What Determines Industrial R&D Expenditure in the UK?

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Abstract

The purpose of this paper is to try and identify some of the factors behind the comparatively poor R&D performance of the UK in the 1990s, a decade when R&D intensity in the business sector declined consistently. We estimate an econometric model of R&D expenditure using a panel of UK manufacturing industries. Our results highlight the importance of industry characteristics such as sales and profitability, product market competition, macroeconomic factors such as real long-term interest rates and the real effective exchange rate, skilled labour, and the composition of R&D expenditure and funding. A rise in either the share of R&D funded by the government or the share of R&D undertaken by foreign firms is found to have a significant positive impact on the aggregate level of R&D expenditure.

JEL classification: F2, H3, L6, O3

Keywords: R&D, Manufacturing, Product market competition, Panel data

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I. Introduction

The importance of technological change for a country's long-run rate of economic growth has received increasing attention from researchers and policymakers over the past decade. A key determinant of technological change is knowledge accumulation through expenditure on research and development. 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 at an aggregated as well as at a disaggregated level, both within and across countries.[1] In recent work undertaken at the OECD Guellec and van Pottelsberghe (2001) find that a 1 per cent rise in the business sector R&D stock generates a 0.13 per cent rise in the growth of multi-factor productivity.

Recognition of the potential importance of R&D for long-run growth and living standards has been reflected in government policies. If innovators are unable to appropriate the full benefits of their innovations, then the amount of R&D may be lower than socially optimal, since the private rate of return will be lower than the social rate of return.[2] In the UK, the current government has introduced an R&D tax credit, with effect from the 2002 fiscal year. Before then direct government support for business R&D had been primarily limited to the provision of funds to finance some R&D activities in private industry.[3]

Despite the renewed importance now attached to R&D, relatively little is known about the determinants of R&D expenditures at an industry or economy-wide level, either in the UK or in most of the other major industrialised economies. This matters because R&D intensity declined in the UK during most of the 1990s, both in the economy as a whole as well as in the business sector. The objective of this paper is to provide some empirical evidence that might help to explain why R&D expenditures were relatively weak during the 1990s. We focus on developments in a panel of 11 manufacturing industries, since the majority of

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[1] See, for instance, Arrow (1962), Romer (1986, 1990), Grossman and Helpman (1989) and Barro and Sala-i-Martin (1995) for the theoretical arguments. Lichtenberg and Siegel (1991), Coe and Helpman (1995), Coe *et al* (1997) and Griliches (1988, 1991, 1998) provide relevant empirical evidence.

[2] See, for instance, Griliches (1979, 1991) and Nadiri (1993).

[3] For a discussion of some of the issues in the design and implementation of an R&D tax credit in the UK see Bloom *et al* (2001).

business sector expenditure on R&D occurs in the manufacturing sector.[4]

In our empirical analysis we attempt to build on previous work undertaken on the determinants of R&D expenditure, most of which has utilised firm level data, drawing on the findings from a detailed survey of the existing literature. Although there are a small number of surveys on topics such as the impact of firm characteristics and market structure on R&D and on the influence of R&D tax credits, to our knowledge a general survey drawing together the full range of potential determinants identified in the existing literature does not exist.

There are five main types of determinants which we identify both in the existing literature and in our empirical analysis. These can be broadly categorised as specific firm/industry characteristics, product market competition, public policies, endowment and location, plus a residual category that includes spillovers from other sectors and support by foreign funds. Our empirical work finds support for many of these factors, with industry characteristics such as sales and profitability, product market competition, skilled labour employed on R&D, government funding and the growing influence of foreign-owned firms all having some significant effects on aggregate expenditure. We also identify two macroeconomic factors which appear to affect all industries over time, the real long-term rate of interest and the real effective exchange rate. A principal components analysis of the variation in R&D spending between industries suggests that there may be significant differences between the factors determining investment in R&D in high- versus low-tech industries.

The paper is organised as follows. The next section discusses some methodological issues related to the existing empirical work. In section III, we summarise the main evidence from the surveyed literature, differentiating between our categories. In the following two sections we outline our empirical model and data set and describe the preliminary econometric results. A brief conclusion is provided in Section VI.

[4] In a cross-country study, Van Reenen (1997) examines why the UK experienced slower growth in aggregate R&D intensity than other major industrialised countries over the period 1974-1992, noting that the UK was the only G7 country whose aggregate R&D intensity stagnated in the 1980s. His results suggest that the reason for this pattern is mainly to be found in the comparative performance of the manufacturing sector.

Methodological Issues

In this section, we give a brief summary of some econometric issues that arise in estimating models of R&D expenditure and the ways they are dealt with in the existing literature.

The majority of the studies surveyed in this paper focus either on R&D expenditures or on R&D intensity, defined as the ratio of expenditure to output. These provide one possible way of measuring the innovative activity of a firm or industry.[5] But it is important to bear in mind that an increase in spending on R&D does not necessarily imply an increase in firms' innovative output and/or efficiency, as R&D expenditures are an input into the innovation process, not an output.[6] Moreover the level of R&D expenditure may be especially difficult to measure accurately. Firms are given considerable latitude in what they choose to classify as R&D, and the definitions used in particular data sets may differ from one another.[7]

Many of the studies we survey, and the model we employ in estimation, take the following form:

$$R_{it} = \alpha_i + \beta_i X_{it} + \delta_i D_{it} + e_{it} \qquad [1]$$

where R&D expenditures in firm/industry *i* at time *t*, denoted R_{it}, are modelled as a function of firm/industry fixed effects (α_i),[8] a vector of control variables X_{it} and a vector of dummy variables D_{it}. The latter can be used to examine the effect of a tax credit ($D_{it} = 1$ when a credit is in place, 0 otherwise) or to discriminate between firms according to whether they are in a joint venture or not, although such an approach lacks precision as it cannot reflect the actual magnitude of the tax credit available to different firms, or of the intensity of cooperation in a joint venture. Time dummies can also be included in [1] to control for omitted variables whose impact varies over time but not across members of the panel.

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[5] A positive correlation between R&D inputs and innovative activity is found by, e.g., Acs and Audretsch (1988).

[6] Patent or innovation counts are often employed as measures of innovative output. While they do measure output rather than input, they both have the problem that the economic value of different patents and innovations is highly heterogeneous. Also, the variation in the propensity to patent varies considerably across industries and countries. Moreover, even a high output of patents does not necessarily imply a high level of innovation as some patents may never be implemented.

[7] Cohen amd Mowery (1984), for instance, found that for the same US firms and years, Standard and Poor's Compustat data reported an average of 12 per cent more R&D than the Federal Trade Commissions's Line of Business Program data, the difference resulting from the definitions used.

[8] Many studies estimate the first difference of [1], thereby removing the firm specific fixed effects.

Regression results may also be subject to endogeneity or simultaneity bias as well as variable measurement error, all of which can be controlled for by using instrumental variables. Busom (2000) emphasises that public funding may be endogenous, as the success of an application for funding depends on the characteristics of the firm and the application. Firm characteristics such as debt, profits and sales, are also under control of the firm and may be determined simultaneously with its R&D investment choice.

Use of lagged R&D in [1] would also require an IV estimator in order to avoid the downward bias that can result when using a fixed effects estimator (Nickell, 1981). Lagged expenditures are likely to be required because of the existence of adjustment costs.[9] Bond *et al* (1999), Guellec and Ioannidis (1997) and Guellec and van Pottelsberghe (1997) use an error correction model which explicitly differentiates between short-run and long-run properties. We adopt a similar approach in this paper.

II. The Existing Literature

In this section, we present the main evidence from the surveyed literature, differentiating between five separate categories of determinants. We draw on the results from the survey in Becker and Pain (2001).

III.1. Characteristics of the Firm or Industry

The two principal firm characteristics identified in the literature are internal finance and sales.[10] In particular, cash-flow has been found to matter in many firm-level studies. It is commonly argued that given capital market imperfections, firms are not able to attract (sufficient) external funds to finance investment in R&D. Being thus financially constrained, they have to rely on internal funds. The theoretical argument that internal finance should be an important determinant of R&D expenditures is long-standing, going back at least to Schumpeter's (1939, 1942) analysis on the evolutionary dynamics of economic systems. However, the results of empirical studies examining the impact of internal finance on R&D

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[9] For empirical evidence, see Bernstein and Nadiri (1986), Hall *et al* (1986) and Himmelberg and Petersen (1994). Theory suggests that adjustment costs are important because of the high cost of temporary hiring and firing of highly qualified labour with firm-specific knowledge, and because a sustained commitment to R&D is often required for projects to be successful. Hall (1993) reports that at least 50 per cent of R&D budgets typically consist of the salaries of professional scientists and engineers.

