, 1992). Additionally, we evaluate another source of competitive pressure – the R&D carried out by overseas businesses. This is also likely to generate potential knowledge spillovers within the country where they operate, as well as increasing the degree of product-market competition, with a possibly positive effect on domestic firms' incentive to innovate (Griffith et al., 2004).

To account for product market competition, we re-write equation (2) as follows:

$$\Delta\ln(R_{it}) = a_0 + \vartheta_1 F\_ratio_{i,t-1} + \vartheta_2 xrate_{t-1} + \vartheta_3 Mpen_{it} + \gamma P + \beta X + \sum_{i=1}^{11} \delta i_i * ind_i + \sum_{t=1}^{9} \tau_t * year_t + \varepsilon_{it} \quad (3)$$

where F_ratio is the share of total R&D performed by overseas businesses, xrate is the real effective exchange rate and Mpen is import penetration. The matrix *P* contains those variables that capture the effect of public policy, while *X* contains industry characteristics. The results for each country are reported in Table 8:

Table 8
Product market competition and R&D

	GER (1)	GER (2)	GER (3)	UK (4)	UK (5)
$\Delta\ln(R_{i,t-1})$	0.062 (0.134)	0.023 (0.136)	–0.004 (0.126)	–0.041 (0.148)	–0.086 (0.126)
$\Delta\ln(Y_{it})$	0.142 (0.185)	0.157 (0.183)	0.258 (0.168)	–0.540 (0.518)	–0.560 (0.444)
$\ln(R_{i,t-1})$	–0.283* (0.096)	–0.290* (0.094)		–0.835* (0.163)	
$\ln(Y_{i,t-1})$	0.030 (0.239)	0.028 (0.231)		0.559* (0.190)	
$\ln(R_{i,t-1} - Y_{i,t-1})$			–0.218* (0.093)		–0.837* (0.148)
$SE\_ratio_{i,t-1}$				0.008 (0.006)	0.010* (0.005)
r	0.011 (0.021)				
$G\_ratio_{i,t-1}$	0.071* (0.009)	0.074* (0.009)	0.076* (0.010)		
F_ratio_{t-1}				0.359 (0.291)	
$Mpen_{it}$[9]	Non signif.	Non signif.	Non signif.	Non signif.	Non signif.
$xrate_{t-1}$	–0.526* (0.215)	–0.387* (0.132)	–0.316* (0.126)	0.403 (0.366)	
$\Delta\ln(HE_t)$		1.423* (0.848)	1.420† (0.849)	1.237* (0.521)	1.149* (0.478)
Industry dummies	Yes	Yes	Yes	Yes	Yes
Wald 1 (P values)	0.338	0.304		0.142	

Note: standard errors in brackets. A '*' indicates that the coefficient is significant at the 5% level, a '†' indicates that the coefficient is significant at the 10% level. Wald 1 is a test of the hypothesis that the long-run R&D-output elasticity equals 1.

[9] In all specifications, the import penetration was never significantly different from zero in either country. We tried to consider it separately from the real effective exchange rate as the two variables are trying to capture the same phenomenon; however, it did not change its impact.

We find in both countries a strong long-run relationship between R&D and output, while the short-run, cyclical output effect is not significantly different from zero. This is consistent with the fact that R&D investments are part of a long-run strategy of a company and characterised by high adjustment costs. Once a commitment to undertake a R&D project is made, a series of fixed or quasi-fixed costs is incurred (research labs are built, highly skilled personnel are hired, etc.). This commitment is unlikely to be affected by short-run output movements.

At the same time, we find that the long-run relationship between R&D and output is better defined in the UK than in Germany, with a significantly higher speed of adjustment in the former country. This can be the result of higher flexibility in the UK institutional and labour market framework, as well as the pursuit of different R&D objectives in the two countries. In Germany, long-term R&D decisions are not particularly affected by output considerations, but they are part of a strategy aimed at promoting innovations. In the UK, the higher sensitivity of R&D to output in the long run suggests that the long-term R&D strategy is more responsive to demand movements rather than a proper set of innovation objectives.

In Germany, both government policies and product market competition play an important role in the determination of R&D. The share of R&D financed by the government always has a positive and significant impact across different specifications. Additionally, the R&D carried out by the higher education institutions is relevant. The interest rate has a negative effect on R&D, but only when we exclude the real effective exchange rate from the model. This indicates that there are some financial constraints but these are relatively less important compared to the competitive pressure. The latter has a negative impact on R&D.

In the UK, the only factor that appears to matter at this stage of the analysis is the availability of skilled workers, scientists and engineers operating in R&D departments, and the spillover effect originating from R&D in the higher education sector. One possible explanation for the UK estimates is the heterogeneity of the industry structure in this country, particularly in the way R&D is concentrated in a few key industries as emphasised earlier. Even though industry dummies are always included, there might be sources of heterogeneity that still cloud our results and make the identification of the determinants of R&D particularly difficult. Hence, a closer investigation of the way different industries perform in relation to R&D investments can shed some light on the determinants of R&D.

The determinants of R&D in high-tech and low-tech industries

We extend our analysis by looking at whether significant differences can be found between high-tech and low-tech industries within and across the two countries. The classification used in the present study is presented in Table 9.

As in the previous section, we start from the analysis of the impact of industry characteristics on R&D. We then proceed to account for the effects of government policies and product market competition.

Table 9
Division of industries into high- and low-tech

Industry	SIC classification	High-/low-tech
Food, Beverages and Tobacco	15–16	High
Textiles and Textile Products	17–19	Low
Wood, Wood Products and Paper	20–22	Low
Chemicals	24	High
Rubber and Plastic Products	25	Low
Other Non-Metallic Minerals	26	Low
Basic Metals and Fabricated Metal Products	27–28	High
Machinery and Equipment	29	High
Electrical and Optical Equipment	30–33	High
Transport Equipment	34–35	High
Other Manufacturing, Recycling	36–37	Low

Our investigation starts with the estimation of equation (1) for the two groups of industries. Initially, we impose the restriction that the slope coefficients in the two countries are the same within each group, but we allow a different intercept for the UK. The results from the pooled model are presented in Table 10:

The pooled estimates show quite a strong cyclical output effect but only among the high-tech industries. A 1% increase of output in the high-tech industries generates a 0.76% increase in R&D in the short run. In the low-tech sector, the rate of growth of output is not significantly different from zero, suggesting that short-term cyclical movements do not affect the amount of resources devoted to R&D. A possible explanation is that, in the high-tech sector, companies are equipped with research labs and research personnel at

Table 10
The impact of industry characteristics on R&D (pooled Germany and UK data)

	High-tech (1)	Low-tech (2)
$\Delta\ln(R_{i,t-1})$	–0.113 (0.101)	0.047 (0.126)
$\Delta\ln(Y_{it})$	0.758* (0.129)	0.284 (0.306)
$\ln(R_{i,t-1})$	–0.282* (0.105)	–0.717* (0.161)
$\ln(Y_{i,t-1})$	0.538* (0.119)	0.007 (0.284)
$SE\_ratio_{i,t-1}$	$0.005^{\dagger}$ (0.003)	
$\Delta\ln(\pi_{it})$		
UK dummy	–0.201* (0.212)	–1.142* (0.481)
Industry dummies	Yes	Yes
Wald 1 (P values)	0.010	0.026
Wald 2 (P values)	0.017	0.105

Note: standard errors in brackets. A '*' indicates that the coefficient is significant at the 5% level, a '†' indicates that the coefficient is significant at the 10% level. Wald 1 is a test of the hypothesis that the long-run R&D-output elasticity equals 1. Wald 2 is a test of the hypothesis of equal coefficients across the two countries.

the outset. Furthermore, they can use these resources more or less intensively according to the cycle. Highly skilled labour is considered a quasi-fixed factor of production whose intensity of use – i.e. the number of hours worked – changes over the cycle in response to demand changes, hence leading to a cyclical R&D expenditure. In low-tech companies, on the other hand, other factors are more likely to affect the decision to invest in R&D.

