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Productivity Growth and R&D Expenditure in UK Manufacturing Firms

by

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Abstract

This paper analyses the relationship between productivity growth and R&D expenditure. A Cobb-Douglas function including R&D intensity is estimated for 170 UK firms. A positive and significant role is found for the firm's own R&D expenditure in influencing productivity growth. Separating their firms according to their innovation histories, the rate of return to R&D is much higher for innovative than non-innovative firms. Firms located in sectors that are defined as net *users* of innovations also appear to have a high rate of return on R&D, both their own and that of other firms in their sector. The innovation history of both the firm and the sector appear to be important in influencing the rate of return to R&D.

Outline

Non-Technical Summary

Renewed interest in the role of technology in productivity was prompted by the productivity slowdown noted in much of the industrialised world in the 1970s. As research into the role of technological change in economic growth indicated that technological change is one of the key explanatory factors in productivity growth, the observed decline in productivity led to concerns that the level of technological change was diminishing. This in turn increased efforts to assess the importance of R&D expenditure, along with other indicators of technology, in influencing both the level and changes in productivity for different countries and different periods. This paper examines the relationship between R&D expenditure and growth in productivity at the firm level; to the best of our knowledge it is the first study to do so for the UK. While the evidence from firm-level studies for other countries confirms a positive role for R&D expenditure in explaining productivity growth, R&D expenditure has been of only limited explanatory power in explaining differences in productivity rates among firms, sectors and countries.

Technology is treated in two different ways in the paper. First, the current commitment of resources to R&D expenditure is taken as one indicator of a firm's technological level. Second, the paper also aims to investigate if the relationship between productivity growth and R&D intensity varies according to the innovation history of the firm. Firms are separated into two groups: innovators and non-innovators based on their past production of innovations. This classification aims to capture some aspects of technology, which are not adequately reflected by R&D expenditure.

The results indicate that the role of R&D expenditure in productivity growth in the UK is similar to that found for other countries such as the US, France and Japan. However, the relationship between productivity growth and R&D intensity was also found to be very sensitive to the inclusion of sector dummy variables, indicating an important role for different sector conditions in explaining variations in productivity growth. The inclusion of the R&D expenditure of other firms in the same sector does not improve the results – other sector-level influences may be more important. No role was found for spillovers of R&D expenditure from innovation-supplying sectors. This is in contrast to many microeconomic studies that have found evidence of important inter-sector spillovers of innovation.

Concerning the differences between innovative and non-innovative firms, innovative firms spent more on R&D expenditure relative to sales than non-innovating firms (2.3% against 0.8% in the period 1988 to 1992). This R&D expenditure also appears to have a higher rate of return than the R&D expenditure of non-innovating firms. The rate of return is particularly high when firms are located in sectors that are net users of innovations. Both the innovation history of the firm, and the sector the firm is located in, appear to be important influences on the rate of return to R&D: innovative firms and firms located in 'innovation

1. Introduction

The renewed interest shown in empirical research into the importance of technology in productivity was prompted by the productivity slowdown noted in much of the industrialised world in the 1970s (Griliches, 1986). As research into the role of technological change in economic growth indicated that technological change is one of the key explanatory factors in productivity growth (Solow, 1957), the observed decline in productivity led to concerns that the level of technological change was diminishing. This in turn increased efforts to assess the importance of R&D expenditure, along with other indicators of technology, in influencing both the level of productivity and changes in productivity for different countries and different periods. Many of the ensuing studies examined the determinants of productivity at an aggregate level, either by country or by sector; some research took the firm as the unit of analysis.

In keeping with the last category of studies this paper examines the relationship between R&D expenditure and growth in productivity at the firm level; it is the first study to do so for the UK. There are a number of advantages in considering the relationship from the perspective of the firm. First, by considering the firm, we can separate productivity improvements that occur as a result of the direct R&D efforts of the firm from the technological improvements and advances that are general to the sector. Thus we can attempt to pinpoint the contribution of the firm's own technological resources to its productivity growth. Second, a greater number of observations are generally available for firms than for sectors. One drawback of the firm approach is the generally poor quality of the R&D data at the firm level. While the evidence from firm-level studies for other countries confirms a positive role for R&D expenditure in explaining productivity growth, R&D expenditure has been of only limited explanatory power in explaining differences in productivity rates among firms, sectors and countries (Griliches and Mairesse, 1990).

Technology is treated in two different ways in the paper. First, the current commitment of resources to R&D expenditure is taken as one indicator of a firm's technological level. Second, the paper also aims to investigate if the relationship between productivity growth and R&D intensity varies according to the innovation history of the firm. In order to do so the firms are separated into two groups: innovators and non-innovators, based on their past production of innovations. This classification aims to capture some aspects of technology, which are not adequately reflected by

R&D expenditure. The innovation history of a firm may proxy accumulated technological advantages, such as the attitude of the labour force and management towards innovation, and the general ability of the firm to implement change. There is some evidence (Blundell *et al*., 1995; Malerba, Orsenigo and Peretto, 1997) that the ability to innovate is persistent and firm specific, making innovative firms qualitatively different from non-innovating firms. To investigate if this is the case our estimates of productivity growth are made separately for innovating and non-innovating firms.