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

have been less clear cut. For instance, the survey by Kamien and Schwartz (1982) concludes that empirical evidence of a significant influence appears weak, whereas most of the studies surveyed by Cohen (1995) point to a positive relationship.

These differences can also be found in more recent studies. A robust, significant positive impact is found for the US by Hall (1992) for cash flow measured gross of R&D expenses and by Hall *et al* (1999) for the US and France. However Bhagat and Welch (1995) do not find such an effect from lagged operating cash flow for the US, although they do suggest that it has a positive and significant impact for large firms in the UK. For Canada, the relevant coefficient indicates a robust, significantly negative (rather than positive) impact of cash flow lagged by two periods. In a multi-country study, Bond *et al* (1999) find that cash flow does not have a significant impact on R&D expenditures by UK and German firms, although it does affect the likelihood of whether firms will undertake any R&D at all.[11]

Himmelberg and Petersen (1994) obtain a robust, positive impact from cash flow on small high-technology manufacturing firms, although the magnitude of the effect depends on the specification used. They argue that a conventional within-firm estimator is downward biased as it does not distinguish between permanent movements of cash flow and transitory shocks; firms may be less likely to respond significantly to the latter due to the high adjustment costs of R&D. Controlling for this effect, they find a large elasticity of R&D expenditures to cash flow.

Alternative measures of financial constraints can also be used. Bougheas *et al* (2001) use the lagged ratio of net profits to capital rather than cash flow as a measure of liquidity and obtain a significant positive effect, thereby supporting the evidence for internal finance being an important determinant of expenditure in R&D. They also find a positive influence from the lagged ratio of sales to capital, which they argue is a proxy for expectations regarding future revenues.[12]

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[11] Contrary to Hall (1992), this result is independent of whether cash flow is measured as net or as gross of R&D expenses.

[12] Their dataset allows for differentiation between R&D financed by each firm itself and R&D financed by other firms or via government grants, enabling them to exclude the latter two from the dataset. They note that this may help to avoid any bias in the estimated impact of different methods of financing, as external (to the firm) funding may allow a firm to incur high levels of investment in R&D even when the firm itself is liquidity constrained.

Some studies also look for wider balance sheet effects. The existing evidence largely indicates that the outstanding stock of debt of the firm does not have a significant influence on R&D expenditures. However Bond *et al* (1999) find that a higher debt-to-capital ratio does seem to prevent UK firms which do not currently invest in R&D from doing so in the next period. Baghat and Welch (1995) also include lagged tax payments and stock returns in their regressions, but a significant relationship robust to the choice of specification appears to exist only for large UK firms.[13]

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 either by sales or by market power.[14] 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 significant positive impact on R&D expenditures. The magnitude of the cash-flow and sales effects varies across studies and may be sensitive to the other controls included in the model. Cash-flow is for instance highly procyclical, so some studies which fail to include cash-flow may instead find stronger pro-cyclical effects from sales growth.

A third, related, firm or industry level characteristic which has been shown to matter is the level of union representation (Menezes-Filho *et al*, 1998). Until recently, the majority of the empirical literature had pointed to a negative relationship between measures of union representation and innovative activity. One possible explanation for this might be that strong trade unions affect the level of real wages, and hence both the rents available from past investments to finance future investment, either in fixed capital or in R&D, as well as the expected future level of rents. Using firm and plant level data for the UK, Menezes-Filho *et al* (1998) show that there is indeed a negative bivariate correlation between R&D intensity and union density, primarily because union density is high in those industries with a low R&D intensity. However, adding controls for other firm and industry characteristics results in an insignificant positive coefficient being obtained on union density.

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[13] Other studies of interest are Jensen and Johnson (1995), who report a decrease in a firm's spending on R&D in response to a dividend drop, and Czarnitzki and Kraft (2000), whose results indicate higher innovative activity by firms with limited liability.

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

III.2. Product Market Competition

Product market competition may have two distinct effects on R&D expenditures. For incumbent firms, especially ones with a degree of market power, greater competition might reduce 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 counter increased competition in order to defend their market share. R&D rivalry in this context has been analysed in models from both the trade and the industrial organisation literature.[15]

The relationship between product market competition and innovation in the UK is investigated by Blundell *et al* (1999) using a panel of manufacturing firms for 1972-82 and a count of innovations from the Science Policy Research Unit. They find that whilst it is the firms with larger market share who are most likely to innovate, the overall effect of competition on the aggregate number of industry innovations is positive. Competition is measured by import penetration and the industry concentration ratio. The implication of these results is that a combination of policies to promote market competition and safeguard the rights of innovators may prove more efficacious than simply seeking to limit the degree of competition faced by incumbent firms who have been important sources of innovations in the past.[16] The results by Symeonidis (2000a) draw a different picture of the impact of competition, however.[17] They show no evidence of a positive effect of increased (price) competition on advertising or R&D expenditure, but rather some (non-robust) evidence of a negative effect.

In this context, it is interesting to differentiate between the effects that increased competition may have on high-tech versus low-tech industrial R&D spending. Investment in product-related R&D may be lower in low-tech than in high-tech industries due to a higher degree of product standardisation 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 undertake innovation themselves. Zietz and Fayissa (1992) find that more intense import competition, approximated by an appreciation of the real effective exchange rate, tends to raise R&D

[15] See, for example, Caves (1995) for a survey, or Clemenz (1990).

[16] It is worth noting that cash flow was insignificant and therefore eliminated from their preferred specification.

[17] Similar conclusions are derived from the analysis in Symeonidis (2000b).

expenditures in high-tech but not in low-tech US industries.[18] This result also holds for domestic competition as proxied by unit labour costs, where the magnitude to the effect tends to be higher than regarding international competition. Zietz and Fayissa (1994) confirm these results. Moreover, they find a positive effect for an all-firms sample, which is driven by the positive high-tech effect outweighing the insignificant low-tech effect.[19]

In contrast, Scherer and Huh (1992) suggest that domestic firms respond to higher competition from abroad in their domestic markets by cutting back their spending on R&D, although their results are not particularly well determined. Competition in foreign markets may however stimulate R&D, with the ratio of net exports to output having a significant positive effect.

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

III.3. Public Policies

Market failures 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 on their innovations, then expenditure on R&D could be lower than socially optimal. Equally, if firms experience significant external financial constraints, with agency costs limiting the funds available from external investors, then expenditure may again be lower than optimal, especially by smaller firms.

Two policy tools available to governments are to provide favourable tax treatment for those firms undertaking R&D or to directly subsidise private R&D projects. While the former is a more market-oriented approach, leaving decisions on the level and timing of expenditure to the private sector, there is mixed evidence on its effectiveness.[20] Governments may also

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[18] They use the observed ratio of R&D expenditures to sales revenue to classify industries as low-tech or high-tech.

[19] In earlier studies, Marin (1985) and Zimmermann (1987) also found that increased foreign competition is counteracted by domestic industries through higher investment in R&D, using samples of Austrian manufacturing and German business firms, respectively.

[20] Although a large number of studies support the view that tax credits are effective, there is also evidence to the contraryas well. Studies obtaining a positive effect include Hall (1993) and Hines (1993) for the US. Bernstein (1986) provides mixed evidence with respect to Canada. Of course, even if effective, any judgment as to the desirability of a tax credit would need to be based on a cost-benefit analysis that included deadweight costs and

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

Hall and van Reenen (2000) provide a recent survey of the evidence. Their overall conclusion from the large amount of existing firm level studies is that tax credits have a significant positive effect on expenditure, although there is considerable variation in the findings of different studies. The consensus view of the own-price elasticity of R&D appears to have risen over time, with earlier summaries by Mansfield (1986) and the US General Accounting Office (1996) suggesting smaller effects.[21] In a cross-country study, Bloom *et al* (2002) find a long-run elasticity of close to 1 for the impact of the user cost on R&D expenditure.

