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The Impact of R&D on Productivity: Evidence from Danish Manufacturing Firms.

by

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Abstract:

The aim of the paper is to examine the relationship between R&D capital and productivity using micro data for Danish manufacturing firms. We account for the influence of factors such as ownership, innovative characteristics and source of funding. The return to R&D capital is estimated to be in the neighbourhood 15 per cent. In the short run R&D labour has a negative effect. Furthermore, we find that the foreign-owned firms' R&D capital is associated with greater returns than domestic firms, whereas the source of funding, innovative characteristics and ownership dispersion seem to have only minor importance for firm productivity.

Keywords: Productivity, R&D, innovation.

JEL Codes: L11, D24.

1. Introduction[1]

Most economists think that investments in R&D - to create valuable knowledge - have been an important factor behind increases in productivity and for economic growth in the past. As a consequence, it is commonplace to recommend the strengthening of R&D efforts to secure future growth and prosperity.

Despite the appearance of a voluminous body of literature dealing with this question, the empirical evidence on the interrelationship between productivity growth and R&D investment is still mixed. Thus, a number of studies find only weak or insignificant evidence of influences from R&D on productivity. There could be at least two reasons for this. Many of the previous studies have been carried out during the 1970s and the beginning of the 1980s, which was a difficult period for production studies because of the first and second oil crises. More recent studies based on data of the 1990s offer more clear (and positive) evidence of the effects of R&D. Secondly some measurement and data problems could explain the differences in the results obtained. As a consequence, the answers to questions like - *Is there a relationship between R&D and productivity* or *how powerful are R&D investments in raising the productivity at the firm, industry or macro level?* - are still relevant to pursue by the end of the 1990s.

Over the last 10 years the real R&D expenditure of the Danish business sector has increased by 90%. At the same time, the business sector R&D expenditure's share of GDP has increased from 0.69 to 1.09, implying R&D investments have grown at a faster rate than the economy as a whole. Dilling-Hansen et al. (1998) analyse the importance of various factors in explaining the R&D behaviour of Danish companies. They find evidence of Danish firms using R&D as a strategic decision parameter and accordingly, that the competitive environment of the firm and a number of firm-specific characteristics like solvency, earnings, size and age play a significant role in the firms' R&D investment decisions. Although there has been a growing interest in empirical research on the potential influence of R&D investment, there is no Danish empirical evidence of the importance of R&D investment on firm productivity.

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The aim of this paper is to present some empirical evidence on the link between investment in R&D and productivity for Danish manufacturing firms. We use the same approach as Griliches (1986)[2] and estimate the output elasticities of R&D using different measures of R&D capital and correcting for double-counting of the R&D inputs (number of researchers and/or capital expenditure). In addition, we account for the influence of ownership control, innovative characteristics of the firm and the source of financing R&D investments. We make use of a survey of Danish firms with detailed information on R&D expenditure and a number of account variables.

In the next section, we briefly summarise two key arguments behind the conventional empirical productivity models. The empirical model is set out in section 3. Section 4 describes the data to be used in the analysis. The empirical results are presented in section 5. Section 6 concludes.

2. Productivity and R&D – a brief overview

The theoretical framework of the majority of studies is the Cobb-Douglas production function, which is presented in logarithms as

$$\log(Y) = a + \lambda t + \alpha \log(K) + \beta \log(L) + \gamma \log(C) + \varepsilon \qquad (1)$$

where Y is a measure of output (production or sales), L a measure of labour input and t is a trend variable. C and K are measures of the cumulated research effort (capital) and other physical capital, i.e. machinery, buildings etc. λ, α, β and γ are the unknown parameters to be estimated. C is normally approximated as a weighted sum of current and past R&D expenditure. Accordingly, γ can be interpreted as the output elasticity of R&D. The error term, ε , frequently called the Solow residual, captures the total factor productivity.