As a comprehensive survey of the impact of R&D on productivity at the firm level already exists (Mairesse and Sassenou, 1991), we will concentrate on the practical problems raised in estimating productivity functions at the firm level and alternative ways of dealing with them. Section Two sets out the relationship to be estimated. Section Three provides information on the sample and outlines the data used. Section Four examines the results, which are presented for all firms and for innovating and non-innovating firms separately. Section Five looks for any variations in the relationship which may occur due to the sector in which the firm is located, including the role of spillovers of innovation from other firms in the economy on firm productivity. The last section gives some conclusions.

2. R&D Intensity and Productivity Growth

The model used to estimate productivity growth is a version of the Cobb-Douglas production function in its growth rate form. The production function includes the standard factors of capital and labour as well as the additional factor of knowledge capital. The objective is to attribute the rate of increase in productivity to increases in its inputs. Productivity is measured as labour productivity and the assumption of constant returns to scale of capital and labour is explicitly tested.

The objective in including knowledge capital in the production function is to account for increases in productivity which occur due to technological improvements at the firm level. A number of proxies can be used for knowledge capital, including stocks of R&D expenditure, patent counts and data on actual innovations. R&D expenditure is the most common choice[1]. The production function is given by:

[1] One problem in including R&D expenditure with capital and labour is that some double counting occurs: capital equipment and researchers in R&D laboratories will be included in the capital and labour variables respectively. As the

$$Q_{it} = Ae^{\lambda t} K_{it}^{\alpha} L_{it}^{\beta} R_{it}^{\gamma} e^{\varepsilon_{it}} \qquad (1)$$

where Q is a measure of output for firm *i* at time *t* (in this case total sales), K is a measure of physical capital, L of labour employed, and R of knowledge capital. A is a constant and α, β and γ are the elasticities of output with respect to physical capital, labour and knowledge capital. λ represents disembodied technical change; ε is an error term. By taking logarithms of the variables and first differencing, the relationship can be expressed as a linear one in terms of the change in labour productivity:

$$(q - l)_{it} = \lambda + \alpha\,(k - l)_{it} + \gamma r_{it} + \theta l_{it} + \nu_{it} \qquad (2)$$

where the variables in lower case are the rates of growth of output (q), labour (l), physical capital (k), and knowledge capital (r). By using the rate of change of productivity, firm heterogeneity related to the *level* of productivity is removed; only firm-specific growth effects remain. Due to the rearrangement of the productivity relationship into labour productivity:

$$\theta = \alpha + \beta - 1$$

which is the constant returns to scale on capital and labour coefficient. If this coefficient is significantly different from zero then constant returns to scale for labour and capital can be rejected. If R&D expenditure data are not available for enough years to calculate the stock of knowledge, the function can be transformed by taking the rate of return to R&D as the parameter of interest rather than the elasticity[2]. As the rate of return ρ is related to the elasticity γ by γ = ρ(R/Q) and the first difference of R is ΔR substituting allows us to include the term ρ(ΔR/Q). By assuming no depreciation in R&D the change in the knowledge capital ΔR is equal to present R&D expenditure RD.

There are a number of potential problems with this R&D return approach (see Hall and Mairesse, 1995, for details). First the rate of return estimated is a gross rate of return, to obtain the net rate of return we need to subtract the (unknown) depreciation rate for R&D; thus the problem of

necessary data are not available double counting cannot be corrected for here. The result is likely to be a downward bias in the estimates of the R&D coefficient.

depreciating incurred when estimated the R&D stock is not avoided[3]. Second the timing of the relationship between R&D flows and productivity growth is not clear (Hall and Mairesse, 1995; Harhoff, 1998). Assuming a contemporaneous relationship appears to be inappropriate so various lag structures have been applied. However, Mairesse and Sassenou (1991) in their survey point out that R&D expenditure by firms is very stable over time, most of the variation is in the cross-section. As a result they find that applying different lags to R&D expenditure has little impact on the results[4]. The relationship to be estimated is given by:

$$(q - l)_{it} = \lambda + \alpha\,(k - l)_{it} + \rho(\mathrm{RD/Q})_{it} + \theta l_{it} + \nu_{it} \qquad (3)$$

where R&D intensity is the average of R&D expenditure over total sales for each year. This is the relationship we will test using the data discussed in the next section.

3. The Sample and Data

The model is tested on a sample of 170 firms quoted on the UK stock market. Data on R&D expenditure are available for all the firms in the sample, although the expenditure is zero for some firms. This sample of firms represents an important part of total manufacturing output (around 50% in 1992). The sample of firms can be divided into innovating and non-innovating firms, based on whether or not a firm was included in the SPRU survey of major innovations. The first group of firms - termed innovating firms - was chosen from the firms included in the SPRU survey (a population of 1845 firms)[5]. That survey is designed to give exhaustive coverage of all firms that have had a major innovation in the UK from 1945 to 1983. The definition of an innovation is “the successful commercial introduction of new or improved products, processes or materials”. The second group was chosen randomly from Datastream, which has data on all quoted firms; those found to have had major innovations were rejected, leaving a sample of non-innovating firms[6].