Mamuneas and Nadiri (1996), using US data, suggest that publicly financed R&D may crowd out private R&D, particularly in low-tech industries. However, differentiating between publicly financed R&D performed within and outside an industry, they found the former to be a complement to, rather than a substitute for, privately financed R&D in the low-tech sector. Busom (2000), using a panel of Spanish firms, found that full crowding-out could not be ruled out for 30 per cent of the firms participating in a subsidised R&D programme. Lach (2000), however, concludes that there is no crowding-out of Israelian private R&D in the long-run, and a similar conclusion is reached by the multi-country studies by Guellec and van Pottelsberghe (1997) as well as Guellec and Ioannidis (1997).[22]

Czarnitzki and Fier (2001) extend the existing literature by examining the effects of R&D subsidies on R&D spending within the service sector. Their results indicate that 1 D-Mark of additional R&D subsidy generates a DM 1.37 increase in privately funded R&D in the next period. Hence they suggest that the benefits of a subsidy to the service sector outweigh the costs and that there is no crowding-out effect.

Guellec and van Pottelsberghe (1997) find a contrary time pattern for the effects of tax credits and direct subsidies in a multi-country study. Tax credits have a significant effect on expenditure in the short-run, but not the long-run, whereas subsidies have a positive effect on

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the relabelling of activities as R&D within corporate accounts (Eisner *et al*, 1984). For a detailed microeconomic evaluation of the effects of a tax credit see Klette *et al* (2000).

[21] In a direct comparison of different studies, the latter also concludes that the consensus range with respect to the US was lower in 1989 than it was by 1996, suggesting a gradual upward movement of the range.

expenditure in the long-run, but not the short-run. Subsidisation rates of 11-19% are estimated to have the strongest effects. Rates above 30% are found to be associated with the substitution of public funds for private funds. Guellec and Ioannidis (1997) provide related results, and suggest that in the UK, reductions in government funding in the 1990s provide an important part of the explanation for the comparatively weak level of business sector R&D.

With respect to the potential importance of international tax differences, Hines (1994) concludes for the US that, contrary to expectations, US multinational firms did not significantly increase the share of R&D performed abroad in response to the US Tax Reform Act of 1986, which reduced the previously 100 per cent tax deductions claimable for R&D expenses incurred within the US.

Whilst the evidence regarding the effectiveness of public policies on R&D remains mixed, on balance it would seem to indicate that public policies can have important effects. Recent studies suggests a negative demand elasticity of R&D with respect to its own tax price of around unity, at least in countries with a tax credit, and a positive one of around 0.2 with respect to direct subsidies. However there is some evidence that high levels of subsidies may crowd out private expenditure, and foreign tax competition may become increasingly important as impediments to capital mobility come down.

III.4. Endowment and Location

A growing body of evidence indicates that the endowment of a firm, for instance in terms of highly qualified human capital, the ability to locate near universities or research centres, and membership in research joint ventures or co-operations[23] may affect the pattern of R&D across countries and regions.

Early evidence regarding the importance of geographic proximity to universities was provided by Nelson (1986) who found that university research fostered innovation in industries related to biological sciences. Jaffe (1989) found a large significant positive effect of university research on industry R&D spending within-States. Jaffe (1989), Acs *et al*

[22] Earlier evidence does not arrive at a consensus, either. See, for instance, Levin and Reiss (1984) for a positive effect with respect to the US and Norway and Lichtenberg (1984, 1987, 1988) for a crowding-out effect in the US. Other relevant studies include Dagenais *et al* (1998), Bernstein (1986) and Hines (1993).

[23] For theoretical literature on the impact of joint ventures and cooperation on R&D spending see, for example, Tirole (1988), Kamien *et al* (1992), or Dixit (1985) for an analysis within the framework of international competition.

(1992) and Jaffe *et al* (1993) all provide evidence that knowledge spillovers from university research to private innovation, as measured by the number of patents or recorded innovations, increases with geographic proximity. The former two studies observe differences in the effects of university spillovers across industry groups. Jaffe (1989), for example, finds a more significant and somewhat larger effect within technical industries such as drugs and chemicals than in the total across industries.

More recently, Adams *et al* (2001) have found that the development of US Industry-University Co-operative Research Centres has fostered knowledge spillovers between member firms and universities. In related work Adams *et al* (2000) suggest that co-operation between federal laboratories and firms has a positive impact on private R&D expenditures. In contrast, Irwin and Klenow (1996) found that amongst firms who participated in Sematech, a joint R&D consortium of US semiconductor producers, there was a drop in the total level of R&D expenditure. They interpret this as supporting the 'sharing' hypothesis, with information flows reducing duplicative R&D, allowing members to spend less on R&D than before.

The existing evidence is suggestive of positive effects from endowment and location on private R&D expenditures. However rather little research has been conducted in this area so far outside the United States, so it remains to be seen how robust the results are.

III.5. Other Determinants of R&D Expenditures

The determinants of R&D expenditures discussed above cover the major variables of influence identified in the existing literature. However, there are other factors examined less frequently, such as the issue of whether there are (positive or negative) externality effects.

A small number of papers attempt to examine the impact of the presence of foreign-owned multinational firms on the R&D intensity of domestic firms. Veugelers and Vanden Houte (1990) note that increased competition may spur domestic firms' innovative activity, possibly helped by potential knowledge spillovers from foreign firms. Equally, however, it may reduce profitability by reducing the scale of production in domestic firms and hence reduce R&D expenditure. The authors' empirical analysis indicates a significant, negative impact of competition from multinational firms on local firms' R&D activities in Belgium.

Driffield (2001) examines the relationship between R&D expenditures by foreign-owned firms in the UK and R&D expenditures by UK-owned firms at the industry level. His results point to intra-industry crowding-out from foreign R&D. Inter-industry spillover effects appear to be insignificant. Industry characteristics, such as the elasticity of demand, as proxied by the advertising intensity, and the availability of funds, proxied by profits, are found to have significant positive effects.

Jaffe (1988) assesses the relative importance of the 'pull' of market conditions versus the 'push' of exogenous technological conditions. Both are found to have a significant positive effect on firm level R&D. Specifically, R&D spillovers from the pool of all other firms encourage R&D, suggesting own and other firms' R&D to be complements, although there is no evidence for significant spillovers from the R&D of firms within the same cluster of technology.

III. The Model

In our econometric analysis, R&D expenditures at the industry level are modelled using indicators of industry level output, product market competition, as measured by import penetration, government and foreign funding, skilled labour endowments and a number of different proxies for financial conditions.

The basic model we estimate can be expressed as:

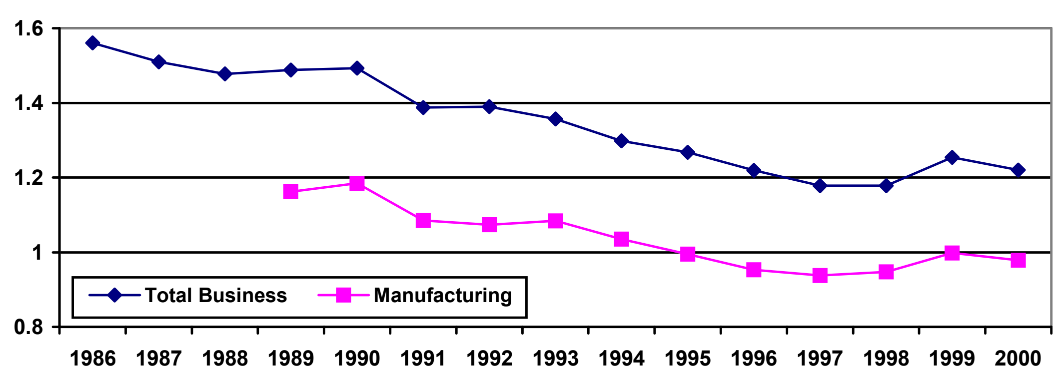
$$\Delta\ln(R_{it}) = a_i + \beta_1\,\Delta\ln(Y_{it}) + \beta_2\ln(R_{i,t-1}) + \beta_3\ln(Y_{i,t-1}) + \beta_4 G_{i,t-1} + \beta_5 F_{i,t-1} + \beta_6\ln(IM_{i,t-1}) + \beta_7\,SE_{i,t-1} + \Sigma\,\gamma_j\,Z_t + \varepsilon_{it} \qquad [2]$$

where R_{it} denotes the volume of R&D expenditure in industry *i* at time *t*, Y is market size as given by value-added output in the industry, G is the proportion of R&D undertaken by businesses and funded by government, F is the proportion of R&D undertaken by foreign-owned firms, IM is import penetration, measured as the ratio of imports to total home sales, SE is a measure of the number of scientists and engineers in the industry, relative to total industry employment, and Z is a vector of additional variables to control for other influences such as financial conditions and macroeconomic policies. The industry-specific fixed effects (a_i) allow for unobserved influences that remain constant over the whole of the sample period. All other influences will be contained in the disturbance term ε_{it}. The inclusion of a lagged dependent variable will induce small sample bias into panel estimates produced using OLS (Nickell, 1981), so that an instrumental variable estimator has to be employed. There are a number of potential instruments that can be used for the lagged dependent variable. In this paper we employ the rank order of the lagged dependent variable (Durbin, 1954) and the second lag of R&D expenditure. The rank order is clearly strongly correlated with the variable being instrumented, but has been 'cleaned' of the lagged disturbance term.

