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R&D and Productivity in Danish Firms: Some Empirical Evidence

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 accumulated R&D capital is estimated to be in the neighbourhood of 9-12 per cent, whereas the short-run effect of R&D is insignificant. Furthermore, we analyse the direct influence from foreign ownership, source of funding, innovative characteristics and ownership dispersion on productivity. However, none of the factors seem to have an impact on firm productivity. The same is the case for the indirect influence coming from interaction with accumulated R&D capital.

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1. Introduction[1]

Most economists think that investments in R&D - to create valuable knowledge - has been an important factor behind increases in productivity and 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 early 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. Further, 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 highly relevant to pursue in the beginning of the new century.

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 that 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 using data 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 the biannual Danish R&D survey which includes detailed information on R&D expenditure and a number of account variables at the firm level.

In the next section, we briefly summarise two key arguments of the conventional empirical productivity models. Our 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 and 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

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

where Y is a measure of output (production or sales), L a measure of labour input and t 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 data at the firm (line of business) level or firm panel data. Some studies use labour productivity as the dependent variable, e.g. Lehtoranta

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

(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, 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)

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

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 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

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

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 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 unobservable heterogeneity. 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.

The concept of innovation, however, 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

[4] See the Oslo-manual.

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] If the firm itself, however, 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. Therefore, 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 makes 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 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

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[5] Griliches (1979).

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

force the managers to be effective in their input decisions. However, there may be other stakeholders than the owners, e.g. banks and other debtholders 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 The Danish Bureau of Statistics. The basic source of information is firm-specific information on the economic performance derived from the legal obligation of companies to publish reports to the authorities. The sample used in this paper uses account data from 1995 and 1997, which was a period of rising business conditions. Furthermore, the output variable is value added, the ordinary firm capital is measured by 'fixed assets' as recorded in the accounts of the firm.

The data on R&D were obtained from the official Danish R&D statistics, which are collected every second year. At the empirical level, the concept of R&D comprises *creative work undertaken 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 (1997) R&D survey, the number of respondents was 2,485 (4,082). 2,019 (3,424) firms returned the questionnaire, giving a response rate of 81% (85%). Of these, 684 (1,013) firms reported having positive R&D expenditure.

The overall data set on R&D, which is biannual, covers the period 1987-1997. 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.

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

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 15-20%, the estimation results did not change much.

The calculation of R&D capital requires the construction of effective firm panels of a certain length. Table 1 gives summary statistics for 1995 and 1997 which are the end years in the two separate panels used in the analysis. Compared to the total Danish R&D statistics, larger firms are over-represented in both panels. Not surprisingly, the 1989/97-panel includes the largest number of firms, which is due to the increasing number of firms included in the Danish R&D Statistics over time.

Table 1. Summary firm statistics (firms with positive R&D capital), for two panels 1987/95 and 1989/97 used in the analysis.

	Number of observations		Mean	
	1987/95	1989/97	1987/95	1989/97
Value added (million DKK)	201	342	360,553	282,582
Labour – number of employees,	201	342	652	520
Capital – rep , “Fixed Assets” (million DKK)	201	342	367,032	284,051
R&D-intensity (R&D expenditure/value added)	201	342	0,0294	0,02449

Note: The figures in the 1987/95 and 1989/97 panels relate to the end years, i.e. 1995 and 1997.
Source: Account data: ”The Danish Bureau of Statistics”. R&D data: The R&D statistics collected by “Danish Institute for Studies in Research and Research Policy”.

Both panels 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 1987-1995-panel, C_{87} is approximated with $R\&D_{87}$. Using a δ-value of 20%, approximately 25% of potential 1987-R&D capital would still not have been written off in 1995, suggesting that R&D capital could be underestimated for some firms.

Data on company-financed and total R&D expenditure also derive from the Danish R&D statistics. It is noted that company-financed R&D expenditure include ‘external’ financing coming from other companies belonging to the same holding company. On average, the company share of R&D investment is 93 %, with a minimum of 20 % and maximum of 100 %.

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 1989-1997 panel in Table 1 results in 227 firms for the analysis below, of which 78% were innovative according to the definition.

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 data set reveals whether the firm is purely owned by foreigners (dummy equal 1, else 0, with a mean value equal to 0.128) and whether 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) and for each panel, the R&D capital is calculated as the sum of the real net investments in R&D in the periods 1987-95 and 1989-1997 using equation (2). Output is measured as value added and other capital (than R&D) as firm fixed assets. For each panel, the model is estimated separately and pools data as within a fixed effect model 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 positive but insignificant 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).

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, R&D personnel has been subtracted from the total stock of labour. This is necessary because the latter includes both R&D- and non-R&D personnel in the reports to the authorities.