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[2] The relationship is frequently estimated in this form giving an estimate of research elasticity; the procedure was introduced by Terleckyj (1974) subsequent studies include Cuneo and Mairesse (1984) and Griliches (1986).
[3] One puzzle is that Hall and Mairesse (1995) find similar gross and net rates; Goto and Suzuki (1989) find mixed evidence.
[4] The output variable Q can also be lagged, see Harhoff (1998).
[5] For more information on the survey see Pavitt *et al*. (1987) and Robson *et al*. (1987). The information in the survey has been used before in sector-level productivity studies such as Geroski (1991) and Sterlacchini (1989).
[6] The innovations refer to a period before that analysed (1945-1983); however there is some evidence (Geroski, 1991) that these innovations have a long-run effect on productivity growth that may last for up to 16 years.

Only firms in the manufacturing sector were chosen for each sample. Since 90% of innovations in the survey were exploited by manufacturing firms this selection covers the majority of innovations (Pavitt *et al*., 1987) [7]. Balance sheet data are available for all the firms from the same source (Datastream), along with the main sector they operate in[8]. The firms are grouped in eighteen sectors based on the 1980 SIC classification and data were collected for a nine-year period from 1988 to 1996 with the exception of the R&D data that is from 1988 to 1992. The full period covers a whole business cycle, from the start of a recession in 1988, through the upturn in 1991 to the start of another (much smaller) dip in GDP growth in 1994. This should reduce any bias from examining only part of the business cycle. Out of this sample, firms with an increase in total sales of more than 80% in any year were rejected as likely to have undergone a merger. These firms can be expected to have experienced productivity changes due to the merger alone, and are thus likely to bias the sample. The resulting sample of 170 firms is evenly split between innovating (85 firms) and non-innovating firms (85 firms). The distribution across sectors is given in Table 1.

The R&D data available from Datastream are of mixed quality and only cover the period 1988 to 1992. Some firms have not registered any R&D expenditure over the period and this may not be an accurate reflection of their actual expenditure. In order to check the consistency of the data, the average R&D intensity (R&D expenditure over total sales) is shown for all firms and for the sample firms in Table 1. The firms are grouped into ten rather than eighteen sectors for clarity. As the sample consists of large quoted firms we would expect the average R&D intensity to be higher than that for the sector as a whole; it is clear from the table that this is the case only in some sectors. Overall, the mean firm R&D intensity for the sample is 1.6%, while the mean R&D intensity for UK manufacturing is 2.1%[9].

There may be a number of explanations for the discrepancy between the sample and the population of firms. One is that R&D expenditure is highly skewed, i.e. there are some firms with very high R&D expenditure. If these firms are missing from the sample the mean will be biased down. In addition, as firms have no legal obligation to reveal their R&D expenditure some may not for reasons

[7] For definitions of the variables, the sectors and the sources see the Appendix.

[8] Only one sector is given for each firm, thus firms with diversified interests will be classified by the sector which constitutes their main line of business.

[9] The under-reporting should not alter any differences found between the innovating and non-innovating groups.

of secrecy. This problem is particularly acute in the office and data machinery sector (sector 5), where the sample has a much lower R&D intensity than the population. One explanation is that this sector includes very diverse firms – from those producing high technology computers to those producing more standardised office equipment; our sample may omit some high R&D spending computer firms explaining the low R&D average.

Table 1: R&D intensity 1988-1992

Sector	N	Innovators	Sample R&D intensity	R&D intensity all firms
All sample firms	170		0.016 (0.030)	0.021
Innovators	85		0.023 (0.036)	
Non-innovators	85		0.008 (0.020)	
1. Metal manufacturing and goods	10	4	0.005 (0.006)	0.004
2. Non-metallic manufacturing	12	4	0.006 (0.009)	0.003
3. Chemical and man-made products	17	14	0.030 (0.041)	0.054
4. Mechanical Engineering	36	22	0.009 (0.013)	0.009
5. Office and Data machinery	9	4	0.008 (0.015)	0.070
6. Electrical and electronic machinery	22	13	0.040 (0.049)	0.070
7. Transport	11	9	0.040 (0.037)	0.042
8. Instruments	5	3	0.044 (0.056)	0.023
9. Food, textiles, leather, footwear, timber, paper and printing	31	8	0.002 (0.003)	0.002
10. Rubber, plastics, other manufacturing	16	4	0.002 (0.003)	0.005

Lagged R&D expenditure is used in many studies but there is no agreement on the correct length of the lag. Hall and Mairesse (1995) and Mairesse and Sassenou (1991) point out the stability of firm R&D over time, for France the US and Germany, and the insensitivity of the results to the choice of lag. Here R&D intensity is an average for the first five years of the full nine-year period[10].