The nominal flow of R&D expenditure is deflated by the industry-specific value-added price deflator to translate it into constant prices. The alternative approach, of deflating using the GDP deflator, was found to generate inconsistent results, because of differences in the deflators for R&D and industry output.

Chart 1 shows total business sector R&D and manufacturing R&D expressed as a share of UK GDP at market prices. It can be seen that for most of the 1990s there has been a general downward trend in R&D intensity, although there are some signs of greater stability at the very end of the decade. The overall downturn in the business sector stems primarily from developments within manufacturing which continues to account for around three-quarters of all business sector R&D.

Chart 1. UK R&D Intensity (%)



The following three charts help to illustrate why difficulties can arise in an empirical analysis if industry-specific output at constant prices is used as a determinant in a model in which industry-specific R&D expenditures are deflated by the GDP deflator, as in the conventional presentation of R&D intensity. We compare UK R&D intensity in the business and in the manufacturing sector as well as in each of the 11 broad industry groups using both UK GDP and sector-specific output as the base measure. Chart 2 shows that for the business sector as a whole the choice of the base measure makes relatively little difference to observed trends over time. In contrast, it matters rather more for the manufacturing sector, as Chart 3 shows. The relatively weak performance of manufacturing in the late 1990s means that the upturn in R&D expenditures at that time appears much more pronounced once expressed as a share of manufacturing output than when expressed as a share of GDP. Chart 4 shows that the gap is particularly large for the chemicals and transport equipment sectors – two of the most important R&D sectors within manufacturing.[24]

Chart 2. UK Business Sector R&D Intensity - Difference Between Using UK GDP and Sector-Specific Output as the Base Measure (%)

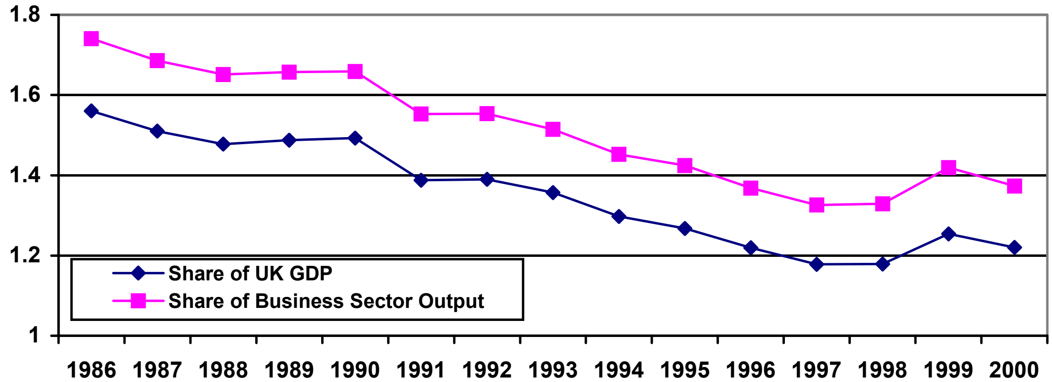
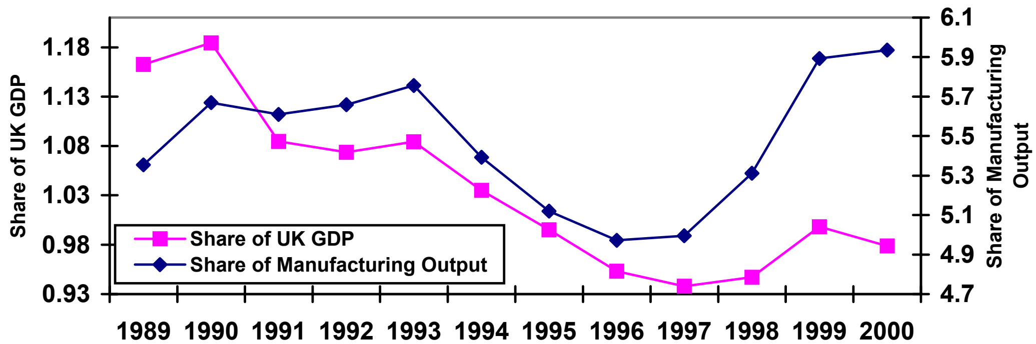
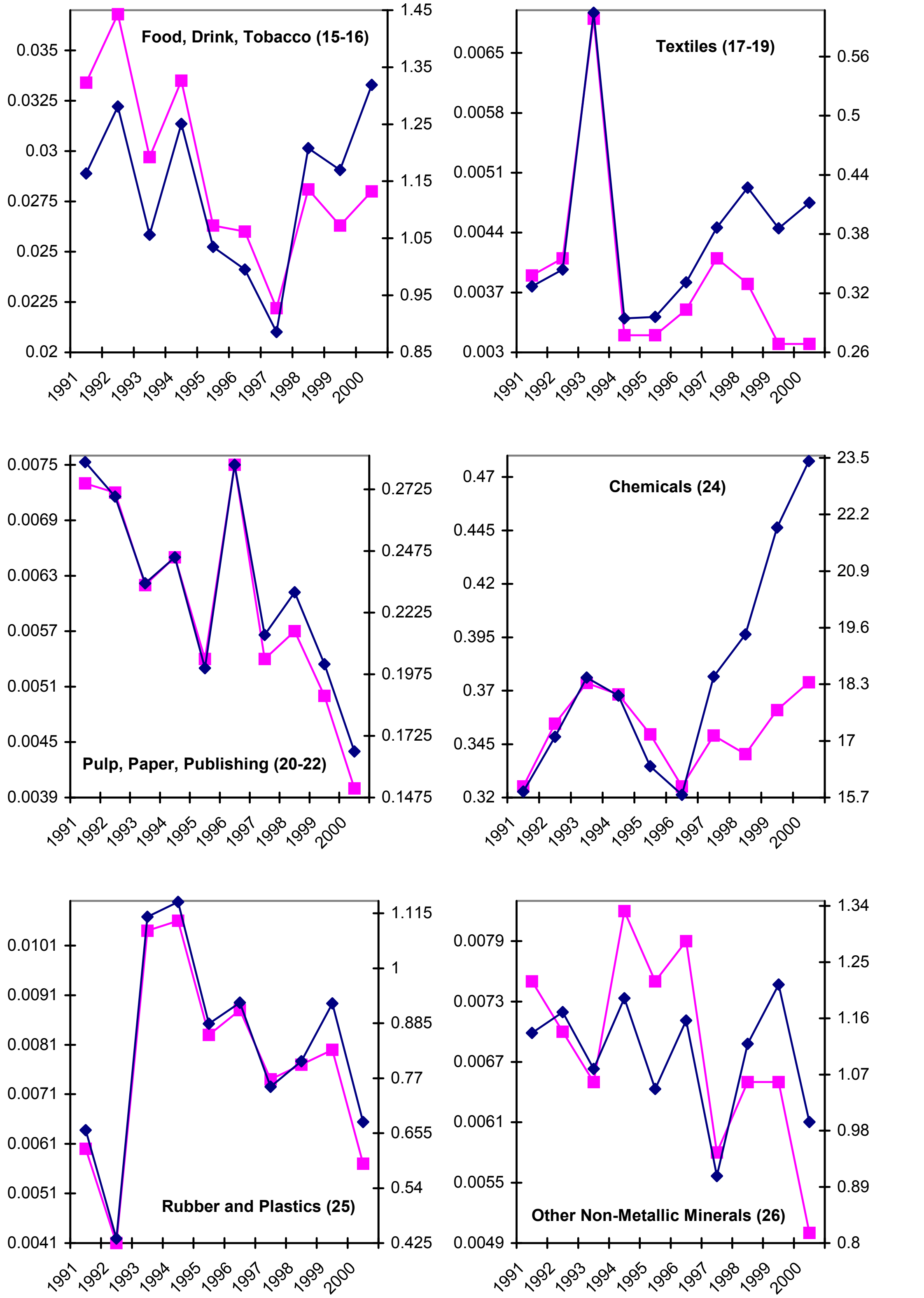