The production function model is the point of departure in a huge body of empirical work. Thus, various versions of the model in equation (1) have been estimated by Griliches (1980), Schankerman (1981), Griliches and Mairesse (1984, 1990), Jaffe (1986), Cuneo and Mairesse (1984), Griliches (1986, 1995), Sassenou (1988), Hall and Mairesse (1995), Husso (1997) and Bartelsman et al. (1996) using either cross-section

[2] See also Husso (1997), Wakelin (1998) and Lehtoranta (1998).

data at the firm (line of business) level or firm panel data. Some studies use labour productivity as the dependent variable, e.g. Lehtoranta (1998).

In general, the estimated elasticity of output with respect to R&D capital, γ, is found to lie between 0.05 and 0.2. In many studies, however, the values of γ are rather small or even statistically insignificant, casting doubt on the productivity enhancing effects of R&D. Recent estimates seem to be higher than the older ones, especially studies from the 1970s and the early 1980s, see Griliches (1995). Hall and Mairesse (1995) using French data for 1980-1987 argue that γ could be as high as 0.25. Thus, there are indications that the 1970s and the early 1980s were unfavourable for measuring the effect of R&D - mainly because of the stagnation of the OECD economies. Under conditions of low growth and declining productivity, the measurement of the effect of R&D becomes difficult. Lehtoranta (1998) estimates a firm level random effect using data for 186 Finnish firms over the period 1991-1994. This is a period characterized by low or negative growth in the Finnish economy. In accordance with the arguments above, the estimations show that the elasticity of R&D capital on labour productivity is about 0.07.

In general, there are problems in measuring the R&D capital stock (C). Several authors have used an alternative form of equation (1)

$$(2) \qquad dlog(Y) = \lambda + \alpha\, dlog(K) + \beta\, dlog(L) + \rho\, (R/Y) + \mu$$

where levels are replaced by growth rates (dlog(X)=(dx/dt)/x) and *R* denotes the annual expenditure on R&D net of depreciation of the previously accumulated R&D capital. The parameter ρ can be interpreted as the rate of return to investment in R&D capital. Thus, it can be shown that $\rho = \gamma$ (Y/K). The main advantage of this formulation is that the productivity growth rate is directly related to some measure of the R&D intensity. However, the problem of measuring C has then been replaced by difficulties of assessing correct values of depreciation in order to measure net R&D expenditure. Another important problem using equation (1) or (2) for empirical analyses is whether the output variable is measured correctly, see below.

Equation (2) was estimated by Mansfield (1965), Link (1983), Clark and Griliches (1984), Odagiri and Iwata (1986), Griliches (1986), Sassenou (1988), Griliches and

Mairesse (1990), Hall and Mairesse (1995), Wakelin (1998) and others using firm data.[3] These studies present evidence for France, the United States, Japan and Belgium. The estimated rates of return lie between 0.2 and 0.5, but it should be noted that the rate of return depends on the unit values of R and Y. In general, however, there seems to be only minor indication of significantly higher rates of return in the studies using industry data as compared to individual firm studies.

In estimating (2), Wakelin (1998) focuses on differences between innovators and non-innovators, with the R&D having the largest productivity effects for the latter group. Furthermore, sector-specific effects are controlled for in order to reduce the bias due to sector- specific unobservables. In general, ρ is significantly positive when no control is made for sector effects, but turns insignificant when the sector dummy variables are introduced. When Wakelin divides the sample into producers and users of innovations, she finds that only firms belonging to the latter group benefit from their own R&D investments. Another noteworthy finding is that spillover effects from the relevant industry seem to be most important for producers of innovations.

3. The empirical model

In line with the majority of studies, the empirical model in this study is a Cobb-Douglas production function augmented with variables taking into account the influence of source of funding R&D, ownership and innovative characteristics of the firm plus industry-specific effects. Thus, the empirical analysis includes only firms with a positive R&D capital stock.

The influence from innovation is introduced separately. In general, firms may be innovative or non-innovative independently of their R&D effort. The main conclusion in Pakes and Griliches (1984) is, however, that there is a strong and positive relationship between R&D and the number of patents at the firm level in cross-section studies. More precisely, if the firm has made a success of its R&D investment by being more innovative, higher overall productivity should be expected. Consequently, the interaction of R&D and innovation is likely to have a positive effect on productivity.