In order to calculate productivity, data were collected on employment, capital and output for each firm. Employment is defined as the firm's number of employees (L)[11]. For the capital variable, total fixed gross assets are used, and deflated over time using the national investment deflator to give real capital (K). Total sales are used for the output variable, deflated by a sector-level producer price index to give real total sales (Q)[12]. Sales and capital are both divided by employment to give per capita values, and the growth rate for each variable is taken as the average of the log of change in growth for each of the years between 1988 and 1996. Table Two gives some descriptive statistics. The variables are shown for all firms, innovating and non-innovating grouped together, and on a sector basis.

Average employment is over 15,000 people per firm in 1992; employment is also highly skewed with the largest firms having almost 200,000 employees. Innovating firms are noticeably larger than non-innovating firms are and there is considerable variation in average firm size per sector. For all firms considered together, deflated sales per employee rose by 2%, with a fall in employment of almost 7.0% and a rise in the real capital to labour ratio of 10% on average over the period. These movements were very similar for the innovating and non-innovating firms.

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[10] Using this sample, a regression of present R&D intensity on lagged R&D intensity cannot reject the hypothesis that the coefficient is one for each year.

[11] The number of hours worked per employee and the level of capital utilisation are not available. As has been noted elsewhere (Odagiri and Iwata, 1986) the impact of changes in hours worked and capital utilisation is considerable over time.

[12] Neither value added nor materials were available. This may lead to an underestimate of the elasticity of physical capital; however, in their survey, Mairesse and Sassenou (1991) find the results are not sensitive to using either value added or sales.

Table 2: Descriptive statistics: means (and standard deviations)

Sector	Employment 1992	Average growth rates 1988-1996: Sales per employee	Capital per employee	Number of employees
All firms	15,874	0.020	0.104	-0.066
	(29,722)	(0.198)	(0.312)	(0.171)
Innovators	21,702	0.019	0.091	-0.071
	(29,328)	(0.174)	(0.155)	(0.122)
Non-innovators	10,694	0.022	0.119	-0.060
	(29,332)	(0.223)	(0.491)	(0.211)
1. Metal manufacturing and goods	10,787	0.104	0.028	-0.099
	(15,020)	(0.409)	(0.169)	(0.249)
2. Non-metallic manufacturing	15,172	0.001	-0.109	-0.048
	(18,578)	(0.024)	(0.272)	(0.131)
3. Chemical and man-made products	31,720	0.012	0.055	-0.071
	(43,770)	(0.057)	(0.039)	(0.099)
4. Mechanical Engineering	6,949	0.0002	0.090	-0.063
	(9,958)	(0.129)	(0.259)	(0.177)
5. Office and Data machinery	2,379	0.062	0.110	-0.149
	(3,605)	(0.216)	(0.230)	(0.065)
6. Electrical and electronic machinery	16,855	-0.004	0.132	-0.107
	(30,216)	(0.083)	(0.336)	(0.154)
7. Transport	40,351	0.015	0.045	-0.066
	(39,051)	(0.075)	(0.184)	(0.165)
8. Instruments	6,202	0.005	0.025	-0.060
	(7,600)	(0.046)	(0.043)	(0.034)
9. Food, textiles, leather, paper & printing, footwear, timber	22,445	0.079	0.148	-0.060
	(42,027)	(0.047)	(0.380)	(0.336)
10. Rubber, plastics, other manufacturing	1,379	-0.108	0.475	0.081
	(2,102)	(0.121)	(0.635)	(0.221)

Examining the relationship at the sector level shows a great deal of diversity among sectors. Labour productivity fell in two sectors: electrical and electronic machinery and rubber and plastics, the latter was the only sector to show a rise in employment. The capital per employee variable was also negative for one sector – non-metallic manufacturing. The sectors with the highest labour productivity growth were metal manufacturing and office and data machinery with 10% and 7% respectively.

4. The Results

A number of different equations are estimated using OLS. Initially the simplest model including only the capital to labour ratio is included (Regression 1). Second, the R&D intensity term is added (Regression 2); and third the additional labour term is included to check for constant returns to scale (Regression 3). The same estimates are then repeated with 10 sector dummy variables (no separate constant is included). The results from all of the estimates are given in Table Three; *N* is the number of observations[13]. The model is estimated for all the firms together, and with innovating and non-innovating firms separated.

The results for the whole sample show a significant role for R&D intensity (at 10%). The gross rate of return to R&D, imposing constant returns to capital and labour, is found to be 0.27 i.e. for every additional pound spent on R&D expenditure output would increase by £1.27 *ceteris paribus*. To interpret this as a net rate of return a depreciation rate (often assumed to be around 15%) needs to be deducted. Although results can be difficult to compare due to the use of different data and assumptions, this result is consistent with similar estimates for Japan and the US (Griliches and Mairesse, 1990) and France (Griliches and Mairesse, 1983), and considerably higher than that found for Belgium (Fecher, 1989). When the sample is split, the rate of return is higher for the innovating than the non-innovating firms, indeed for the non-innovators the rate of return is negative, although not significant. Being an innovator does appear to be an important factor in influencing the rate of return to R&D expenditure.