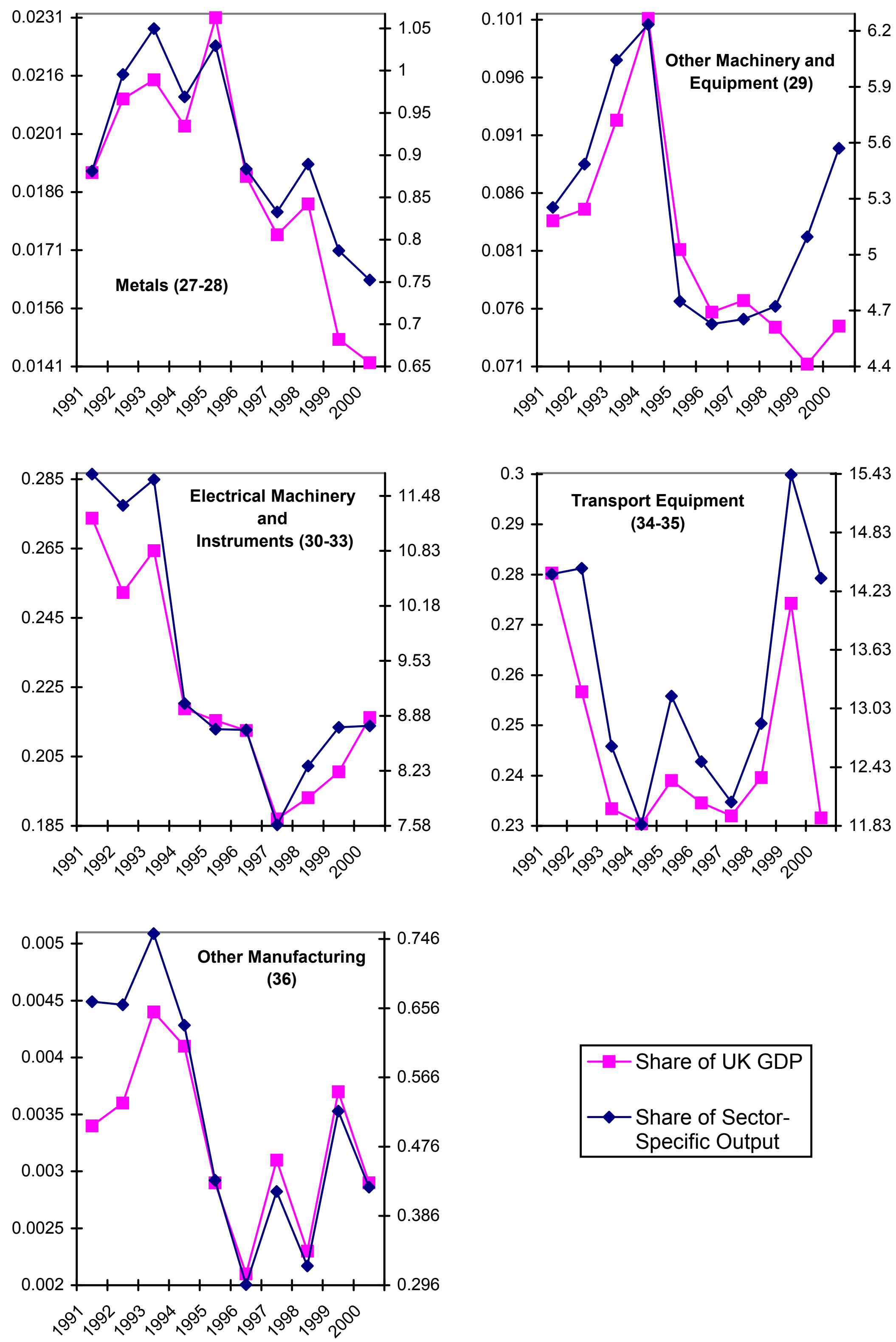
Chart 3. UK Manufacturing R&D Intensity - Difference Between Using UK GDP and Sector-Specific Output as the Base Measure (%)



[24] For ease of exposition, in charts 3 and 4 the two axes show approximately the same per cent increase from the minimum to the maximum of the scale per graph.

Chart 4. UK R&D Intensity in 11 Broad Manufacturing Product Groups - Difference Between Using UK GDP and Sector-Specific Output as the Base Measure (%)




Metals (27-28)
0.0231
0.0216
0.0201
0.0186
0.0171
0.0156
0.0141
1.05
1
0.95
0.9
0.85
0.8
0.75
0.7
0.65
Other Machinery and Equipment (29)
0.101
0.096
0.091
0.086
0.081
0.076
0.071
6.2
5.9
5.6
5.3
5
4.7
4.4
Electrical Machinery and Instruments (30-33)
0.285
0.265
0.245
0.225
0.205
0.185
11.48
10.83
10.18
9.53
8.88
8.23
7.58
Transport Equipment (34-35)
0.3
0.29
0.28
0.27
0.26
0.25
0.24
0.23
15.43
14.83
14.23
13.63
13.03
12.43
11.83
Other Manufacturing (36)
0.005
0.0045
0.004
0.0035
0.003
0.0025
0.002
0.746
0.656
0.566
0.476
0.386
0.296
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
Share of UK GDP
Share of Sector-Specific Output

In the empirical work we use an industry sample for 1993-2000. This relatively short time frame reflects the difficulties in constructing consistent data series for industry-level R&D when the standard industrial classification has changed over time. Detailed surveys of R&D were also undertaken only on a triennial basis prior to the early 1990s, limiting the amount of detailed information available. We split manufacturing R&D into the 11 broad product groups shown in Table 1 and Chart 4. The only divisions excluded completely from the manufacturing sector are division 23, refined petroleum products and nuclear fuels and division 37, recycling. Three of the 11 groups are relatively R&D intensive – chemicals, electrical machinery and transport.

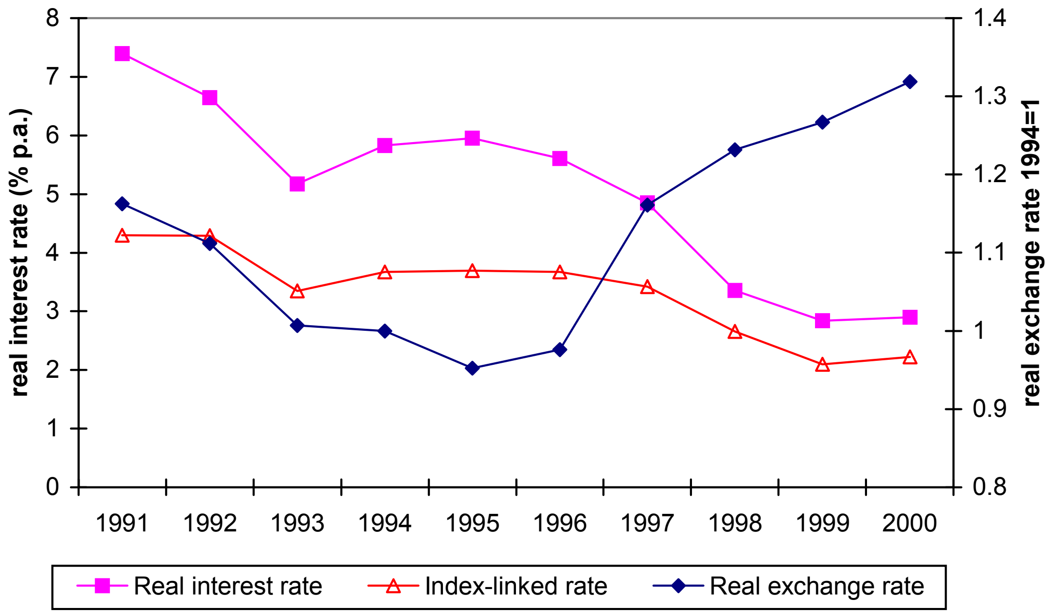
Table 1. Manufacturing Product Groups

Industry Group	SIC(92)
Food, drink and tobacco	15-16
Textiles	17-19
Pulp and paper and publishing	20-22
Chemicals	24
Rubber and Plastics	25
Other non-metallic minerals	26
Metals	27-28
Other Machinery and Equipment	29
Electrical Machinery and Instruments	30-33
Transport Equipment	34-35
Other Manufacturing	36