The results in Table 10 show that the ratio of scientists and engineers over total employment is only significant in the high-tech sector. This is explained by higher skill intensity of this group of industries. The UK dummy is negative and significant in both specifications, suggesting that an industry located in the UK has a lower R&D growth compared to an industry located in Germany. Moreover, the size of the coefficient estimates is much larger in the low-tech compared to the high-tech sector, suggesting that the disadvantage for a UK company, in terms of R&D expenditure, is particularly high in the low-tech sector (see also Van Reenen [1997] on this issue). Since the hypothesis of equal slope coefficients in the two countries cannot be rejected for the low-tech industries (Wald 2), we present single country estimates only for the high-tech sector in Table 11.

In Germany, cyclical output movements are particularly important in affecting R&D expenditure among high-tech industries. On the other hand, the long-run relationship between output and R&D is not well determined. In fact, the lagged output and lagged R&D levels are not significantly different from zero. This model implies the presence of a stronger short-run relationship between R&D and output compared to the long run. The results also suggest that, in the long run, R&D expenditure is influenced by other factors in addition to output.

The UK results, on the other hand, are characterised by a different trend with a larger long-run output elasticity (1.349) compared to the short run (0.516). It has been argued that R&D has *two faces* – i.e. it stimulates innovations and it facilitates the imitation of other discoveries (Griffith et al., 2004). The two types of R&D certainly imply different uses of resources and, particularly, a different time frame. It is widely accepted that investing

Table 11
The impact of industry characteristics on R&D (Germany and the United Kingdom)

High-tech industries	Germany (1)	Germany (2)	United Kingdom (3)
$\Delta\ln(R_{i,t-1})$	0.048 (0.136)	0.058 (0.126)	–0.152 (0.140)
$\Delta\ln(Y_{it})$	0.477* (0.177)	0.469* (0.184)	0.516* (0.184)
$\ln(R_{i,t-1})$	–0.173 (0.111)		–0.697* (0.180)
$\ln(Y_{i,t-1})$	0.247 (0.191)		0.940* (0.176)
$\ln(R_{i,t-1} - Y_{i,t-1})$		$-0.183^{\dagger}$ (0.103)	
SE_ratio_{it-1}			0.015* (0.005)
$\Delta\ln(\pi_{it})$			$0.193^{\dagger}$ (0.109)
Industry dummies	Yes	Yes	Yes
Wald 1 (P values)	0.724		0.024

Note: standard errors in brackets. A '*' indicates that the coefficient is significant at the 5% level, a '†' indicates that the coefficient is significant at the 10% level. Wald 1 is a test of the hypothesis that the long-run R&D-output elasticity equals 1.

in something new is more uncertain and more time-consuming than imitating a new product or process that has already proven to be successful. The faster response of R&D to output in the UK, compared to Germany, suggests that R&D investments in the two countries might be following different objectives – i.e. they might be more focused on innovation in Germany and on imitation in the UK.

The first set of results shows that the high-tech and low-tech industries in the two countries behave differently; hence, heterogeneity is an important issue. The results also suggest that there are some similarities in the low-tech sector in Germany and in the UK, while the R&D carried out in high-tech is affected by different factors and appears to have a different scope in the two countries. In the next section, we investigate how these patterns are affected when we account for government policies and product market competition.

The impact of government policy and product market competition on the R&D expenditure of the high-tech and low-tech sectors

In this section, we present and discuss the results of the estimation of equations (2) and (3) in the high- and low-tech sectors. The estimates of the pooled model are presented in Table 12.

Table 12
Government policy, product market competition and R&D (pooled model)

	High-tech (1)	High-tech (2)	Low-tech (3)	Low-tech (4)
$\Delta\ln(R_{i,t-1})$	–0.126 (0.094)	–0.143 (0.100)	0.102 (0.133)	0.119 (0.128)
$\Delta\ln(Y_{it})$	0.383* (0.194)	0.336† (0.185)	–0.583 (0.383)	–0.598 (0.377)
$\ln(R_{i,t-1})$	–0.296* (0.095)	–0.285* (0.090)	–0.853* (0.160)	–0.900* (0.150)
$\ln(Y_{i,t-1})$	0.393* (0.121)	0.368* (0.124)	–0.515† (0.311)	–0.348 (0.355)
SE_ratio(t–1)				
r	–0.032* (0.014)	–0.027* (0.013)	–0.076* (0.024)	–0.073* (0.025)
G_ratio (t–1)			0.056* (0.010)	0.055* (0.012)
$\Delta\ln(HE_t)$	0.510† (0.269)	0.590* (0.245)		0.903† (0.486)
$F\_ratio_{i,t-1}$		0.584* (0.223)		
$IM_{i,t-1}$				
xrate				–0.437 (0.295)
UK dummy	–0.714* (0.258)	–0.848* (0.245)	–1.537* (0.567)	–1.469* (0.566)
Industry dummies	Yes	Yes	Yes	Yes
Wald 1 (P values)	0.645	0.470	0.001	0.003
Wald 2 (P values)	0.030	0.090	0.004	0.009

Note: standard errors in brackets. A '*' indicates that the coefficient is significant at the 5% level, a '†' indicates that the coefficient is significant at the 10% level. Wald 1 is a test of the hypothesis that the long-run R&D-output elasticity equals 1. Wald 2 is a test of the hypothesis of equal coefficients across the two countries.

As mentioned earlier, we find a significant impact of short-run output changes on R&D in the high-tech industries, although the size of the coefficient is smaller when we account for government policies and product market competition. In the low-tech industries, changes in output are characterised by a negative sign, although the coefficient is not significantly different from zero. The hypothesis of a long-run unit relationship between R&D and output is rejected in the low-tech industries while it cannot be rejected in the high-tech.

The interest rate affects R&D expenditure negatively in both the high-tech and the low-tech sectors, with a significantly stronger effect on the latter. The estimates of the impact of direct government funding (G_ratio), on the other hand, are positive and significant only in the low-tech industries, suggesting that these direct government interventions are particularly effective in stimulating innovations in this sector. The impact of the R&D carried out in higher education is also stronger in the low-tech than the high-tech industries. This suggests that low-tech industries have a high absorptive capacity and that they are able to use the results from the R&D carried out in universities and research centres to boost their own R&D.

The results of the effect of industry characteristics and government policies are virtually unchanged when we account for product market competition (columns [2] and [3]) with the additional positive impact of the R&D carried out by foreign affiliates in the high-tech industries.

In Germany, a distinctive feature of the high-tech industries is the large impact of the share of publicly funded R&D, as shown by the large coefficient on the G_ratio variable. This can be explained by the fact that in Germany high-tech industries obtain more direct funding from the government. Among the low-tech industries, the impact of public funding is still significant but the size of the effect is much smaller compared to the high-tech sector. We do not find that publicly financed R&D crowds out private R&D in low-tech industries, but we do find that the impact is much smaller compared to the high-tech sector.

The estimated effect of the R&D carried out in higher education institutions suggests that spillovers from the research activity of universities and research centres only affect low-tech industries. It is likely that the presence of well-trained, intermediate skilled workers in German firms promotes the transfer of knowledge from higher education to the industry, but it is more difficult to envisage why this does not happen among the high-tech industries. One might suggest that the impact of the higher education variable, which is a country and not an industry variable, is not well determined for this group of industries.