[3] Moreover, Scherer (1982) and Griliches (1995) estimate the production function on industry level data.

However, the concept of innovation does include activities that are not related to R&D efforts.[4] A firm can invest in new equipment embodying technological innovations; it can buy software and new technology connected to technological innovations, e.g. patents, non–patented inventions, licenses and consultant services in connection with the implementation of technological innovations. If the firm chooses a strategy to buy innovations for implementation in its own production, R&D and innovation services end up being substitutes. In that case, low R&D figures could be the result of a strategy of buying innovations instead of undertaking the risky R&D investments oneself. *A priori* the net effect of innovation on firm productivity is expected to be positive.

In line with Griliches (1986), we analyse the influence of the financing of R&D i.e. externally (which is mainly publicly) vs. company financed R&D capital. In principle, no differences on productivity should be expected at the firm level as a 'dollar is a dollar' irrespective of source.[5] However, if the firm itself is responsible for the entire financing of its R&D-project, the investment would probably only take place if the expected return is quite high. For that reason we expect that a higher ratio of company financed R&D investments to total R&D investment will raise the average productivity of the firm.

The corporate governance literature[6] suggests that it does make a difference whether a firm is controlled by the managers or by its owners. Differences in the objective functions of owners and managers in combination with the separation of ownership from control may have behavioural implications for the firms. Thus, ownership control is expected to have a positive influence on firm productivity and furthermore, these firms are expected to be more R&D effective.

In this paper we pay attention to two aspects of ownership control. First, we distinguish between domestically or foreign-owned firms. The motive for investing in another country is often that production will be efficient compared to national firms. Thus, foreign-owned firms constitute a selected group of firms. Moreover, when a parent firm decides to invest in R&D in a subsidiary company abroad, that decision is probably made in expectation of a rather high average return of that investment. Generally, R&D

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[4] See the Oslo-manual.

[5] Griliches (1979).

[6] See Short (1994), Mayer (1996), Berglöf (1996) and Shleifer and Vishny (1998) for some recent surveys.

investments are more risky than ordinary investments made in the home country and therefore, it is obvious that an extra premium on R&D investments abroad is expected. Thus, we expect that output elasticity of R&D is higher in foreign-owned firms compared to national-owned firms.

The second dimension of ownership is straightforward and relates to the number of shareholders. If there are many small owners, the managerial discretion will increase. Thus, we expect that if there are owners holding a significant share of the firm, the ownership control will force the managers to be effective in their input decisions. However, there may be other stakeholders than the owners, e.g. banks and other debt holders who may exercise control and therefore need to be taken into account in a more complete analysis.

4. Data

The data used in this study are based on public information on the economic performance of Danish firms and on a unique data set containing - in principle - all R&D investments in Danish firms.

The general information on economic performance of firms comes from data from a private company (*Købmandsstandens Oplysningsbureau LTD.*). However, the basic source of information is firm-specific information on the economic performance derived from legal obligation of companies to publish reports to the authorities.[7] All firm data on economic performance have been converted to calendar year accounts and all firms have been assigned an industry code corresponding to the Nace-code classification. The sample used in this paper uses account data from 1993 and 1995, which was a period of rising business conditions. Furthermore, the output variable has been approximated with the net-turnover of the firm and as measure of firm capital 'fixed assets' has been preferred.

The data on R&D were obtained from the official Danish R&D statistics, which are collected every second year by the Danish Institute for Studies in Research and Research Policy.[8] At the empirical level, the concept of R&D comprises *creative work undertaken*

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[7] For a description of the account data, see Dilling-Hansen et al. (1997).

[8] Until the 1995 issue The Danish Ministry of Education and The Danish Ministry of Research were responsible for providing the data and for publishing the statistics.

on a systematic basis in order to increase the stock of knowledge of man and society, and the use of this stock in order to devise new applications; see the Frascati-manual p. 29.