The variables we include in the vector **Z** are the real long-term interest rate, the UK real effective exchange rate and the real value of industry profits. Real long-term interest rates are measured using the current nominal 10 year government bond rate plus a forward-looking convolution of inflation over the next 10 years. This is equivalent to assuming that the average annual inflation rate over this period was forecast perfectly, which may be a strong assumption, although as UK price inflation has been broadly stable over the last decade it is unlikely to be totally misleading. Data on inflation expectations are partly constructed using the numbers on the January 2002 forecast base produced by NIESR for the UK economy as estimated outturns.

The profiles of the real interest rate and real exchange rate are shown in Chart 5. Real interest rates have fallen substantially since the early 1990s, primarily reflecting lower nominal rates. In contrast the real exchange rate depreciated in the first half of the decade, but has since strengthened significantly. An alternative measure of the real interest rate is provided by the average annual yield on UK index-linked government securities. We also show the yield on a 2011-dated gilt in Chart 5. It can be seen that the variance of this series is closely correlated with that of the constructed real rate.

Chart 5. UK Real Interest and Exchange Rates



The government and foreign share variables in [2] allow us to test whether the total level of R&D expenditures is higher in those industries in which a relatively higher proportion of funding is supplied by the government and a relatively higher proportion of expenditure is undertaken by foreign-owned firms. The proportions of manufacturing R&D funded by the government and undertaken by foreign-owned firms are shown in Chart 6.[25] The government funding share declined consistently up to 1997, but has since begun to recover. The foreign-owned share rose over the course of the 1990s, and by the end of the decade accounted for about a third of annual R&D expenditures.

[25] Manufacturing in this chart comprises the industries used in the regression analysis.

Chart 6. Government and Foreign Shares of R&D Funding in Manufacturing (%)

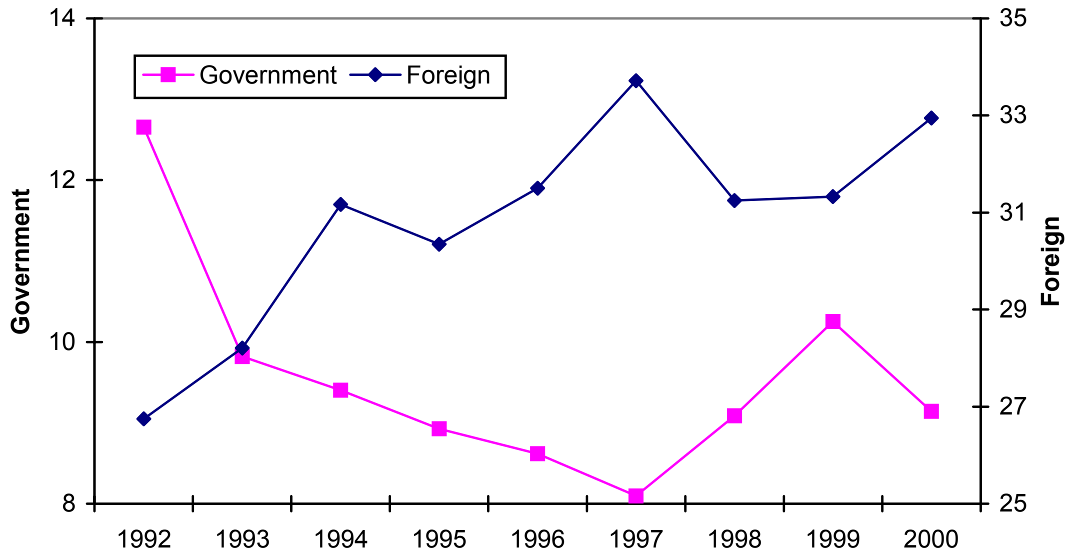
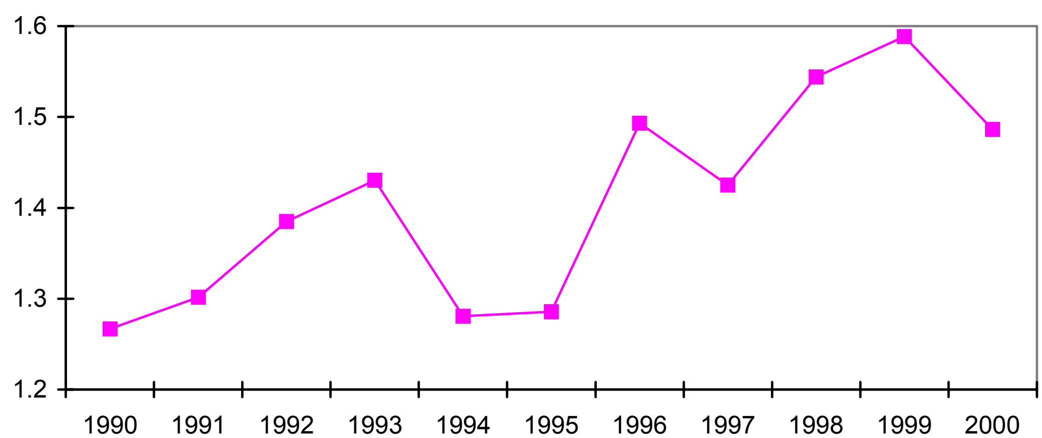


Chart 7. Share of Full-Time Equivalents Scientists and Engineers Employed on R&D in Total Employment - Manufacturing (%)



We use data on the number of scientists and engineers employed on R&D, relative to total employment, in order to approximate the potential impact of skilled labour on expenditures in R&D. As chart 7 shows for the manufacturing sector as a whole, the share of scientists and engineers showed a general upward trend throughout the 1990s. By the end of the decade it was at the highest levels since the mid-1980s. The share of scientists in total employment is relatively high, at 5-6 and 3-4 per cent, respectively, in three sectors – chemicals as well as electronics and transport equipment.

V. Empirical Results

The initial empirical results are summarised in Table 2. All the equations in this table are estimated using an IV estimator, with the lagged dependent variable and current profits being treated as endogenous. Time dummies are included in Column [C], but not in any of the other specifications.[26] Industry fixed effects are included in all equations. Taken together the results appear to be consistent with many of the firm level findings suggested by our literature survey, with consistently significant effects being obtained for output, government and foreign funding and indicators of financial pressure.

R&D is clearly procyclical in the short-term, with a 1% rise in output being associated with growth in R&D of over 1%. However the magnitude of the coefficient on the output growth term varies considerably across the four models. The inclusion of time dummies in [C] or real industry profits in [D] causes the size and significance of the coefficient on output growth to fall. This suggests that it is picking up time-varying effects common to all panel members, which is why it becomes less significant when time dummies are included, and also that it is difficult to distinguish between fluctuations in output and fluctuations in profits as the key short-term determinant of variation in R&D. This in turn probably reflects the pro-cyclical sensitivity of cash-flows. As expected, output and profits fluctuations are highly jointly significant, as suggested by a Wald chi-squared test for [D] [denoted Wald(2)=24.96].[27]

In the longer-run, other things being equal, R&D expenditure will rise in line with output. Although the point estimate of the long-run output elasticity in [A] is just 0.63%, the imposition of a unit elasticity cannot be rejected on the basis of a Wald test [Wald(1)=1.69], and imposing a unit elasticity in [B] has relatively little effect on the remaining coefficients. In [C] and [D] the output elasticity is freely estimated, but it is clearly close to unity and can readily be imposed at 1.