We find a high cyclical output impact on R&D in the high-tech industries only. In the low-tech industries, the rate of growth of output is not significantly different from zero. Accounting for government policies and product market competition does not change our previous results. We do not find a long-run relationship between R&D and output. In fact, the lagged level of R&D expenditure and the lagged output level are not significantly different from zero in the high-tech industries.

In the UK, we find several distinctive features between the high-tech and the low-tech industries. Specifically, government funding has a positive effect only among low-tech industries. This supports the results found in an earlier study on high-tech and low-tech

R&D investment in the UK (Becker and Hall, 2004) and contrasts with our results for Germany. Another difference between the two countries and within the two sectors can be found in the impact of product market competition. The competition originating from foreign direct investments, and captured by the proportion of R&D in foreign affiliates (F_ratio), has a large and positive impact on the R&D of the high-tech sector. This suggests

Table 13
Government policy, product market competition and R&D (Germany)

	High-tech (1)	Low-tech (3)	Low-tech (4)
$\Delta\ln(R_{i,t-1})$	0.030 (0.133)	0.056 (0.216)	0.079 (0.220)
$\Delta\ln(Y_{it})$	0.479* (0.180)	–0.085 (0.425)	–0.291 (0.427)
$\ln(R_{i,t-1})$	–0.164 (0.110)	–0.560* (0.209)	–0.459* (0.184)
$\ln(Y_{i,t-1})$	0.251 (0.194)	–0.356 (0.456)	–0.537 (0.473)
$\text{SE\_ratio}_{I,t-1}$			
r		–0.058* (0.023)	–0.071*(0.025)
G_ratio_{t-1}	5.866* (1.581)	0.073* (0.014)	0.080*(0.014)
$\Delta\ln(HE_t)$		4.198* (1.689)	4.101* (1.726)
$\text{F\_ratio}_{i,t-1}$			
$\text{IM}_{i,t-1}$			–1.901 (1.184)
Industry dummies	Yes	Yes	Yes
Wald 1 (P values)	0.679	0.142	0.108

Note: standard errors in brackets. A '*' indicates that the coefficient is significant at the 5% level, a '†' indicates that the coefficient is significant at the 10% level. Wald 1 is a test of the hypothesis that the long-run R&D-output elasticity equals 1.

Table 14
Government policy, product market competition and R&D (United Kingdom)

	High-tech (1)	High-tech (2)	Low-tech (3)	Low-tech (4)
$\Delta\ln(R_{i,t-1})$	–0.169 (0.123)	–0.195 (0.139)	–0.014 (0.210)	0.054 (0.193)
$\Delta\ln(Y_{it})$	0.307 (0.398)	0.902* (0.184)	0.160 (0.415)	–1.408* (0.630)
$\ln(R_{i,t-1})$	–0.635* (0.179)	–0.693* (0.152)	–0.922* (0.218)	–1.074* (0.180)
$\ln(Y_{i,t-1})$	0.827* (0.176)	1.146* (0.178)	0.458 (0.294)	0.442 (0.290)
$\text{SE\_ratio}_{i,t-1}$	0.011* (0.005)	0.009* (0.004)		
r				
G_ratio_{t-1}			2.460* (1.231)	1.825 (1.200)
$\Delta\ln(HE_t)$	0.454 (0.463)			1.671* (0.587)
$\text{F\_ratio}_{i,t-1}$		0.619* (0.206)		
$\text{IM}_{i,t-1}$		–0.016* (0.007)		
Industry dummies	Yes	Yes	Yes	Yes
Wald 1 (P values)	0.028	0.000	0.124	0.049

Note: standard errors in brackets. A '*' indicates that the coefficient is significant at the 5% level, a '†' indicates that the coefficient is significant at the 10% level. Wald 1 is a test of the hypothesis that the long-run R&D-output elasticity equals 1.

that there is a positive spillover effect, and also a possible incentive effect as British companies are prompted to invest more in R&D to maintain their market shares. Our results do not provide evidence of a crowding-out effect from foreign R&D as in Driffield (2001). However, they show that the positive UK attitude towards foreign direct investments does contribute to foster investments in innovative activities. The other proxy for product market competition – the import penetration ratio – has a marginal negative effect, limited again to the high-tech sector.

An important factor for R&D expenditure in the low-tech industries, next to government funding, is the R&D carried out by higher education. Similar to the results for Germany, only the low-tech industries appear to benefit from the spillover of knowledge originating in universities and research centres. This suggests that, in both countries, low-tech industries make a larger use of other discoveries compared to the high-tech industries.

5 Conclusions

This study has shown that the UK and Germany differ in the amount of resources devoted to R&D and in the factors that affect the decision of business enterprises to invest in innovations.

Germany has a higher R&D intensity compared to the UK both in the overall aggregate figures as well as in the industry level data collected for this study. Several factors have contributed to the weaker R&D performance in the UK. First, there has been a strong decrease in the military component of R&D, which has traditionally been very high in the UK, after the Peace Dividend. As a result, government-financed R&D has strongly decreased since the 1980s. Second, the way in which R&D is performed across industries appears to be different in the two countries, and this has also contributed to the low R&D intensity in the UK. Specifically, while in Germany R&D investments are more evenly performed across all sectors, in the UK they are concentrated in a few target industries, such as pharmaceutical, electronics and communications, office and computing (Van Reenen, 1997).

The initial descriptive analysis of our industry data has also underlined that there is a higher proportion of scientists and engineers working in R&D departments in Germany compared to the UK. This suggests that there might be a skill shortage in Britain that is likely to negatively affect the creation of innovation. Although the supply of workers with a first degree is higher in the UK than in Germany, the latter country is endowed with a large group of intermediately skilled workers who are highly trained thanks to an effective vocational training system. The intermediate skill shortage in the UK is likely to result in higher labour costs at the top end of the skill distribution. Also, given that a large part of R&D expenditure is devoted to the wages of highly skilled workers, this skill shortage can negatively affect the composition of R&D expenditure and the innovation ability of the UK system.

Another distinctive feature of the composition of R&D expenditure in the two countries is the large proportion of the total R&D carried out by foreign firms in the UK. The UK institutional framework is particularly suitable to foreign direct investment, given the higher institutional flexibility compared to Germany and the rest of continental Europe. However, it is possible that a high proportion of foreign R&D further strengthens the already existing high concentration of R&D within the high-tech sector, thereby hindering the distribution of R&D across all manufacturing industries.

Our econometric analysis shows that output is an important determinant of R&D expenditure. An increase in output, measured in this study as value added, leads to an increase in R&D both in the short and the long run. Further refinements of our analysis show that output movements are significant only in the high-tech industries, and their impact is much stronger in the UK than in Germany. In particular, the long-run relationship between R&D and output is less significant in Germany compared to the UK, which is consistent with the evidence of existing studies (Bond et al., 2003). This result could stem from the different institutional settings in the two countries – i.e., more flexibility in the UK compared to Germany, and the greater ability to adapt R&D

requirements to final demand. However, we also believe that there is a deeper issue at the root of this outcome. As emphasised in Griffith et al., (2004), R&D has two 'faces': it involves the creation of new products and processes, and the imitation of existing ones. Assuming that imitation, or catching up, is faster than pure innovation and more subject to cyclical movements, our results suggest two different R&D strategies in the two countries. In Germany, there is more emphasis on generating new technologies, and this objective is less likely to be influenced by output movements in the long run. In the UK, however, the focus is on imitation and technology transfers, which are likely to be more responsive to changes in demand. This conclusion is reinforced by other outcomes of our analysis. For example, the German government devotes a large amount of resources to basic research. Furthermore, we find a positive impact of government-financed R&D in the high-tech industries for Germany.