The basic reporting unit of the R&D survey is the legal firm unit, which can be identified in the account statistics. In the 1995 R&D survey, the number of respondents was 2,485. 2,019 firms returned the questionnaire, giving a response rate of 81%. Of these, 684 firms reported having positive R&D expenditure, see The Danish Ministry of Research (1997).

The overall data set on R&D, which is biannual, covers the period 1987-1995. Missing R&D information is estimated for each firm by calculating the arithmetic mean for the two adjacent years. Next, the R&D capital stock is calculated by accumulating annual R&D expenditure assuming a constant depreciation rate on R&D capital, δ, the capital is the sum of all real investments in R&D, $R_{i,t}$, in the past.

(3) $$C_{i,t} = \Sigma R_{i,t} (1-\delta)^t = (1-\delta) C_{i,t-1} + R_{i,t}$$

Experiments were made in order to decide on the value of δ, see Dilling-Hansen et al. (1999). In the analysis below, δ has been chosen to be at 20%. It should, however, be mentioned that within a δ-values range of 10-20%, the estimation results did not change much.

Table 1. Summary Firm Statistics (firms with positive R&D-capital), for two panels 1987/95 and 1991/95 used in the Empirical Models.

	Number of observations		Mean	
	1987/95	1991/95	1987/95	1991/95
Net-Turnover, 1995 (million DKK)	195	259	637.656	542.570
Labour – number of employees, 1995	195	259	575	482
Capital – rep , 1995 "Fixed Assets" (million DKK)	195	259	351.303	294.982
R&D-intensity, 1995.	195	259	0.034	0.040

Source: Account data: "Købmandsstandens Oplysningsbureau A/S". R&D data: The R&D statistics collected by "Danish Institute for Studies in Research and Research Policy".

The calculation of R&D capital for e.g. 1995 requires the construction of effective firm panels of a certain length. Table 1 gives summary statistics for 1995 of the firms in two separate panels, one covering the period from 1987 to 1995 and another from 1991 to 1995. Naturally, the longer panels, e.g. 1987/95, include fewer firms. In addition, it will be seen that larger firms are overrepresented in both panels. Not surprisingly, the 1987/95-panel includes the largest firms, which on the other hand are firms with a lower R&D intensity in 1995.

Both panels of different lengths have been used in the construction of the R&D capital variable. Using equation (3), initial values for R&D capital, C_o, are needed. In accordance with other studies, C_o is approximated by the R&D investment for the starting year. Thus, for the long panel C_{87} is approximated with $R\&D_{87}$ and using the shorter panel $C_{91}=R\&D_{91}$. In the latter case, using a δ-value of 20%, approximately 30% of potential 1990 R&D investment would still not have been written off in 1995, suggesting that R&D capital could be underestimated for some firms.[9]

Data on the fraction of company financed to total R&D expenditures also derive from the Danish R&D statistics. It is noted that company financed R&D expenditures include 'external' financing coming from other companies that belong to the same holding company. On average, the company share of funding R&D investment is 93 percent, with a minimum percentage of 20 percent and maximum of 100 percent.

In addition to the data mentioned above, we add firm-level information from the CIS II –survey for Danish firms. As mentioned above, innovative firms are expected to be more productive. In the Innovation Survey, firms are defined to be innovative if they either have introduced new technology news or have improved production processes or products or have unsuccessful projects aiming at introducing new or improved production processes or products during 1994-1996. Merging the data from the Innovation Survey with the longer panel in table 1 results in 136 firms for the analysis below, of which 78% were innovative according to the definition.

[9] Dilling-Hansen et al. (1999) estimate equation (2) using pooled data for 1186 Danish firms for 1995/94 and 1993/92 data. The ρ-estimates are *negative* and significant in all estimations, indicating that the model assumptions may not have been fulfilled.

Finally, information on ownership is added. This information has been collected from various issues of the yearly publication *Greens - Børsens håndbog om dansk erhvervsliv*. The firms included in *Greens* either have more than 50 employees or a turnover exceeding DKK 50 million in 1994 prices. For this project only data for the manufacturing firms have been completed. The information given in this data set is whether the firm is purely owned by foreigners (dummy equal 1, else 0, with a mean value equal to 0.128); the firm has at least 3 owners, each in holding of more than 5% of the firm (ownership control dummy equal to 1 else 0, with a mean of 0.328).