Table 3: Labour productivity growth in manufacturing in the UK, 1988-1996.

Regression	**k/l**	**l**	**RD/Q**	**R^2**	**k/l**	**l**	**RD/Q**	**R^2**
Without sector dummy variables					**With sector dummy variables**			
All Firms *N = 98*	0.21 *** (0.06)			0.13	0.20 *** (0.06)			0.24
Innovators *N = 51*	0.25 ** (0.11)			0.09	0.22 ** (0.12)			0.21
Non-innovators *N = 47*	0.21 *** (0.06)			0.23	0.24 *** (0.06)			0.45
All Firms	0.20 *** (0.06)		0.34 * (0.18)	0.16	0.19 *** (0.06)		0.28 (0.21)	0.25
Innovators	0.22 ** (0.11)		0.28 (0.23)	0.10	0.22 ** (0.12)		0.19 (0.26)	0.22
Non-innovators	0.21 *** (0.06)		-0.21 (0.53)	0.23	0.24 *** (0.07)		0.08 (0.70)	0.45
All Firms	0.15 *** (0.06)	-0.14*** (0.04)	0.27 * (0.16)	0.26	0.13** (0.06)	-0.14*** (0.04)	0.29 (0.19)	0.33
Innovators	-0.08 (0.10)	-0.32*** (0.06)	0.26 (0.18)	0.47	-0.04 (0.11)	-0.33*** (0.07)	0.30 (0.21)	0.52
Non-innovators	0.21 *** (0.06)	0.005 (0.06)	-0.20 (0.54)	0.23	0.23 *** (0.07)	-0.02 (0.06)	0.07 (0.71)	0.45

[13] This is lower than 170 because of missing data.

The coefficient on the R&D intensity variable is no longer significant when sector dummy variables are included (although it is now positive for the non-innovators as well). This result is consistent with other studies such as Odagiri and Iwata (1986) for Japan and Griliches and Mairesse (1983) for France and the US which have found coefficients to be reduced by as much as half through the inclusion of sector dummies.

The inclusion of industry effects aims to account for factors which may vary by industry and which have been omitted from the model. In the present model there are no variables which indicate the different economic conditions experienced in each industry. As shown by the descriptive statistics presented in Section Two, there is considerable heterogeneity among sectors. By including sector dummies the estimates are reflecting the role of the explanatory variables in explaining productivity growth for firms within each sector rather than for firms in different industries. Odagiri and Iwata (1986) find a strong role for sector dummies, and conclude that this indicates the importance of inter-industry differences in the rate of exogenous technical progress.

However, the role of the industry variables in reducing bias has been called into question (Mairesse and Cuneo, 1985; Mairesse and Sassenou, 1991). They argue that in order to pick up sector specific effects it may be more appropriate to introduce variables which have been omitted - such as the level of technological opportunity in the sector, and the presence of inter-sector spillovers - instead of the dummy variables. This approach will be implemented in the next section.

The results for the capital to labour ratio for all the firms are not altered essentially by the inclusion of the sector dummies. In general the coefficients are similar for those found for other countries in different studies with an elasticity of around 0.2 found for all the firms together. The coefficient on the labour variable, which is included to check for constant returns to scale to capital and labour, is significantly different from zero for all firms; when the sample is split this result is found only for the innovating firms. Diminishing returns are present in both these cases i.e. the sign on the variable is negative. A similar model for the US and Japan, Griliches and Mairesse (1990), also found evidence for the US of diminishing returns at a comparable level with the results found here. Their results for Japan showed even larger diminishing returns (-0.24 when sector dummies were included). The rejection of constant returns to scale to labour and capital may be due to the exclusion of raw materials and intermediate products from the production function that could be particularly important in the case of innovating firms. Nickell *et al*. (1992) found diminishing returns for a panel of UK firms, which they attribute to measurement error associated with the capital and labour terms. When the diminishing returns for innovative firms are taken into account in Regression 3, the coefficient on the capital to labour ratio drops dramatically from 0.22 to –0.08. No such effect is found for the non-innovative firms. We would expect the coefficient to decline as any increase in the capital to labour ratio has a more limited effect on productivity if there are diminishing returns; nevertheless this is a large fall in the coefficient[14].