It is in fact a practice of the German government to directly finance specific high-tech projects, which are likely to be more risky but also characterised by higher returns. In the low-tech sector, the impact of direct government funding is still significant but much smaller than in the high-tech sector. However, the evidence of large spillovers from the R&D carried out in higher education institutions suggests a high absorptive capacity within the low-tech sector.

In the UK, government subsidies do not have any significant impact on the high-tech sector. Instead, the R&D carried out by foreign affiliates plays a very important role. Direct government-financed R&D only affects the R&D of low-tech industries in the UK. At the same time, we provide evidence of a significant spillover effect from the research in the higher education institutions to the low-tech industries, although the impact is not as strong as in Germany.

Hence, we can infer that important differences in R&D policy exist in the two countries. In Germany, direct government funding is mainly directed towards high-tech industries and higher education in order to construct a solid innovative base. In the UK, government funding appears to be mainly directed towards the low-tech industries as well as towards higher education.

The following policy implications can, therefore, be drawn. More focused government interventions towards high-tech/high-risk projects is one of the possible options, confirming suggestions from the existing literature. Next to direct incentives towards higher R&D expenditure, education and training policies should aim at reducing the skill shortage in the UK, particularly improving the intermediate skill supply. This will imply that an increase in R&D expenditure will meet the necessary supply of skills. Otherwise, measures to boost R&D might result in a large increase in the wage of the highly skilled with fewer welfare gains. The availability of the right supply of skills has a crucial importance in the development of innovations, particularly in the present dynamic technological environment. An increased availability of skilled labour will also improve the absorptive capacity both within the high-tech and the low-tech sectors, leading to a more efficient transfer of technology.

References

Acs, Z.J. and Audretsch, D.B. (1990) *Innovation and Small Firms*. Cambridge, MA: MIT Press.

Aghion, P. and Howitt, P. (1992) 'A model of growth through creative destruction'. *Econometrica* 60: pp 323–351.

Baldwin, W.L. and Scott, J.T. (1987) *Market Structure and Technological Change*. Chichester: Harwood.

Barrel, R. and Pain, N. (1997) 'Foreign direct investment, technological change and economic growth within Europe'. *Economic Journal* 107(445): pp 1770–1786.

Becker, B. (2006) 'The determinants of investment in research and development in a panel of UK manufacturing industries'. PhD Thesis, chapter 1. London: Birkbeck College, University of London.

Becker, B. and Hall, S.G. (2004) 'Testing the pooling assumption in an industry panel of R&D investment: What do we learn?'. NIESR Working Paper 241.

Becker, B. and Pain, N. (2003) 'What determines industrial R&D expenditure in the UK?'. NIESR Working Paper 211.

Blundell, R., Griffith, R. and Van Reenen, J. (1999) 'Market share, market value and innovation in a panel of British manufacturing firms'. *Review of Economic Studies* 66: pp 529–554.

Bond, S., Harhoff, D. and Van Reenen, J. (2003) 'Investment, R&D and financial constraints in Britain and Germany'. Centre for Economic Performance Discussion Paper 0595.

Caballero, R. and Jaffe, A. (1993) 'How high are the giants' shoulders: An empirical assessment of knowledge spillovers and creative destruction in a model of economic growth'. In O. Blanchard and S. Fischer (eds) *NBER Macroeconomics Annual* 8. Cambridge, MA: MIT Press.

Caves, R.E. (1985) 'International trade and industrial organisation. Problems solved and unsolved', *European Economic Review* 28: pp 377–395.

Clemenz, G. (1990) 'International R&D competition and trade policy', *Journal of International Economics* 28: pp 93–113.

Coe, D.T. and Helpman, E. (1995) 'International R&D spillovers'. *European Economic Review* 39: pp 859–887.

Cohen, W. (1995) 'Empirical studies of innovative activity'. In P. Stoneman (ed.) *Handbook of the Economics of Innovation and Technological Change*. Oxford: Blackwell.

Cohen, W.M. and Levin, R.C. (1989) 'Empirical studies of innovation and market structure'. In R. Schmalensee and R.D. Willig (eds) *Handbook of Industrial Organisation II*. Amsterdam: North-Holland: pp 1059–1107.

Dasgupta, P. and Stiglitz, J. (1980) 'Industrial structure and the nature of innovative activity'. *Economic Journal* 90: pp 266–293.

Driffield, N. (2001) 'The impact on domestic productivity of inward investment in the UK'. *Manchester School* 69: pp 103–119.

Görzig, B., Schintke, J., Schmidt, M. (2002) 'Productivity and factors of production in Germany, calculations for 31 manufacturing industries', DIW Berlin.

Griffith, R., Redding, S. and van Reenen, J. (2004) 'Mapping the two faces of R&D: Productivity growth in a panel of OECD industries'. *Review of Economics and Statistics* 86: pp 883–895.

Griliches, Z. (1979) 'Issues in assessing the contribution of research and development to productivity growth'. *Bell Journal of Economics* 10, pp 92–116.

Griliches, Z. (1988) 'Productivity puzzles and R&D: another nonexplanation'. *Journal of Economic Perspectives* 2: pp 9–21.

Grossman, G.M. and Helpman, E. (1991) 'Trade, knowledge spillovers and growth'. *European Economic Review* 35: pp 517–526.

Jaumotte, F. and Pain, N. (2005) 'An overview of public policies to support innovation'. OECD Economics Department Working Paper 456.

Kamien, M.I. and Schwartz, N.L. (1982) *Market Structure and Innovation*. Cambridge: Cambridge University Press.

Kanwar, S. and Evenson, R. (2003) 'Does intellectual property protection spur technological change?'. *Oxford Economic Papers* 55: pp 235–264.

Sako, M. (1994) 'Training, productivity and quality control in Japanese multinational Companies'. In M. Aoki and R. Dore (eds) *The Japanese Firm, Sources of Competitive Strength*. New York: Oxford University Press.

Schumpeter, J.A. (1939) *Business Cycles*. London: Allen and Unwin.

Schumpeter, J.A. (1942) *Capitalism, Socialism, and Democracy*. New York: Harper.

Van Reenen, J. (1997) 'Why has Britain had slower R&D growth?'. *Research Policy* 26: pp 493–507.

Zietz, J. and Fayissa, B. (1992) 'R&D expenditures and import competition: Some evidence for the U.S.'. *Weltwirtschaftliches Archiv* 128: pp 52–66.

Appendix

Data

United Kingdom

R&D series

All data have been converted from the Office for National Statistics (ONS) R&D product group (*PG*) codes to the standard industrial classification SIC(92) using a concordance provided by the ONS. The data were taken from ONS MA14 or the ONS website (www.statistics.gov.uk) where available. According to information from the ONS, MA14 editions with detailed industry data exist only for 1989 and 1993–2000. Data for total R&D (variable *R*) and for selected other series totals (sum of all *PG*s) are published in revised form on the ONS website, including the years 1990–92.

R – expenditure on R&D performed in UK businesses, ONS website.

G – expenditure on R&D performed in UK businesses and funded by the government (*GOVT*) as a share of *R*.