5. Results

The empirical results are based on the Cobb-Douglas production function shown in equation (1). The data on economic performance are mainly from 1995, and the R&D capital is calculated as the sum of the real net investments in R&D in the period 1987-95 using equation (2). Output is measured as the net-turnover and capital as firm fixed assets. The models are estimated by OLS-framework.

The basic model in table 2 (column 1) introduces R&D in the productivity model by a dummy for positive R&D investments in the period 1987-95, which gives a significant negative (!) impact on productivity from R&D. However, a positive R&D investment without any information on intensity, number of periods with investments etc. is a very simple measure of R&D knowledge. Estimations with R&D capital are given in column (2) and (4).

In column (2) a simple version of equation (1) including R&D capital - estimated by equation (3) using a 20 % depreciation rate - has been set out. Due to the log transformation, only firms with positive investments in R&D are included in the estimations. There are small decreases in labour productivity and a small increase in the productivity of capital, and the effect of R&D capital now becomes positive. However, the coefficient is significant only at the 10 percent level of significance and is rather small numerically. Still, no correction has yet been made for the double counting of R&D input in the labour and capital variable.

Table 2. Productivity and R&D, 1995.

	Simple model including R&D dummy. (1)	Including R&D capital, no correction. (2)	Correction for double-counting in R&D capital. (3)	Including R&D labour input in the short run. (4)
Intercept	5.9321 (0.2366)	5.5617 (0.2883)	5.5823 (0.2861)	5.2487 (0.4057)
Log (labour, non R&D)	0.7895* (0.0530)	0.7403* (0.0715)	0.7595* (0.0650)	0.7667* (0.0652)
Log (R&D labour stock)	-	-	-	-0.0583 (0.0503)
Log (capital)	0.1897* (0.0329)	0.2120* (0.0451)	0.1756* (0.0354)	0.1712* (0.0355)
Log (R&D capital)	-	0.0377*** (0.0209)	0.0785* (0.0251)	0.1274* (0.0491)
R&D dummy	-0.0454 (0.0703)			
Number of observations	266	194	110	110
R^2 - adj.	0.785	0.809	0.880	0.880

Notes: The R&D capital is based on investments in R&D for the period 1987 to 1995 with a 20% depreciation rate. Numbers in brackets are standard errors of the estimated parameters. * indicates that the estimated parameter is significantly different from zero at the 1% level of significance. * *at the 5% level, and *** at the 10% level.

To avoid double counting, we next separate R&D and non-R&D capital and distinguish between the employees working with R&D production and other workers as two separate labour inputs. Thus, non-human R&D capital has been deducted from the firm capital as recorded the legal firm accounts (where there is no distinction between different kinds of capital). In addition the R&D personnel has been subtracted from the total stock of labour. This is necessary in the reports to the authorities because the latter includes both R&D- and non-R&D personnel.

The results are reported in column (3). Correction for double counting results in highly significant parameters - at the 1% level. In particular the output elasticity of R&D-capital

is close to 8%, which is a little lower than e.g. the results of Griliches (1986) but above the value reported in the recent study of Lethoranta (1998).

The rather low return on R&D in column (3) might reflect potential time lags for R&D-investments to increase output. As a consequence the number of R&D workers is included in the equation and R&D-wage expenditures have been deducted from the latest year. Keeping the overall employment constant, the short run effect of allocating more labour resources from production to R&D is expected to have a negative influence on (short run) productivity.

The estimation with four production factors is set out in column 4. We can see that the R&D labour has no (or negative) direct effect on productivity and that the elasticity of output with respect to R&D capital is significant at the 1% level and is close to the estimates found in the international literature, between 10-15 percent, see section 2.

5.1 Decomposing the effect of R&D on productivity

Besides the direct effect of R&D on productivity , the accumulation of knowledge can affect the production process itself, which may result in changed returns from other production factors.