5. Spillovers and Sector Variation

There is a lively debate on the role of spillovers of innovations in the economy and their effect on economic growth. The attention given to attempts to quantify the role of technology spillovers has increased considerably since their recent inclusion in growth models (for instance, Romer, 1986, and Grossman and Helpman, 1991). It is the characteristics of technological change – namely non-rivalry in the use of innovations and difficulties in appropriating new technology – which have led to its association with spillovers. One seminal contribution, Griliches (1979), suggests the existence of two different types of economic spillovers: rent spillovers and knowledge spillovers. The former are associated with difficulties in capturing the full economic benefits of an innovation via its price, while the latter deal with flows of knowledge which are not part of an economic transaction. Rent spillovers occur because the producer of an innovation does not charge a price that fully reflects the benefits of the innovation to the user. As a result productivity improvements accrue to the user firm from the R&D expenditure of the producer firm[15].

Knowledge spillovers relate to the production of knowledge that has public-good characteristics limiting the ability of the firm to stop another firm (or person), exploiting it. Not all knowledge falls into this category: some may be private and easily appropriated by the firm. Knowledge transmitted through scientific journals and via the product itself (accessible through reverse engineering), and the

[14] The capital to labour ratio, and the labour variable, have a high negative correlation for both innovative and non-innovating firms (around -0.45). For the innovating firms the effect of the labour variable dominates, while for the non-innovating firms the effect from the capital to labour ratio is of greater importance.
[15] In principle, rent spillovers could be accounted for by using perfect price deflators.

movement of skilled personnel between firms, fall into this category. The result is that a firm may use knowledge originating in another firm without paying the full price for its benefits.

Surveys of the literature on the estimation of spillovers (Nadiri, 1993; Griliches, 1992) generally conclude that while there is evidence that they raise productivity, estimates of their importance vary greatly across studies. There is variety in the proxies chosen to measure spillovers: R&D expenditure, patent information and innovation surveys have all been used. In addition, different estimates of the technological distance of firms from each other, and of sectors, have been used to weight this technology stock (Jaffe, 1986). We use two different variables to represent R&D undertaken by other firms in the economy.

The first innovation proxy introduced is the R&D expenditure of other firms in the same sector as the firm (the firm's own R&D is excluded). This is included to capture the technological level of the sector in which the firm is located. While not all R&D conducted by other firms in the same sector will necessarily spill over to the firm, the level of R&D activity in the sector gives an indication of the level of technological opportunity and the size of the available pool of technological knowledge. In contrast to this positive effect of productivity-enhancing spillovers, the R&D expenditure of other firms may also raise the quality of their products and thus increase competition in the sector. As a result there are both positive and negative effects from R&D undertaken by other firms in the sector. The R&D expenditure at the sector level is divided by total sales in the sector to give sector R&D intensity ($SECRD/Q_s$). The deviation of firm R&D intensity from sector R&D – termed RDDIF – (RD/Q – SECRD/Q) is also included as an indicator of firm-specific R&D; both R&D variables are for the period 1988-1992.

A second variable is designed to account for spillovers of R&D expenditure from other sectors in the economy. It is necessary to apply a weighting system to this R&D expenditure as not all sectors in the economy will have the same technological distance from each other. To this end a matrix has been created from the SPRU survey of innovations giving a map of the production and use of innovations among sectors[16]. The sector in which the innovation is produced is known, as is the sector in which the innovation is first used; together these are used to create a matrix in which the off-diagonal elements give the flows of innovations between sectors[17]. The diagonal elements of the matrix show the number of innovations used in the same sector they were produced in. This value turns out to be highly correlated with each sector's R&D expenditure and is not used in the estimates. The matrix of off-diagonal elements gives the flow of innovations from the innovation-producing sector S_p to the innovation-using sector S_u. Each flow is calculated as a proportion of the total production of innovations from each producing sector. In some cases – mechanical engineering and instrument engineering – as much as 60% of the innovations produced are used in other sectors. In others such as food, drink and tobacco it is less than 5%. This proportion then weights the average R&D expenditure from 1988 to 1992 for each innovation-producing sector. This gives the amount of R&D spilling over to the using sector S_u from the producing sector S_p in the same proportion as the innovations which flow between the two sectors. The weighted R&D is then divided by the total sales in sector S_u in order to give a spillover intensity variable ($SPILL/Q_s$). Only those innovations both used and produced within manufacturing are considered[18].

While the survey is a unique source of information on innovation diffusion in the UK, it has some limitations. Only the place of first use of the innovation is known so diffusion after the first user is not captured. In addition, the survey includes only major innovations rather than small or incremental innovations. As a result, the matrix may understate the actual diffusion of each innovation across sectors. This second spillover proxy used in this paper is more effective in capturing rent spillovers, based as it is on producer-user relationships, than knowledge spillovers. Neither proxy directly measures knowledge spillovers, although using the R&D expenditure of other firms in the sector may reflect knowledge availability in the sector. The results are given in Table 4 for innovating and non-innovating firms.

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[16] The eighteen-sector classification is used rather than the ten-fold one used earlier in the paper in order to have greater precision in estimating the spillovers.

[17] The entire period of the survey 1945-1983 is used to make the matrix. However, using the last five years of the survey alone makes little difference to the pattern found (Wakelin, 1997). The pattern of use and production of innovations is very stable over time.