Data for the *GOVT* series total were taken from the ONS website. *GOVT* at the detailed *PG* level is not available in revised form for 1993–98 and not available at all for 1991 and 1992. Data for 1993–98 were collected from various editions of the ONS MA14. The data for 1993–95 were converted from 1993–96 *PG*s using conversion factors based upon *R*, the only series for which data in the old and the new form are available for all relevant years. For 9 out of 20 *PG*s, the conversion factor was 1. In the absence of any information to the contrary, pre-1993 data at the detailed *PG* level were then obtained by applying 1993 *PG* shares in the series total to the revised series totals of the relevant years. In order to match 1999 data revisions, 1993–98 data at the detailed *PG* level were revised in a similar way using the respective shares in each year.

F – expenditure on R&D performed in UK businesses by foreign-owned firms (*FOREIGN*) as a share of R. Revised data for 1993–99 were provided by the ONS. Pre-1993 data for *FOREIGN* were not available either for the total or at the detailed *PG* level. The series total for those years was therefore interpolated using information on foreign funding of business R&D. Data at the individual *PG* level were then obtained as for *GOVT*.

HE – UK-wide expenditure on R&D performed by higher education (universities), ONS MA14.

Non-R&D series

Y – real gross value added, *EPKE* data set (www.niesr.ac.uk/research/epke/database.html)

IM – import penetration, calculated as the ratio of imports to home demand. Trade data were taken from ONS MQ10 (website). Turnover data were obtained as for total net capital expenditure.

Real effective exchange rate – *NIESR* forecast base.

Real long-term interest rate – *NIESR* forecast base; the measure of the real long-term interest rate uses the current nominal 10-year government bond rate plus a forward-looking convolution of inflation over the next 10 years. While this is equivalent to assuming that the average annual inflation rate over this period was forecast without error, which may be a strong assumption, it does not seem inappropriate to make this assumption as UK price inflation has been broadly stable over the last decade. Data on inflation expectations were partly constructed using the numbers on the *NIESR* forecast baseline for the UK economy as estimated outturns.

Germany

Data sources and compilation

The initial data collected for Germany included 29 manufacturing industries and covered a longer time period (1983–2001). However, the data for the UK could not be extended to the same cross sectional and time series dimension; therefore, German data were aggregated to the same level of detail as for the UK. The German data used in the interim report mainly included information on output, wage costs, and imports and exports, while the UK data included all the variables listed earlier. In order to carry out a comparative analysis, the German data set was expanded so that it now includes all the various determinants of R&D expenditure that were originally only used for the UK.

The following data sources have been collected in order to maintain a comprehensive data set for the German manufacturing industries. Biannual data describing R&D activities in the German manufacturing industry originate from the Stifterverband für die deutsche Wissenschaft (Donors' Association for the Promotion of the Sciences and Humanities in Germany). This database contains R&D series performed in the enterprise sector (variable *R*), the amount of R&D performed in the business sector but funded by the government (variable *G*), and the amount of R&D performed in the business sector by foreign affiliates (variable *F*). The gaps in the R&D series were estimated by using the OECD *ANBERD* database as a complementary source. The Stifterverband changed the industry classification in 1995 from the *SYPRO* to the European census classification NACE Rev. 1.[10] In order to receive consistent time series for the data set, we converted them into the WZ 93 classification. A detailed description of the conversion now follows. The data are available for Germany from 1991 onwards.

Information on industry characteristics were taken from the DIW database, *Productivity and Factors of Production in Germany*, by Görzig, Schintke, and Schmidt (2002) published in 2004. The data set contains yearly industry-specific information on factors like value added (variable *Y*), net investment (*I*), total sales, wage rates, etc. for 29 branches in the selected two- and three-digit classification. From 1991 onwards, the data are for both West and East Germany. The import series, variable *IM*, has been drawn from the DIW International Trade database. The variable *HE*, expenditure on R&D performed by higher education (universities) in Germany, has been obtained from the OECD database, Main Science and Technology Indicators (MSTI), published in 2004. Real value added, real effective exchange rate and real long-term interest rate have been obtained from the same sources as the UK data.

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[10] NACE = *Nomenclature générale des activités économiques dans les communautés européennes.*

The conversion of the R&D data from *SYPRO* to NACE Rev.1

In order to produce a backward projection of the *SYPRO* data into the new classification, we used a comparison of the goods in the classification of the GP 89.[11] The GP 89 classification defines both WZ 93 and GP 89; thus, we could obtain factors from the gross production values of the GP 89 for the transformation of the data. The determined conversion factors for each industry refer to the base year 1991, and were collected in a conversion matrix.

The conversion matrix we applied for re-classification has a dimension of 210 columns[12] for the sales and employees figures, which were given for the *SYPRO* basis. The 222 lines of the conversion matrix[13] correspond to the WZ 93 classification to which the conversion factors are finally geared. In the next step, a table containing the absolute values is calculated. Columns and lines have been collapsed from the four-digit level to the three-digit level.

The new structure of the matrix was given in percentages and new weights were obtained, which were needed for the recalculation of the absolute values. The dimension of the new matrix G(*NACE; SYPRO*) was now given by 46 columns (j) and 61 lines (i). With this instrument in hand, we could use a vector with a *SYPRO* classified series – for example, R&D expenditures of dimension i = 46 called *X(SYPRO)* – via matrix multiplication from the right side with the conversion matrix *G* to obtain a vector on basis of the NACE classification:

$$X(NACE) = G(NACE; SYPRO) * X(SYPRO)$$

The computed vector *X(NACE)* has been the result of the sum of scalar products of the conversion factors in form of weights and the *SYPRO* data. This vector is of dimension 61 and contained information at the three-digit level. Further aggregation was then undertaken in order to obtain 11 main groups of industries.

Econometric methodology

The empirical analysis will be based on a dynamic (error correction) model of the determinants of R&D, following Becker and Pain (2003). The specification of a dynamic model is necessary as R&D is inherently a dynamic process. Firms will not immediately adjust to long-run levels due to adjustment costs and other factors.

Both R&D and value added at current prices are deflated by the industry-specific value added price deflator to convert them into constant prices. R&D is usually deflated using a GDP deflator, but in our analysis this method was found to generate inconsistent results in both countries. A similar problem is discussed in Becker and Pain (2003) in relation to

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[11] *Güterverzeichnis für Produktionsstatistiken*, Edition 1989. Statistisches Bundesamt, 1999, Wiesbaden.

[12] Four-digit *SYPRO* classification.

[13] Four-digit WZ 93 classification.

an analysis based on UK industry data. The use of the ratio of scientists and engineers employed on R&D over total employment is intended to approximate the impact of skilled labour on R&D expenditure. Profits are calculated as real value added minus total employment costs.

Equation (1) is estimated using the Least Square Dummy Variable (LSDV) approach. Although the use of instrumental variable estimators is advisable in such models, given the endogeneity of some of the variables included (for example, the lagged dependent variable), finding suitable instruments is notoriously difficult. A common practice is to use lagged levels of the endogenous variables as instruments, and then implement a Generalised Method of Moments (GMM) estimator (Van Reenen, 1997). However, given the small cross sectional dimension of our sample, the GMM estimator will result in biased estimates that are more problematic than the bias caused by the presence of the lagged endogenous variable. Moreover, Judson and Owen (1999) show that for panels of the size used in our study, and given the size of the coefficient estimates of the lagged dependent variable that we present in the main body of this report the bias of the LSDV model is, indeed, very small.