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[26] Time dummies are included for five of the eight years of the sample period, excluding one time dummy each for the constant term and the two macroeconomic factors that vary only across time, not across industries. Including two more time dummies instead of the two macroeconomic factors does not affect the rest of the coefficients precisely because the two macroeconomic factors pick up time-varying effects only.

[27] When including growth in profits in [A] instead of growth in output, the coefficient is significant (0.6817[2.4]). This supports the hypothesis that it is difficult to distinguish between fluctuations in output and fluctuations in profits as the key short-term, industry-specific, determinant of variation in R&D.

Government funding appears to play an important role. For instance in [A], a sustained rise of 1 percentage point in the share of business R&D expenditure funded by the government is estimated to raise the level of R&D expenditure by 1.8%. One possible explanation is that many firms experience some external financial constraints and are more able to sustain R&D efforts with more secure government funding. The decline of 4.8 percentage points in the share of manufacturing R&D financed by the government between 1992 and 1997 clearly plays an important part in the explanation of the comparatively poor R&D performance seen over the 1990s.

Table 2. Panel Data Results For Industry R&D

Dependent Variable: $\Delta\ln(R_{it})$; Sample Period 1993-2000

	[A]	[B]	[C]	[D]
$\Delta\ln(Y_{it})$	2.1790 (5.6)	2.1760 (5.3)	1.2763 (3.1)	1.2790 (1.7)
$\ln(R_{i,t-1})$	-0.6077 (7.2)	-0.5964 (7.3)	-0.6776 (8.3)	-0.6320 (6.2)
$\ln(Y_{i,t-1})$	0.3828 (2.1)	0.5964 (7.3)	0.6914 (3.2)	0.5486 (2.6)
$G_{i,t-1}$	0.0108 (2.9)	0.0121 (3.3)	0.0058 (1.9)	0.0116 (2.3)
$F_{i,t-1}$	0.0055 (3.8)	0.0057 (3.6)	0.0051 (4.2)	0.0051 (3.1)
$\ln(IM_{i,t-1})$	0.3476 (1.5)	0.2933 (1.1)	0.8623 (3.3)	0.4620 (2.0)
(Real interest rate $_t$)	-0.0839 (2.8)	-0.0811 (2.7)	0.0011 (0.0)	-0.0789 (2.6)
ln(Real exchange rate $_t$)	-0.7484 (2.3)	-0.7470 (2.3)	-0.9764 (1.2)	-0.6103 (1.8)
$\Delta\ln$ (Profits $_{it}$)				0.5280 (1.8)
No. of observations	88	88	88	88
$\overline{R}^2$	0.742	0.741	0.786	0.671
Standard Error	10.95%	10.98%	9.99%	12.43%

Notes: heteroscedastic-consistent t-statistics in parentheses. Dummy variables were included in estimation in order to account for outlying observations.

The growing share of R&D undertaken by foreign-owned companies also appears to have a significant positive impact on the aggregate level of R&D expenditures, although the magnitude of this effect is lower than that from government funding. So in column [A] for instance, a sustained rise of 1 percentage point in the share of business R&D expenditure undertaken by foreign firms is estimated to raise the level of R&D expenditure by 0.9% [100.0 * (0.0055 / 0.6077)].

There is some evidence that greater domestic market competition, as measured by the import penetration ratio, tends to have a significant positive impact on the level of R&D, although the magnitude of this effect is clearly sensitive to the specification adopted. It is possible that some of the impact of competition is also picked up by conditioning on other indicators such as output, and it is notable that the import penetration coefficient rises in [C] and [D] when the output growth coefficient is smaller.

Real long-term interest rates appear to have a large significant negative effect on the level of R&D expenditure, as might be expected for expenditure on projects with a long payback period. In column [D] for instance, a permanent rise of 1 percentage point in the real interest rate, a change which is unlikely to be observed very often, is estimated to reduce the volume of R&D expenditure by 12½%. Again this effect appears to be common to all panel members, since the real interest rate term becomes insignificant if time dummies are included in the specification.

There is also evidence of a negative impact on R&D from the level of the real exchange rate, suggesting that the sustained rise in sterling since 1996 might have adversely affected the level of R&D. However interpretation of this term is difficult. A higher real exchange rate might reduce output and raise external competition. Yet both of these effects are already included in the model by conditioning on output and import penetration. There are two other possible explanations. First fluctuations in the real exchange rate may be affecting the level of R&D undertaken by foreign-owned firms who use the UK as an export base, so that the rise in overall expenditure that would be expected when foreign firms raise their share of expenditure is delayed at times when the exchange rate is high.

Another explanation may be that the real exchange rate is picking up variations in financial pressures on companies. One way in which UK exporters have responded to the strength of sterling in recent years is to cut their profit margins on exports to almost zero. Some support for this hypothesis is provided by the results in column [D]. We were unable to reject the hypothesis of equal and opposite coefficients on current and lagged profits [Wald(1)=0.12], suggesting that it is only changes rather than the level of profits that affects the level of R&D. Although the profits growth term is significant only at the 10% level, its inclusion serves to reduce both the size and the significance of the real exchange rate term, although it does not eliminate it entirely.

Finally, our results confirm that adjustment costs matter. The lagged dependent variable is significant, indicating some persistence in the level of R&D expenditures.

In Table 3 and 4 we explore the sensitivity of our results to two extensions. The first, in Table 3, is to add a measure of skilled labour endowments, as proxied by the share of the number of scientists and engineers employed on R&D in total employment, in each industry to the four models in Table 2. This term appears to be both significant, and largely orthogonal to the other variables, although it is notable that it causes the estimated impact and significance of both the import penetration ratio and the real exchange rate to rise. An explanation may be that those industries with highly specialised human capital are better placed to use R&D as a strategic variable to counter increased competition.

The estimated long-run effects vary a little across the four specifications. A sustained rise of 1 percentage point in the ratio of the number of scientists and engineers to total employment (which for the manufacturing sector as a whole would imply an increase of almost two-thirds in the ratio) is estimated to raise the level of R&D expenditure by between 18.7% (model [D1]) and 16.9% (model [A1]). While a large part of this increase will reflect the salary paid to the new employees,[28] it also indicates the beneficial effect of highly specialised knowledge in an industry on investment in R&D.

The measure of the real interest rate we use is a generated regressor. Variables of this kind are likely to have a lower variance than the true unobserved series, and should therefore be instrumented to obtain an unbiased estimate of their standard error (Pagan, 1984). Table 4 shows the impact of re-estimating the models in Table 3 with the index-linked bond yield being used as an instrument for the constructed real interest rate. All the models are similar to those in Table 3, although the size and significance of the real interest rate term are reduced a little.

[28] See also footnote 8.

Table 3. Panel Data Results For Industry R&D Including Skilled Labour

Dependent Variable: $\Delta\ln(R_{it})$; Sample Period 1993-2000

	[A1]	[B1]	[C1]	[D1]
$\Delta\ln(Y_{it})$	2.2420 (6.2)	2.2411 (6.0)	1.3166 (3.6)	1.2800 (1.8)
$\ln(R_{it-1})$	-0.6912 (8.2)	-0.6839 (8.1)	-0.7841 (9.7)	-0.7376 (6.7)
$\ln(Y_{i,t-1})$	0.4932 (2.7)	0.6839 (8.1)	0.8465 (4.1)	0.6983 (3.1)
$G_{i,t-1}$	0.0105 (2.8)	0.0116 (3.2)	0.0049 (1.6)	0.0112 (2.3)
$F_{i,t-1}$	0.0043 (3.2)	0.0045 (3.1)	0.0036 (3.0)	0.0036 (2.3)
$\ln(IM_{it-1})$	0.3720 (1.7)	0.3250 (1.4)	0.9489 (3.6)	0.5008 (2.3)
(Real interest rate $_t$)	-0.0959 (3.4)	-0.0938 (3.4)	-0.0005 (0.0)	-0.0932 (3.4)
ln(Real exchange rate $_t$)	-1.0112 (3.4)	-1.0173 (3.4)	-1.2400 (1.9)	-0.9181 (3.0)
$SE_{i,t-1}$	0.1137 (3.1)	0.1168 (3.2)	0.1342 (3.9)	0.1378 (2.9)
$\Delta\ln$ (Profits $_{it}$)				0.5724 (2.1)
No. of observations	88	88	88	88
$\overline{R}^2$	0.759	0.759	0.810	0.683
Standard Error	10.6%	10.6%	9.4%	12.23%

Note: heteroscedastic-consistent t-statistics in parentheses. Dummy variables were included in estimation in order to account for outlying observations. The real interest rate and the real exchange rate are jointly significant at the 5% level of significance in equation [C1]. Growth in output and growth in profits are jointly significant at the 1% level in [D1].