[18] This does not include innovations which originate outside manufacturing e.g. in R&D services, but are used in manufacturing; however, these are a very small proportion of the total. A large number of innovations are produced in manufacturing and used in other sectors of the economy, and this flow of innovations is also not included in the classification.

Table 4: Sources of innovation outside the firm

Regression	k/l	l	RDDIF	$SECRD/Q_s$	$SPILL/Q_s$	R^2
All firms	0.15 ***	-0.14 ***	0.26	0.31	-0.08	0.26
	(0.06)	(0.04)	(0.19)	(0.20)	(0.22)	
Innovators	-0.08	-0.31 ***	0.23	0.32	-0.06	0.47
	(0.10)	(0.06)	(0.20)	(0.24)	(0.21)	
Non-innovators	0.22 ***	0.002	-0.16	-0.20	-0.57	0.23
	(0.07)	(0.06)	(0.74)	(0.58)	(2.02)	

The results for the capital to labour variable and the constant returns variable are essentially the same as in the earlier model. The sector R&D intensity variable itself has a rate of return of around 0.31 for all firms but is not significant; most of this effect seems to refer to the innovating firms while the non-innovating firms have a negative rate of return. Firm-specific R&D RDDIF is also positive only for the innovators but again is not significant. No significant effects were found for spillovers of R&D from related sectors. The results from Geroski (1991) confirm those found in this paper: the impact on the TFP growth in UK sectors of innovations both used and produced in neighbouring sectors was small in magnitude. These results are in contrast to the Goto and Suzuki (1989) results for Japan[19]. The authors found that their technology flow matrix (consisting of the R&D expenditure of supplying industries) had a much larger coefficient than each firm's own R&D expenditure when estimating TFP growth.

One explanation for the lack of evidence for inter-industry spillovers is the type of proxy used, and whether it measures rent or knowledge spillovers. In order to investigate the importance of knowledge spillovers in the sample, alternative measures of spillovers need to be used. Jaffe (1986) found evidence for a strong role for a spillover variable defined to capture knowledge rather than rent spillovers. Los and Verspagen (2000) included a number of different proxies for indirect R&D stocks in their panel-data study for US firms. In general they found knowledge spillovers to be a more important source of productivity growth than rent spillovers. In addition, studies that include innovation spillovers in a time-series model (e.g. Coe and Helpman, 1995 with international spillovers) generally find stronger evidence for spillovers. This is confirmed by panel-data studies

[19] The Goto and Suzuki (1989) technology-flow matrix was based on the purchase of inputs from different sectors rather than the use of innovations, it was thus reflecting different linkages in the economy and is not comparable to the one used here.

(such as Los and Verspagen, 2000) which find more support for the existence for spillovers over time than in the cross-section dimension.

In order to investigate the relationship between R&D intensity and productivity growth across different sectors a division of firms into different groups is adopted. This allows a different marginal contribution to productivity growth for different groups. As there are only a limited number of firms in some sectors, giving small degrees of freedom, the sector division used earlier is not applied. Instead, the firms are separated into two groups based on the characteristics of the sector in which they are located: net users of innovations i.e. sectors that use more innovations than they produce, and net producers of innovations, sectors which produce more innovations than they use[20].

This separation is based on information on innovation taken from the SPRU survey. As the use and production of innovations at a sector level are very stable over time the delay between the survey data and the sample used here is not a problem. This classification based on the net production of innovations is preferred to the more frequently used one based on the technological level of the sector according to its R&D level[21]. The separation used here captures one of the most interesting characteristics of a sector, and one which has considerable implications for the economy as a whole – the ability of the sector to generate innovations which are subsequently used in other sectors. As the data collected from this survey have already shown (Pavitt, 1984; Robson *et al*., 1987) some sectors in the economy produce a high proportion of the innovations used in the economy as a whole, and as a result play an important role in the diffusion of innovation and hence economic growth. The results using this separation are reported in Table Five; the last regression includes the two spillover variables experimented with in Table 4 and the deviation of firm from sector R&D RDDIF.

[20] The 18-sector classification is used to give more detail. Some of the sectors are large producers of innovations that are used in many other sectors; they include: chemicals, mechanical engineering, instruments and electrical and electronic machinery. See Robson *et al*. (1987) for more details.

[21] Odagiri and Iwata (1986) make estimates based on a separation into innovating and non-innovating sectors using on R&D intensity; Griliches and Mairesse (1984) separate firms into 'scientific' firms and 'other' firms also based on R&D intensity.