Figures and tables

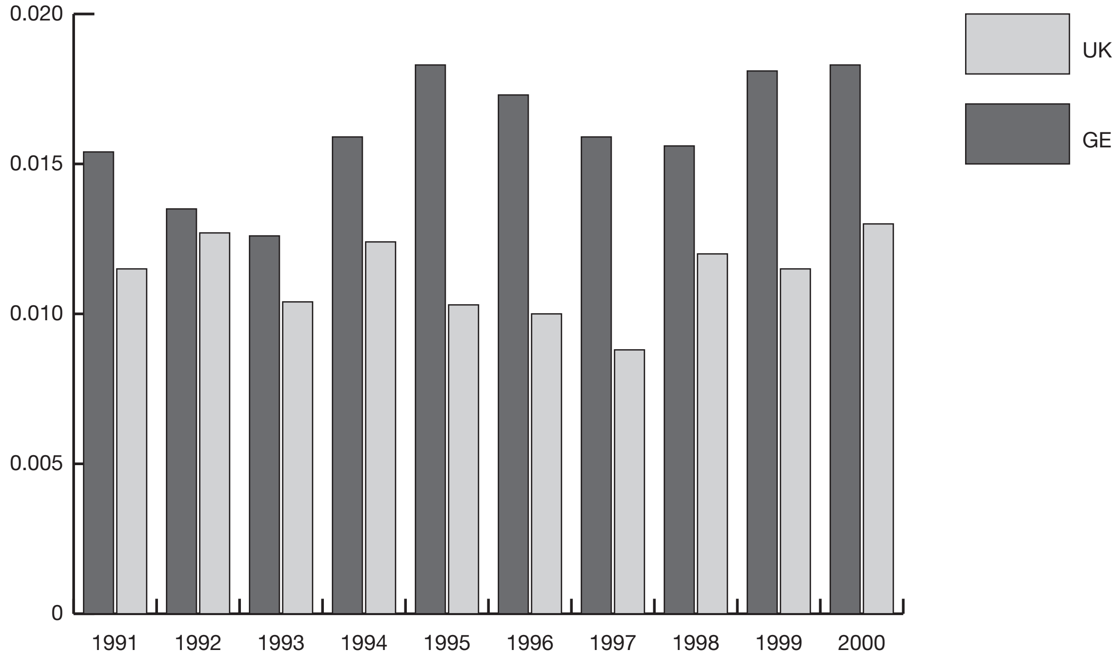

Figure A1
R&D intensity – Food, Beverages and Tobacco

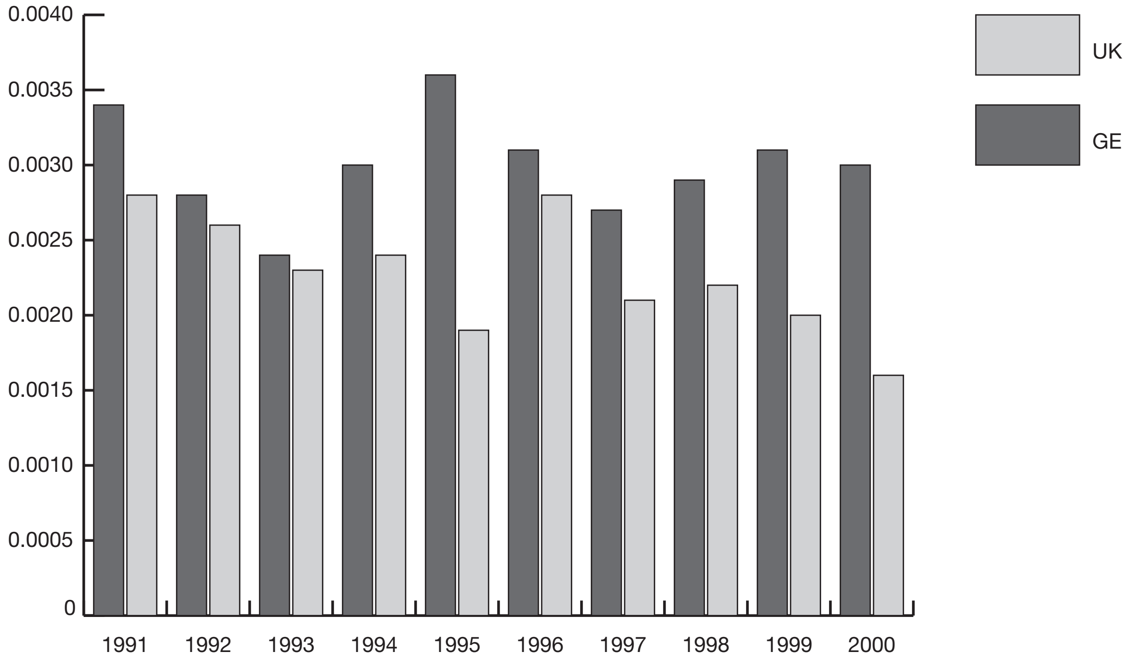

Figure A2
R&D intensity – Wood and Wood Products

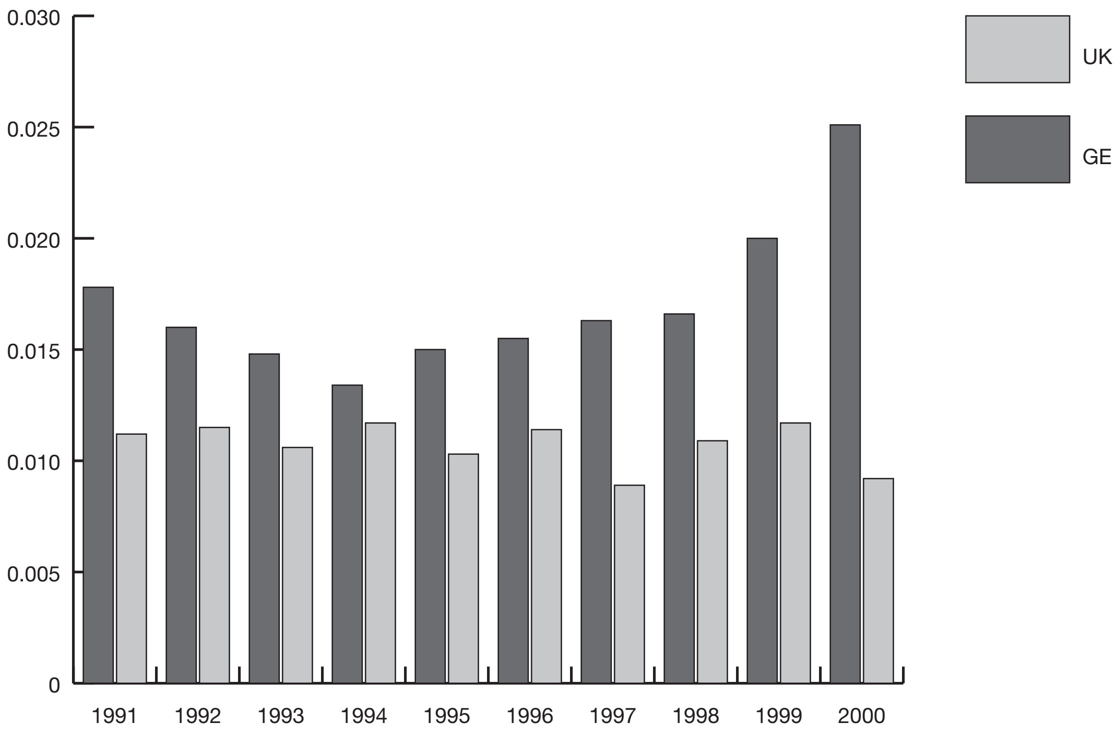

Figure A3
R&D intensity – Other non-Metallic Mineral Products

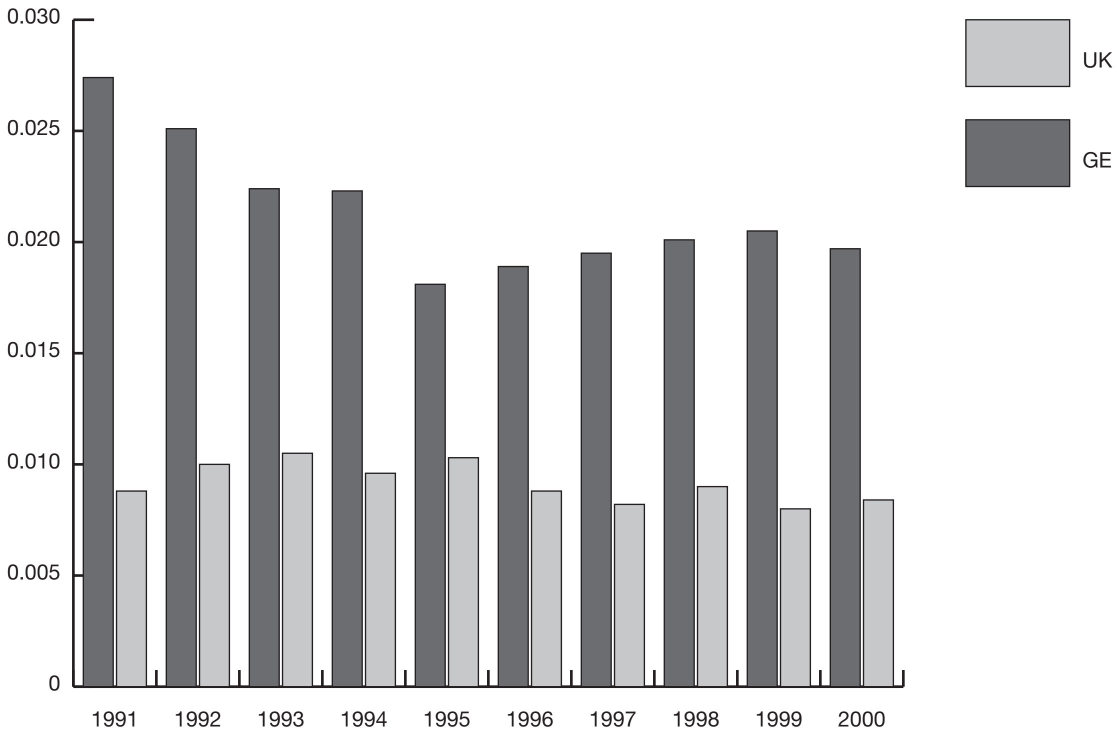

Figure A4
R&D intensity – Basic Metal and Fabricated Metal Products

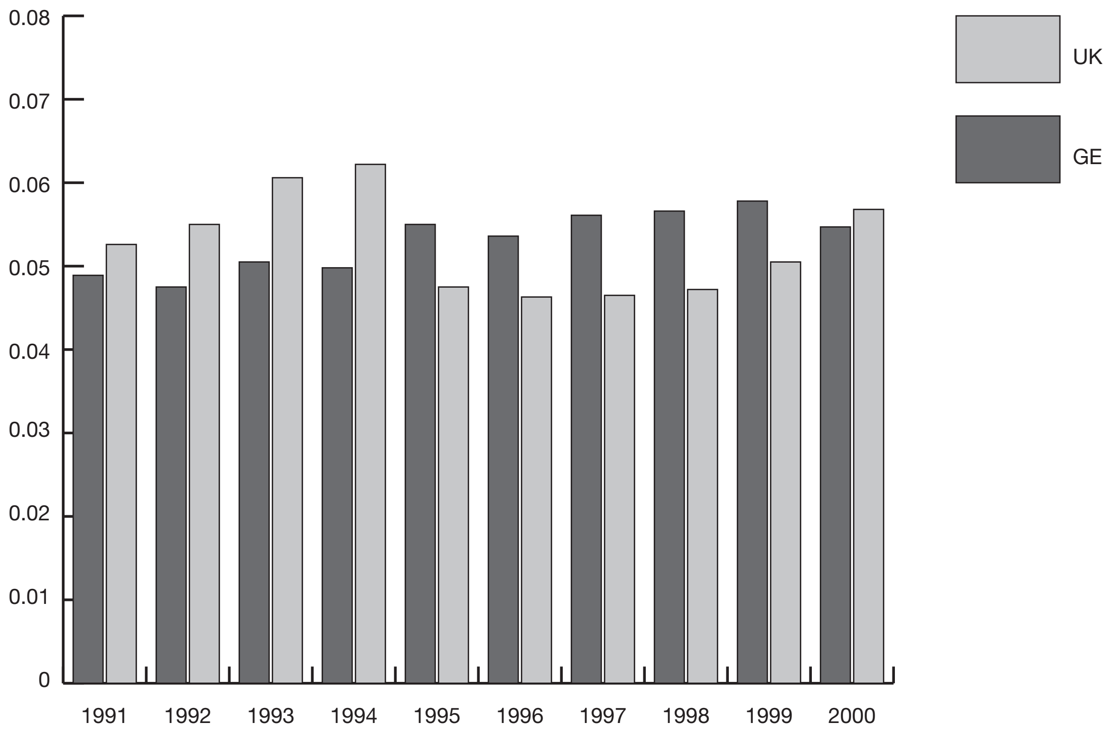

Figure A5
R&D intensity – Machinery and Equipment

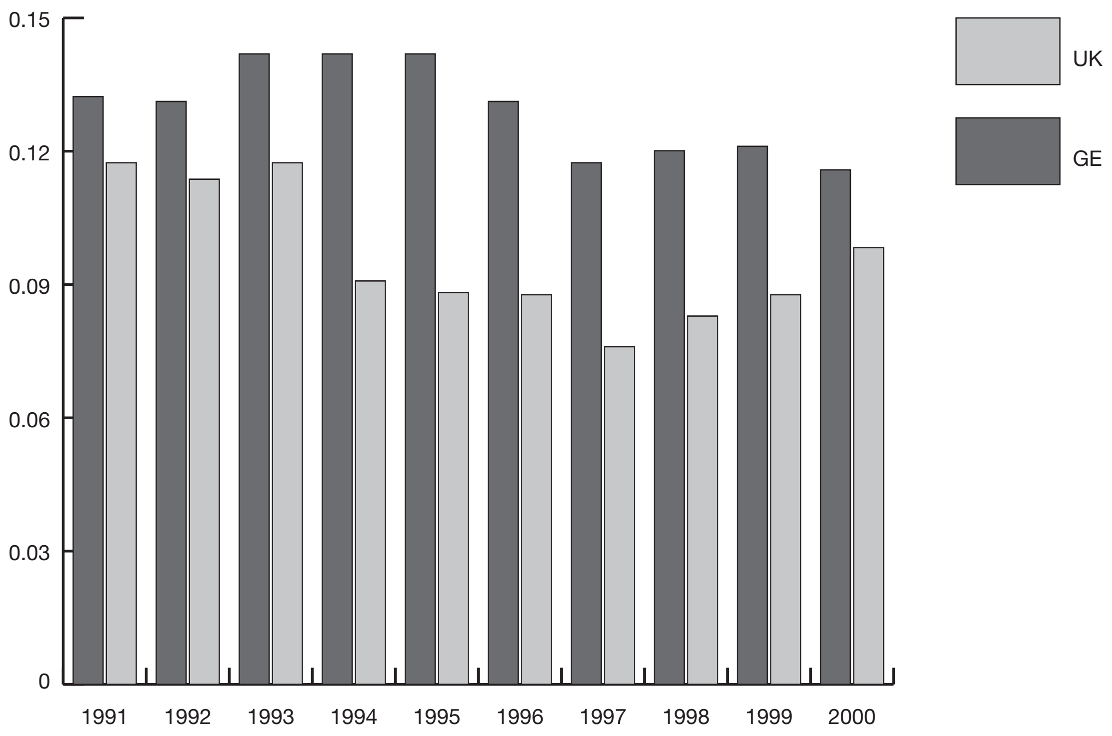

Figure A6
R&D intensity – Electrical and Optical Equipment

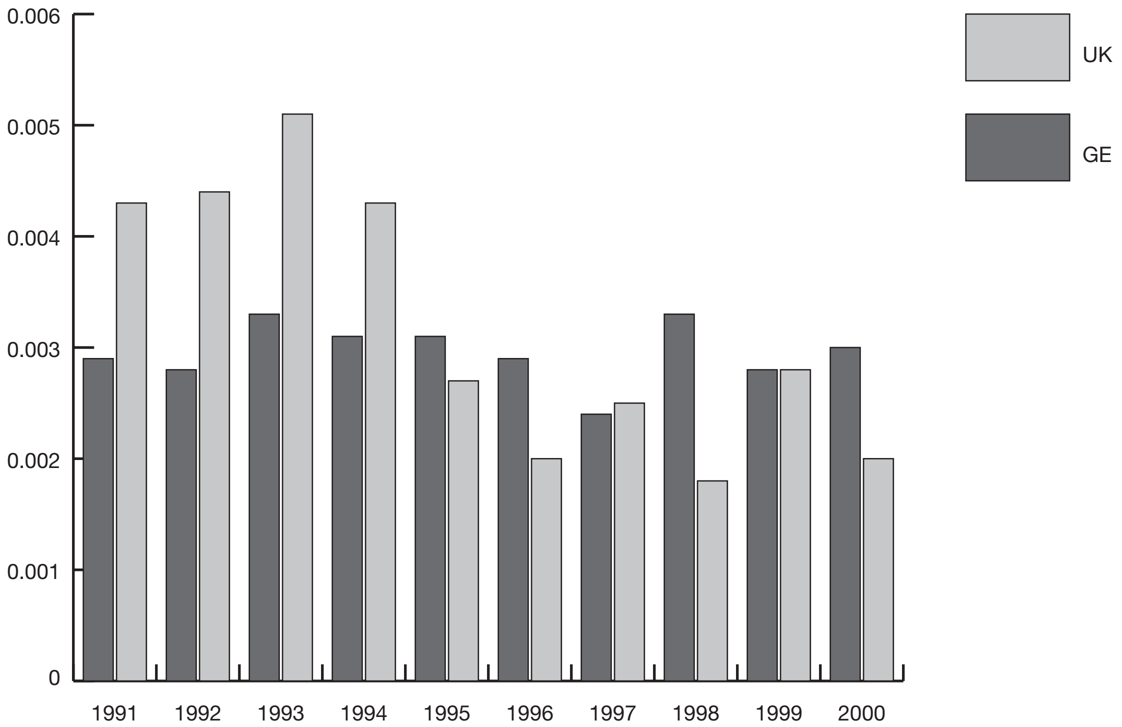

Figure A7
R&D intensity – Other Manufacturing, Recycling

Table A1
Summary statistics of the determinants of R&D expenditure in Food

	Mean	St Dev	Min	Max		Mean	St Dev	Min	Max
Germany					**Britain**				
F_ratio	0.001	0.001	0.000	0.004	F_ratio	0.285	0.080	0.162	0.380
G_ratio	0.013	0.007	0.005	0.030	G_ratio	0.008	0.003	0.005	0.014
SE_ratio	8.658	1.209	6.917	10.226	SE_ratio	3.929	0.507	3.482	5.253
Mpen	14.504	1.069	12.534	15.819	Mpen	16.433	1.537	14.418	19.210

Table A2
Summary statistics of the determinants of R&D expenditure in Pulp, Paper and Publishing