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	4.0704 (0.2011)	4.1954 (0.2318)	4.1970 (0.2304)	4.3799 (0.3782)
Log (labour, non R&D)	0.5167* (0.0416)	0.4729* (0.0440)	0.4700* (0.0439)	0.4742* (0.0472)
Log (R&D labour stock)	-	-	-	0.0365 (0.0509)
Log (capital)	0.4212* (0.0271)	0.3730* (0.0299)	0.3728* (0.0298)	0.3090* (0.0318)
Log (R&D capital)	-	0.0840* (0.0160)	0.0884* (0.0162)	0.1254* (0.0449)
R&D dummy	0.0793 (0.0560)			
Number of observations	310	201	201	150
R^2 - adj.	84	86	87	88

Notes: The R&D capital is based on investments in R&D for the period 1987-1995 using 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.

The results are reported in column (3). Correction for double counting also results in highly significant parameters. In particular, the output elasticity of R&D-capital increases a little and is close to 9%, 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 modest elasticity of 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 expenditure have been deducted from the latest year assuming that earlier years' human R&D capital is internalized within the firm. Keeping the overall employment constant, the short-run effect of allocating more labour resources from production to R&D is expected to have only a insignificant influence on (short-run) productivity.

Table 3. Firm-specific fixed effects models, 1995-1997.

	Incl. R&D-labour in the short run, 1995 (1)	Incl. R&D-labour in the short run,1997 (2)	Fixed effects estimation, 1995-1997 (3)	Estimation on 1. differences 1995-1997 (4)
Intercept	4.3799 (0.3782)	4.9750 (0.2472)	-[1)]	0.0172 (0.0243)
Log (labour, non R&D)	0.4742* (0.0472)	0.5023* (0.0412)	0.5472* (0.1150)	0.6075* (0.1115)
Log (R&D labour stock)	0.0365 (0.0509)	0.1100* (0.0370)	-0.0593 (0.0471)	-0.0381 (0.0492)
Log (capital)	0.3090* (0.0318)	0.2674* (0.0247)	0.1247* (0.0281)	0.1298* (0.0323)
Log (R&D capital)	0.1254* (0.0449)	0.0801* (0.0288)	0.0858* (0.0647)	0.0880 (0.6900)
Dummy for 1997			0.0624* (0.0259)	
Number of observations	150	227	378	109
R^2 - adj.	88	86	99	36

Notes: The R&D capital is based on investments in R&D for the periods 1987 to 1995 (column (1)) and 1989-1997 (column (2)). In both cases a 20% depreciation rate has been used. The model in column 3 is based on a pooled data set for 1995-1997 and includes firm-specific fixed effects. 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.

[1)] Firm-specific levels not presented.

The estimation with four production factors is set out in column 4. It is easily seen that the R&D labour stock has no significant influence on productivity and that the elasticity of output with respect to R&D capital is significant at the 1% level and close to the estimates found in the international literature, 10-15%, see section 2.

Table 3 resumes column 4 of Table 2 and in addition, the table includes estimations on the 1997 data set separately and as fixed effects estimations. 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 in the productivity of capital as well, and the effect of R&D capital now becomes positive and highly significant, suggesting an output elasticity in the neighbourhood of 8%. Still, no correction has yet been made for the double counting of R&D input in the labour and capital variable.

To some extent, introducing data for 1997 - column (2) - gives different results than those in column (1). Thus, the output elasticities with respect to R&D capital drop to approximately 9%, which is nearly one third lower than the 1995 output-elasticity. On the other hand, the output-elasticity of R&D-labour is positive, nearly 11% and highly significant. However, the overall returns to scale are nearly identical in the two years, i.e. in the neighbourhood of 0.95, suggesting slightly decreasing return.

Finally, columns 3 and 4 present results in which we have allowed for firm-specific fixed effects in order to correct for unobserved firm-specific heterogeneity. The estimated coefficients to capital are lowered dramatically but on the other hand, the returns to labour increase. As a consequence, the total returns to labour and capital are only lowered insignificantly. Furthermore, the short-run effect of R&D seems to have no significant effect, which is in accordance with the a priori assumptions. It should be noted, however, that the coefficient to R&D capital becomes insignificant when estimating on first differences, probably because of the relatively low number of data available.

Concluding this section, the computations give evidence on a stable, significant and positive effect of accumulated R&D-capital on firm productivity. In the short run, however, R&D effort does not seem to have much effect on firm productivity.

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, and it may result in changed returns from other production factors.

In an 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) $\ln Y_{non} = \mathbf{X}_{non}\, \beta'_{non}$

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

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

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.