Table 5: Dividing the sample by sector

k/l	L	RD/Q or RDDIF	SECRD/Q_s	SPILL/Q_s	R^2
0.15 **	-0.17 ***	0.06			0.2
(0.06)	(0.05)	(0.23)			9
0.15 **	-0.17 ***	0.09	0.01	-0.02	0.2
(0.06)	(0.05)	(0.26)	(0.28)	(0.24)	9
0.13	-0.08	0.64 ***			0.2
(0.12)	(0.07)	(0.26)			4
0.21 *	-0.05	0.42	0.95 ***	-2.48	0.3
(0.12)	(0.06)	(0.30)	(0.30)	(1.54)	2

In general we would expect firms in sectors which are net producers of innovations to have similar results to the innovating firms. Diminishing returns are found for firms in the innovation-producing sectors, as earlier they were found for the innovating firms. There is also a lower elasticity on the capital to labour ratio. The results for the R&D intensity variables are the most interesting. Only firms in sectors that are net users of innovations have a significant coefficient on the R&D variable; in addition, the rate of return to R&D is higher for firms in these sectors (0.64 i.e. over double that of the sample as a whole).

That R&D intensity is significantly related to productivity growth only for firms in the innovation-using sectors may be explained by the hypothesis put forward by Cohen and Levinthal, (1989). They suggested that firms may need some R&D capabilities to improve the firm's 'absorptive capacity' in order to benefit from the innovations of other firms. Firms in the innovation-using sectors may thus gain a higher rate of return on R&D as it allows them to benefit from innovations originating outside the firm. When R&D is divided into two components – that specific to the firm (RDDIF) and that of other firms in the sector, it is the latter that appears to be significant in influencing productivity growth. Firms in using sectors appear to benefit from the R&D of other firms in the sector more than from their own.

The innovation-producing sectors on the other hand, do not appear to benefit from their own or others' R&D expenditure. One explanation is weaknesses in the R&D expenditure variable, which make it an inadequate proxy for technology. This would particularly affect firms in innovative sectors as they have greater technological capabilities to be captured.

Overall the results do not indicate a stable relationship between R&D intensity and productivity growth for all firms in the sample. Although a significant positive relationship between the two is found, when sector fixed effects are included this relationship is no longer significant. There is no evidence to support the existence of spillovers of R&D from innovation-supplying sectors. R&D expenditure within the same sector only has a positive relation to productivity for some sectors – those that are net users of innovations.

6. Conclusions

The results presented in this paper indicate that the role of R&D expenditure in productivity growth in the UK is similar to that found for other countries such as the US, France and Japan. However, the relationship between productivity growth and R&D intensity was also found to be very sensitive to the inclusion of sector dummy variables, indicating an important role for different sector conditions in explaining variations in productivity growth. The inclusion of the R&D expenditure of other firms in the same sector does not improve the results – other sector-level influences may be more important.

No role was found for spillovers of R&D expenditure from innovation-supplying sectors. This is in contrast to many microeconomic studies that have found evidence of important inter-sector spillovers of innovation. This result may be due of the measurement of spillovers used: the production and use of innovation matrix captures only a certain type of relationship between sectors reflecting mainly rent spillovers. The matrix represents only the flow of major innovations to the first user, rather than incremental and small innovations and the greater diffusion of innovations across sectors.

As there is considerable heterogeneity among firms, attempts were also made to group the firms according to their innovation histories. Innovative firms spent more on R&D expenditure relative to sales than non-innovating firms (2.3% against 0.8% in the period 1988 to 1992); this R&D expenditure also appears to have a higher rate of return than the R&D expenditure of non-innovating firms. The rate of return is particularly high when firms are located in sectors that are net users of innovations. Both the innovation history of the firm and the sector appear to be important influences on the rate of return to R&D: innovative firms and firms located in ‘innovation using’ sectors both have higher rates of return than other firms.

Appendix: Data definition and sources

Real capital: total fixed gross assets from Datastream deflated by the investment deflator from the 1996 UK National Accounts.
Real total sales: total sales taken from Datastream deflated by the producer price output index taken from the UK Monthly Digest of Statistics (1993).
R&D expenditure taken from Datastream.
Sector R&D expenditure came from First Release CSO, various issues.
Sector level output came from the CSO Report on the Census of Production Summary Volume PA 1002 from Business Monitor, various issues.
Data on innovations come from 'Innovations in the UK since 1945' Science Policy Research Unit, University of Sussex; data obtained from the ESRC archive, Essex.
The number of employees was taken from Datastream.

The sector classification used is given below for 18 sectors. The 2-digit 1980 revised SIC classification is given after the name of the sector. When a 10-sector division was used sectors 1 (metal manufacturing) and 4 (other metal goods) were included together as where the two transport sectors 8 and 9. All the sectors from 11 to16 were included as one sector; sectors 17 and 18 were also grouped together.

The Sector Classification

1 metal manufacturing (22)	10 instrument engineering (37)
2 non-metallic manufacturing (24)	11 food, drink & tobacco (41/42)
3 chemical & man-made products (25 & 26)	12 textiles (43)
4 other metal goods (31)	13 leather goods (44)
5 mechanical engineering (32)	14 footwear & clothing (45)
6 office and data machinery (33)	15 timber (46)
7 electrical & electronic machinery (34)	16 paper & printing (47)
8 motor vehicles & parts (35)	17 rubber & plastics (48)
9 other transport (36)	18 other manufacturing (49)

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