	Mean	St Dev	Min	Max		Mean	St Dev	Min	Max
Germany					**Britain**				
F_ratio	0.004	0.005	0.000	0.018	F_ratio	0.300	0.091	0.212	0.477
G_ratio	0.039	0.009	0.019	0.054	G_ratio	0.012	0.013	0.000	0.030
SE_ratio	3.071	0.510	2.146	3.665	SE_ratio	0.185	0.584	0.000	1.847
Mpen	23.475	1.732	20.049	26.703	Mpen	17.797	1.202	16.133	20.253

Table A3
Summary statistics of the determinants of R&D expenditure in Other non-Metallic Minerals

	Mean	St Dev	Min	Max		Mean	St Dev	Min	Max
Germany					**Britain**				
F_ratio	0.035	0.009	0.015	0.045	F_ratio	0.139	0.041	0.085	0.214
G_ratio	0.040	0.010	0.025	0.060	G_ratio	0.021	0.010	0.000	0.036
SE_ratio	10.610	1.299	7.509	11.902	SE_ratio	4.011	3.455	0.000	6.897
Mpen	15.096	1.215	13.175	16.881	Mpen	15.355	1.166	13.494	17.066

Table A4
Summary statistics of the determinants of R&D expenditure in Metals

	Mean	St Dev	Min	Max		Mean	St Dev	Min	Max
Germany					**Britain**				
F_ratio	0.005	0.004	0.003	0.016	F_ratio	0.275	0.072	0.145	0.399
G_ratio	0.004	0.001	0.002	0.005	G_ratio	0.051	0.025	0.020	0.097
SE_ratio	4.200	0.331	3.599	4.678	SE_ratio	3.605	0.850	1.957	5.502
Mpen	22.155	1.994	18.851	26.614	Mpen	24.563	1.473	22.364	26.357

Table A5
Summary statistics of the determinants of R&D expenditure in Other Machinery and Equipment