In a Oaxaca decomposition process, see e.g. Oaxaca (1973), the total average productivity difference between companies with and without R&D investments is decomposed into two components, a *characteristic component*, C, and a *coefficient component*, D. Two production functions are observed, one for R&D active firms, see (4), and one for companies without investments in R&D, see (5).

$$(4) \quad \ln Y_{R\&D} = \mathbf{X}_{R\&D}\, \beta'_{R\&D} + \mathbf{Z}_{R\&D}\, \gamma'_{R\&D}$$

$$(5) \quad \ln Y_{non} = \mathbf{X}_{non}\, \beta'_{non}$$

with **X** being the matrix of common explanatory variables for the two types of firms and **Z** being the explanatory variables for the R&D active firms. The Oaxaca-decomposition (evaluated using R&D-coefficients) may be written as

The first two terms in (6) containing the common explanatory variables are decomposed into the two components, C and D, while the last term only contributes for active R&D firms.

$$(6)\quad \overline{\ln Y_{R\&D}} - \overline{\ln Y_{nonR\&D}} = \overline{\mathbf{X}}\hat{\beta}'_{R\&D} - \overline{\mathbf{X}}\hat{\beta}'_{nonR\&D} + \overline{\mathbf{Z}_{R\&D}}\hat{\gamma}'_{R\&D}$$
$$= (\overline{\mathbf{X}_{R\&D}} - \overline{\mathbf{X}_{nonR\&D}})\hat{\beta}_{R\&D} + \overline{\mathbf{X}_{nonR\&D}}(\hat{\beta}_{R\&D} - \hat{\beta}_{nonR\&D})' + \overline{\mathbf{Z}_{R\&D}}\hat{\gamma}'_{R\&D}$$
$$= C + D + R\&D$$

On the basis of the extented models estimated in table 2, columns 3 and 4, the Oaxaca decomposition has been made in accordance with equations (4)-(6). The results are presented in table 3 where the total difference in average productivity between companies with and without R&D has been split into a *characteristic components*, C_i, and a *coefficient component*, D_i. The average R&D contribution ($\overline{Z_{R\&D}}\hat{\gamma}'_{R\&D}$) has been placed below the constant component in the *coefficient component*, D.

The overall difference in average productivity is decomposed in a *characteristic component* and a *coefficient component*. From table 3 we see that the overall difference (C+D= 0.451) mainly is caused by differences in factor intensity (C=0.356). The *coefficient component* (D=0.095) is smaller but still interesting. Keeping the factor intensity constant, we see that the average difference in labour (0.376) and physical capital (0.414) productivity is high between firms with/without investments in R&D.

Table 3. Oaxaca-decomposition of the average difference in productivity between firms with/without investments in R&D.

	Model based on col. 3 in table 2		*Model based on col. 4 in table 2*	
	Characteristic component, C	*Coefficient component*, D	*Characteristic component*, C	*Coefficient component*, D
Log (L)	0.275*	0.336	0.277*	0.376
Log (K)	0.081*	0.462	0.079*	0.414
Intercept	0	-1.469	0	-1.803
R&D-level	-	0.766	-	1.107
Components	0.356*	0.095	0.356*	0.094
All		0.451		0.451

* indicates that the component is significant at the 5% level of significance

In both models in table 3 the total average difference in productivity between firms with and without R&D is approx. 50%, and as mentioned above we see that the difference in productivity is mainly due to differences in company size, C_i. On the other hand, from the *coefficient component* it is clear that the factor productivity of labour and physical capital will increase if the company has invested in R&D. However at the 5% level of significance only differences in characteristics are significant.

The models estimated in table 2 show that there is a positive influence from the invested R&D capital. The results in table 3 indicate that there is a potential positive interaction effect between R&D investments and the other input factors. These interaction effects will be analyzed below.