Table 4. Additional Panel Data Results

Dependent Variable: $\Delta\ln(R_{it})$; Sample Period 1993-2000

	[A2]	[B2]	[C2]	[D2]
$\Delta\ln(Y_{it})$	2.2288 (6.1)	2.2253 (5.9)	1.3166 (3.6)	1.2441 (1.7)
$\ln(R_{it-1})$	-0.6900 (8.2)	-0.6824 (8.0)	-0.7841 (9.7)	-0.7367 (6.6)
$\ln(Y_{i,t-1})$	0.4932 (2.7)	0.6824 (8.0)	0.8465 (4.1)	0.7015 (3.1)
$G_{i,t-1}$	0.0105 (2.8)	0.0116 (3.2)	0.0049 (1.6)	0.0112 (2.2)
$F_{i,t-1}$	0.0044 (3.2)	0.0045 (3.1)	0.0036 (3.0)	0.0036 (2.3)
$\ln(IM_{it-1})$	0.3653 (1.7)	0.3178 (1.3)	0.9489 (3.6)	0.4914 (2.2)
(Real interest rate $_t$)	-0.0924 (3.2)	-0.0899 (3.1)	-0.0005 (0.1)	-0.0873 (3.0)
ln(Real exchange rate $_t$)	-0.9751 (3.2)	-0.9770 (3.2)	-1.2399 (1.9)	-0.8567 (2.6)
$SE_{i,t-1}$	0.1128 (3.1)	0.1158 (3.2)	0.1342 (3.9)	0.1368 (2.9)
$\Delta\ln$ (Profits $_{it}$)				0.5805 (2.1)
No. of observations	88	88	88	88
$\overline{R}^2$	0.759	0.759	0.810	0.681
Standard Error	10.6%	10.6%	9.4%	12.3%

The extensions made in Tables 3 and 4 have not greatly changed the picture shown by the initial estimates in Table 2. The precise long-run effect of a given change in one of the explanatory variables varies according to the model adopted. In Table 5 we report the range of estimates that result from the regressions in Table 4.[29]

Table 5. Marginal Effects on R&D

Impact on R&D volume of a 1% rise in:	
Output	0.71% to 1.08%
Impact on R&D volume of a 1% point rise in:	
Real exchange rate	–1.16% to –1.58%
Import penetration	+0.47% to +1.21%
Real interest rate	–11.9% to –13.4%
Government funding share	+0.62% to +1.70%
Foreign funding share	+0.46% to +0.66%
Skilled employment share	+16.3% to +18.6%

The profile of the time dummies included in [C][30] suggests there may be one principal macroeconomic driving force behind the pattern of variation between R&D expenditure in different industries. However, whilst testing for a common trend by means of principal components analysis did indicate non-stationarity of the first principal component and stationarity of all other ones, supporting the hypothesis of one overall trend, the variation accounted for by this component was only 46%. Explaining around 90% of the pattern of correlation between R&D investment in the 11 industries requires the cumulative explanatory power of the first four components. Repeating the analysis for the maximum time period for which total industry R&D data were available, 1985-2000, drew a similar picture, with an explanatory power of the first principal component of only 39%.[31] These results indicate that there is not one common factor that accounts for most of the variation in R&D spending

[29] We omit the real interest rate effect from column [C2], which is clearly subsumed within the effects attributed to the time dummies.

[30] We now replace the real interest and exchange rate term with two additional time dummies.

[31] However, it is interesting to note that the (cumulative) explanatory power of the first (47%) and of the first four (94%) principal components over the first half of the period, 1985-1992, are essentially the same as for the second half.

across all industries. Rather, the industry split of the effect of the first component suggests there may be significant differences in the factors determining R&D spending in high-tech versus low-tech industries over the period under investigation.[32] This is one avenue of further research.

VI. Conclusions

In this paper we have sought to address the reasons why UK R&D intensity was relatively weak during the 1990s. It is perhaps surprising that there is relatively little literature which can be used to answer this question given that R&D is regarded as an important determinant of long-term productivity growth. The majority of work on R&D has been undertaken at the firm level and has not really sought to address the influence of industry or economy-wide developments. Our detailed survey of the literature highlights a number of factors that may however be important, including firm- (or industry-) specific characteristics, product market competition, public policies and the presence of foreign firms.

Using a panel data model for 11 broad manufacturing industry groups over the period 1993-2000 we find that the main explanations for the comparatively low level of R&D seen during the 1990s appear to be weak output growth, the declining level of government funding for private industry and the appreciation in the real effective exchange rate since 1996. Taken together these factors have largely outweighed the stimulus being offered by the decline in long-term interest rates during the 1990s, the growing share of R&D expenditure being undertaken by foreign-owned firms, the rising level of competition in product markets and the increase in skilled labour employed on R&D in the latter half of the decade.

[32] The weights applied to the first principal component in expressing each individual industry R&D series as a linear combination of the components are highest (79% to 94%) for the three most R&D intensive industries and negative for the five low-tech industries (textiles, paper, plastics, other non-metallic minerals and other manufacturing).

Data Appendix

This Appendix gives a brief description of the data used in the empirical work and their main statistical source. For two-digit SIC(92) industry coverage, see text.

R&D series:

All data have been converted from the Office for National Statistics (ONS) R&D product group (PG) codes to SIC(92) using a concordance provided by the ONS. Data were taken from ONS MA14 or the ONS website 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 1990-1992.

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 GOVT series total were taken from ONS website for each year. GOVT at detailed PG level is not available in revised form for 1993-1998 and not available at all for 1991 and 1992. Data for 1993-1998 were collected from ONS MA14, various editions. The data for 1993-1995 was converted from 1993 to 1996 PGs 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 nine out of twenty PGs, the conversion factor was 1. In 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, we revised 1993-1998 data at the detailed PG level 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 1993-1999 provided by the ONS. Pre-1993 data for FOREIGN were not available either for the series total or at the detailed PG level. The series total for those years was thus interpolated using information on foreign funding of business R&D. Data at individual PG level were then obtained as for GOVT.

SE – number of scientists and engineers employed on R&D performed in UK businesses, full-time equivalents (S&E), as a share of total employment. S&E data obtained as for GOVT. Data for total employment collected from ONS Census of Production Summary Volume PA1002, various editions, for 1992-1997, and from the ONS Annual Business Inquiry website for the years 1998 and 1999. Pre-1993 data converted from SIC(80) to SIC(92) using an unpublished concordance provided by the ONS, as in Hubert and Pain (2001).

Non-R&D series:

Y – gross value added, 1995 prices, ONS Blue Book (website).

IM – import penetration ratio, calculated as value of imports over home demand. Trade data from ONS MQ10 (website). Turnover data from ONS Annual Business Inquiry (website) for 1995-1999, linked to equivalent series in ONS Census of Production Summary Volume PA1002, various editions, for the earlier years. Pre-1993 turnover data converted from SIC(80) to SIC(92) as for total employment.

Profits – obtained as gross value added minus total employment costs. Data linked from ONS Annual Business Inquiry (website) and ONS Census of Production Summary Volume PA1002 as for turnover. Total employment costs for the earlier years obtained as sum of total wages and salaries plus employers' national insurance contributions. Pre-1993 data converted from SIC(80) to SIC(92) as for total employment.

Real effective exchange rate - January 2002 NIESR forecast base.

Real long-term interest rate – January 2002 NIESR forecast base, see text for details.

GILT – average annual yield on UK index-linked government securities.

Nominal series were deflated using the gross value added deflator, 1995=100, as obtained from gross value added at constant and at current prices, ONS Blue Book.

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