	Mean	St Dev	Min	Max		Mean	St Dev	Min	Max
Germany					**Britain**				
F_ratio	0.009	0.004	0.004	0.014	F_ratio	0.234	0.025	0.209	0.287
G_ratio	0.028	0.004	0.021	0.038	G_ratio	0.243	0.068	0.148	0.350
SE_ratio	37.056	3.180	31.755	40.592	SE_ratio	15.428	2.464	11.935	19.832
Mpen	23.324	2.265	19.270	27.409	Mpen	44.277	2.520	40.111	47.219

Table A6
Summary statistics of the determinants of R&D expenditure in Electrical Machinery and Equipment

	Mean	St Dev	Min	Max		Mean	St Dev	Min	Max
Germany					**Britain**				
F_ratio	0.040	0.017	0.016	0.071	F_ratio	0.316	0.040	0.231	0.377
G_ratio	0.038	0.003	0.033	0.043	G_ratio	0.164	0.015	0.129	0.181
SE_ratio	82.009	7.289	67.211	93.202	SE_ratio	38.205	3.511	32.743	44.455
Mpen	41.259	4.853	34.355	47.784	Mpen	61.151	6.806	50.254	68.229

Table A7
Summary statistics of the determinants of R&D expenditure in Other Manufacturing

	Mean	St Dev	Min	Max		Mean	St Dev	Min	Max
Germany					**Britain**				
F_ratio	2.914	0.679	1.910	4.476	F_ratio	0.194	0.083	0.103	0.357
G_ratio	8.905	1.632	6.542	12.690	G_ratio	0.021	0.028	0.000	0.067
SE_ratio	77.051	17.281	53.840	90.657	SE_ratio	0.412	1.301	0.000	4.115
Mpen	29.400	2.012	25.258	31.266	Mpen	34.835	2.900	29.435	37.793