The results found depend on the validity of the specified Cobb-Douglas production function. Berndt & Christensen (1973) proposes an extented version of the production function, the translog model. The translog models allow interaction between the input factors in general and the Cobb-Douglas function is regarded as a special case. Assuming constant-returns-to-scale and Hicks-neutral technical changes, the unrestricted model can be formulated as

$$(7) \quad \ln Y = \ln \beta_0 + \sum_i \beta_i \ln X_i + \frac{1}{2} \sum_i \sum_j \gamma_{ij} \ln X_i \ln X_j$$

The models in table 2 have been tested against the unrestricted tranlog model, see (7), using a simple F-test on the restriction coefficients, H_0: $\gamma_{ij}=0$. In all cases we find that the restricted model, the Cobb-Douglas specification used, cannot be rejected. In other words, the test based on the translog model shows no indications of misspecifications in the models used.

5.2 Estimating productivity using fixed-effect models

A number of models were estimated to test the effects of using "net turnover" instead of "value added". Selected models with pooled data for 1993 and 1995 are presented in Table 4. The general picture is very much the same as in table 2. The introduction of 2-digit industry dummies and controlling for year-effects in column 2 give results very similar to those in column (4) in table 2: The output elasticities with respect to labour and R&D capital are almost unaffected while the returns from real capital are slightly lower. In other words, after controlling for productivity differentials between industries, remaining inter-firm differences are related to R&D capital.

Table 4. Productivity and R&D. Models with industry effects and firm-specific fixed effect models, balanced panel for 1993 and 1995.

	Basic Model Dummy for year included (1)	Model including dummy for NACE 2 level industries, 1995. (2)	Model including firm-specific fixed effects (3)
Intercept[1]	-	-	-
Log (labour)	0.7893* (0.0559)	0.7479* (0.0818)	0.9896* (0.0894)
Log (R&D labour)	-0.1103** (0.0448)	-0.0743 (0.0554)	0.0402 (0.0293)
Log (capital)	0.1846* (0.0316)	0.1440* (0.0501)	0.0319 (0.0308)
Log (R&D capital)	0.1499* (0.0446)	0.1386** (0.0682)	0.0815* (0.0354)
Number of observations	176	88	176
R^2 - adj.	0.900	0.940	0.990

Notes: The R&D capital is based on investments in R&D for the period 1987 to 1995 with a 20% depreciation rate. Model in column 3 includes firm-specific fixed effects. The R&D capital for the two years is based on the previous 5 years' investments in R&D, 1989-1993 and 1991-1995. Wages for R&D workers in the end years is not included. Numbers in brackets are standard errors of the estimated parameters. A * indicates that the estimated coefficient is significantly different from zero at the 1% level of significance. * * at the 5% level, and *** at the 10% level.

[1] Year, industry or firm-specific levels not presented.

Column 3 presents results in which we have allowed for firm-specific fixed effects in order to correct for unobserved firm specific heterogeneity. The estimated coefficients to labour and capital change dramatically and the coefficient to R&D capital is halved but is still significant.

5.3 Interaction between R&D and other inputs

In section 3 some other factors affecting productivity were discussed. The source of funding R&D, the presence of foreign investments, the number of large owners and the level of innovative activities are likely to affect the overall level of productivity and moreover, they are likely to have an impact on the influence from R&D on productivity. For a sample of 110 firms, information on ownership (foreign and number of owners) and innovative activities has been merged with the data used in the earlier analyses. The results from using this sample are given in Table 5. In the models presented in the first 3 columns, the extra information is included as dummies, which interact with the R&D capital.

In the first column, an innovative firm dummy is entered as an additional explanatory variable. The main effect is fairly significant but imprecisely estimated and the interaction with the R&D capital stock attaches a negative and insignificant coefficient. Thus, the innovative activity information does not add anything noteworthy.

The next additional regressor tried out is a dummy equal to unity for firms with a concentrated ownership (i.e., three or more owners in possession of at least five per cent each of the firm). As is evident from column 2, this variable is not able to add to our understanding of differences in firms' total factor productivity.

The third potentially contributing factor is foreign ownership, which is accounted for in the third column. Once again, the returns to non-R&D capital and labour are robust and the main effects carry a numerically large albeit insignificant coefficient. The estimated interaction effect is also relatively large and differs from zero on the 6 per cent significance level. The larger productivity effect of R&D for foreign-owned firms is consistent with some earlier findings of multinational firms being better performers than domestic firms; see Griffith (1999) for a study of production differences in the UK car industry.