On the basis of the extended models estimated in Table 3, columns 3 and 4, the Oaxaca decomposition has been made in accordance with equations (4)-(6). The results are presented in Table 4 where the total difference in average productivity between companies with and without R&D has been split into a *characteristic component*, C_i, and a *coefficient component*, D_i. The average R&D contribution ($\overline{\mathbf{Z}}_{R\&D}\,\hat{\gamma}_{R\&D}$) 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*. Table 4 shows that the overall difference (C+D= 2.541) mainly is caused by differences in factor inputs (C=1.775), suggesting that on average firms with positive R&D capital are larger than non-R&D firms. The *coefficient component* (D=0.769) is smaller but still interesting. Keeping the factor input constant, we see a positive difference in the labour coefficient component (0.335) and a large negative difference for the physical capital coefficient component (-2.974). However, the coefficient component of the intercept is positive. Taken together, the net effect of the 3 coefficients is -0.264. Finally, the influence from the R&D input (the significance cannot be tested) is large and positive suggesting a positive productivity effect in firms with investments in R&D.

Table 4. Oaxaca-decomposition of the average difference in productivity between firms with/without investments in R&D - 1997 sample.

	Model based on col. 3 in Table 3		*Model based on col. 4 in Table 3*	
	Characteristic component, C	*Coefficient component*, D	*Characteristic component*, C	*Coefficient component*, D

Log (L)	1.208*	0.517*	1.097*	0.335*
Log (K)	0.726*	-2.805*	0.677*	-2.974*
Intercept	0	2.030*	0	2.376*
R&D-level	-	0,856	-	1,033
Components	1.934*	0.594*	1.775*	0.769*
All (C+D)		2,529		2,544

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

In both models in Table 4 the total average difference in productivity between firms with and without R&D is quite similar and as mentioned above, 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 net effect on total factor productivity is positive for companies having invested in R&D.

The models estimated in Tables 2 and 3 show a positive influence from the invested R&D capital. The results in Table 4 indicate a potential positive interaction effect between R&D investments and the other input factors. These interaction effects are analysed below.

The results found depend on the validity of the specified Cobb-Douglas production function. Berndt & Christensen (1973) propose an extended 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 where the interaction term in (7) is restricted to zero.

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

The models in Tables 3 and 4 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, it is found that the restricted model, the Cobb-Douglas specification used, cannot be rejected meaning that the test based on the translog model shows no indication of mis-specifications in the models used in the previous section.

5.2 Interaction between R&D and other inputs

In Section 3, other factors affecting productivity were discussed. The source of funding R&D, the presence of foreign investors, the number of large owners and the level of innovative activities are potential factors influencing the overall level of productivity and moreover, they are likely to have an impact on the influence from R&D on productivity. For samples including 149 and 227 firms in 1997, 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 interacting 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 positive but insignificant coefficient.

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 significantly different from zero.

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

	Innovative charactistic	Concentrated ownership	Foreign ownership	Company-financed R&D
Intercept	4.8280 (0.3034)	4.7678 (0.3596)	4.6497 (0.3531)	4.3661 (1.0037)
Log (labour)	0.5001* (0.0419)	0.4014* (0.0487)	0.3977* (0.0506)	0.5078* (0.0419)
Log (R&D labour)	0.1183*	0.0792	0.0867***	0.1113* (0.0374

	(0.0384)	(0.0504)	(0.0503)	
Log (capital)	0.2717* (0.0253)	0.3165* (0.0302)	0.3317* (0.0333)	0.2646* (0.0250)
Log (R&D capital)	0.0911*** (0.0317)	0.1106* (0.0422)	0.1011* (0.0421)	0.1249* (0.0995)
Innovation dummy	0.2549 (0.3171)			
Innovation dummy*log(R&D capital)	-0.0280 (0.0335)			
Concentrated ownership dummy		-0.0702 (0.5921)		
Concentrated ownership* log(R&D-cap.)		-0.0030 (0.0608)		
Foreign ownership dummy			0.3800 (0.4656)	
Foreign ownership* log(R&D capital)			-0.0263 (0.0460)	
Company-financed R&D, (share).				0.6332 (1.0268)
Company-financed R&D* log(R&D-capital)				-0.0463 (0.0993)
R^2 – adj.	87	87	87	87
Number of observations	226	149	137	226

Notes: see Table 2.

6. Conclusions

Investments in R&D are expected to increase the firms' productivity. In this paper, we use a production function approach to estimate the effects of R&D capital on total factor productivity. Based on Danish firm-level data from 1985 to 1997, 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 9-12%, which is in line with other international studies, noting however that the estimation years - the second half of the 1990s - were upturn years for the Danish economy.

The Oaxaca decomposition of the productivity into a *characteristic component* and a *coefficient component* shows that the overall difference is due to both factors, though on average the influence on productivity coming from firm size is twice as large as the coefficient component. On the other hand, given the direct effect from R&D on productivity, the evidence on the indirect effect of R&D via increased productivity from labour and capital is mixed. We find that investments in R&D increase the factor productivity of labour and decrease the productivity of physical capital.

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. As a consequence, 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 - directly or indirectly. 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.

Furthermore, we find no significant effect on productivity from foreign ownership. This result is not in line with Smith et al. (1999) who (on a smaller data set) find a positive but weak effect. Thus, the question whether Danish firms pick up productivity gains due to technology transfer or to selective foreign investments in productive industries is up to further studies to answer.

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