The final empirical point of discussion is the influence from internal financing of R&D. In column (4) the share of R&D financed by the company itself is added to the model both as a separate variable and in interaction with R&D capital. It is easily seen that albeit relatively more internally financed R&D has a positive effect on productivity, none of the estimated parameters are significant. Moreover multicollinarity problems between the interaction term and R&D capital invalidate the significance of the coefficient to R&D capital[10]

Table 5. Productivity model estimations with R&D interactions.

	Innovative charactistic	Concentrated ownership	Foreign ownership	Company financing R&D
Intercept	5.038 (0.8533)	5.1262 (0.4178)	5.4348 (0.4091)	4.8156 (1.4136)
Log (labour)	0.8013* (0.0832)	0.7598* (0.0648)	0.8340* (0.0681)	0.8102* (0.0620)
Log (R&D labour)	-0.0334 (0.0636)	-0.0681 (0.0501)	-0.0503 (0.0536)	-0.0481 (0.04677
Log (capital)	0.1508* (0.0444)	0.1792* (0.0354)	0.1435* (0.0360)	0.1821* (0.0337)
Log (R&D capital)	0.1541*** (0.0893)	0.1402* (0.0496)	0.0948** (0.0517)	0.0927 (0.0736)
Innovation dummy	0.4256 (0.8005)			
Innovation dummy∗log(R&D capital)	-0.0527 (0.0795)			
Concentrated ownership dummy		0.0166 (0.6601)		
Concentrated ownership∗ log(R&D-cap.)		-0.0217 (0.0654)		
Foreign ownership dummy			-1.4478 (0.9056)	
Foreign ownership∗ log(R&D capital)			0.1646** (0.0879)	
Company financed R&D, (share).				0.2907 (1.4283)
Company financed R&D∗ log(R&D-capital)				0.0085 (0.1243)
R^2 – adj.	0.860	0.882	0.886	0.90
Number of observations	86	110	110	108

Notes: see Table 3.

[10] Reestimating column (4) without an interaction term resumes the results of table 2 and 4 by giving a significant output elasticity of R&D capital near 10%. However the direct influence from company financed R&D remains insignificant.

6. Conclusions

Investments in R&D are expected to increase the firms' productivity. In this paper we have used a production function approach to estimate the effects of the R&D capital on total factor productivity. Based on Danish firm-level data from 1987 to 1995, R&D capital is constructed, using a depreciation rate of 20% and accounting for problems with double counting. We find a positive output elasticity of R&D capital in the area of 12-15% in line with other international studies, noting however that the estimation years - the mid 1990's - were upturns years for the Danish economy.

The Oaxaca decomposition of the productivity into a *characteristic* and a *coefficient component* shows that the overall difference in productivity on average is mainly due to firm size, i.e. a higher level of factor inputs. On the other hand, given this difference between firms with and without R&D investments, we find that investments in R&D increase the factor productivity of labour and physical capital. However this effect is not fully significant.

The amount of company funding does not affect productivity directly, neither positively nor negatively. Thus, there is no Danish evidence that e.g. public funding of R&D has a direct effect on the productivity of firm R&D capital, i.e. externally financed R&D capital has the same productivity as company financed R&D capital. Thus the main reason for e.g. public funding of business sector R&D would be the indirect effect via the stimulation effect on company financed R&D investments.

Other factors like innovations, ownership control and foreign ownership are also expected to affect the productivity. In this paper the influence on productivity of interaction effects between R&D and the above mentioned factors is tested. The number of large owners do not affect the productivity of the R&D investments, and innovative firms do not have higher productivity returns to their R&D investments.

On the other hand, we find a positive effect on productivity from foreign ownership and moreover, the R&D capital is more productive compared to that of domestically owned firms. Whether this effect is due to technology transfer or to selective foreign investments in productive industries is up to further studies.

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