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The short-run impact of business sector R&D activities on total factor productivity

Empirical evidence from the Danish economy

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Abstract: During the last couple of decades private sector expenditure related to research and development activities has generally increased relatively fast in most industrialized countries. Both theoretical arguments and empirical evidence can be put forward in favor of an increasing flow of resources directed towards R&D activities as the impact on productivity is found to be positive.

In the present study data from the Danish economy is used to further analyse some empirical aspects of the relationship between total factor productivity and business sector R&D expenditure. A positive relationship between private sector R&D activity - measured as research expenditure relative to value-added production - and total factor productivity is detected and most likely, research effects show up with a two-period lag structure which also seems in accordance with a priori expectations.

Keywords: Total factor productivity; Business sector R&D; short-run impact of innovation.

JEL Codes: L11, D24, O3.

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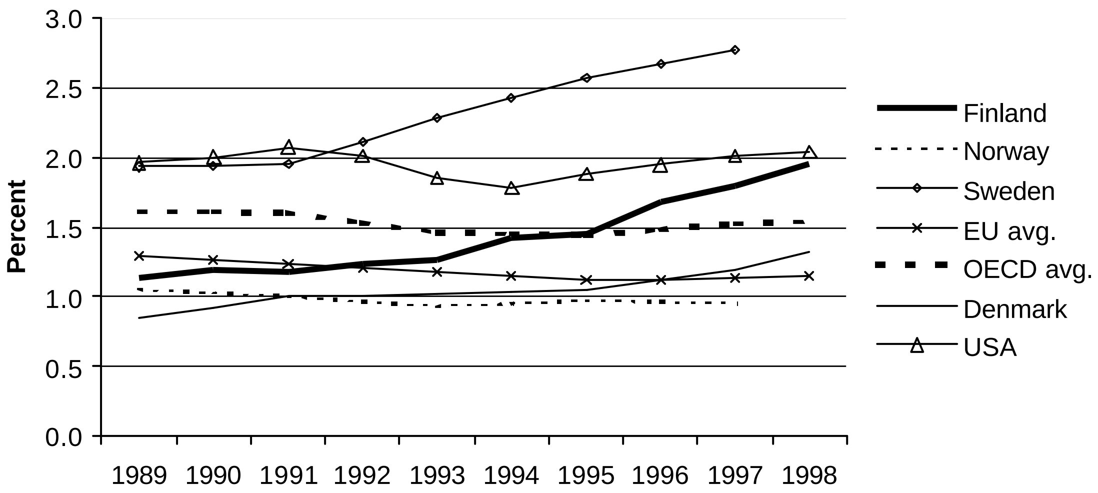
1. Introduction

Over the last decades the R&D expenditure in the business sector has increased relatively fast in the majority of the industrialized countries although recently, the growth rates of R&D activities have been more heterogeneous. Thus, looking at the industrialized countries as a whole, business enterprise R&D expenditure in per cent of GDP has been quite stable around a level of 1.5% since the late 1980s. However, in this period some countries have experienced rather large relative increases in business sector R&D, e.g. Finland, Sweden and Denmark, whereas other countries are more in line with the OECD average, e.g. USA and Norway.

Figure 1. Business sector R&D expenditure in per cent of GDP in various countries, 1989-1998.



Source: Main Science and Technology Indicators, various issues, OECD.

Both theoretical arguments and to some extent empirical evidence are in favour of strenghtening the business sector R&D expenditure (BERD) as the impact on private sector productivity is expected to be positive. As a consequence, most economists recommend strengthening the R&D-effort in order to secure future growth and better standards of living.

Still, the empirical evidence on the magnitude of the impact of R&D on productivity is blurred, and a number of empirical studies give evidence of only a weak and insignificant productivity effect from R&D activities. There are at least two reasons for this. Firstly, many empirical investigations use data from the late 1970s and early 1980s, which was a period of sluggish growth and moderate business conditions caused by the oil crises. Consequently, producitivity effects from investments were hard to trace and, secondly, in the empirical analysis measurement and data problems could potentially have weakened the causality of R&D investments on output. In addition more recent studies demonstrate, see Jones & Williams (1998), that the estimates from regression analysis of total factor productivity on R&D investment represent a lower bound on the social return to R&D.

The aim of this paper is to present further empirical evidence on the relationship between total factor productivity and business sector R&D expenditure, using the framework of Jones and Williams (1998) as the starting point. Thus, applying the methodology from the recent time series econometric literature it is demonstrated that data for productivity and research expenditure show up to be non-stationary variables. Hence, the variables have to be first-differenced in order to obtain stationarity and thus making standard statistical inference valid. No appropriate model is estimated from the level values as they do not seem to form any sensible or stable long-run relationship, but regression analyses with the first-difference variables reveal some insight into the short-run dynamics of factor productivity. The result of the empirical analysis points towards a positive relationship between private sector R&D activity - measured as research expenditure relative to value-added production - and total factor productivity. Furthermore effects on productivity form R&D investments most likely show up with a two-period lag-structure, which in addition seems to be in accordance with a priori expectations.

The paper is organized as follows: In the next section we give a brief review of the earlier mainstream studies within this field. Section 3 then presents the data to be used in the analysis and section 4 discusses the empirical results. Finally, section 5 concludes the paper.

2. Review of the empirical evidence

The aim of this section is to give a brief overview of the empirical results and applied methodologies in the mainstream type of studies using standard econometric techniques when analysing the influence of R&D on productivity. Productivity increases or increases in social output are seen as the result of the R&D efforts when evaluating the benefits of R&D because of the difficulties in measuring the output of scientific and technological efforts, defined as *additions to economically valuable knowledge*, which seems quite difficult to handle in an empirical analysis. As a consequence, standard production functions are applied and the productive returns to R&D expenditure are estimated simultaneously with the effects from other firm inputs which certainly complicates the analysis.

The theoretical framework in the majority of empirical studies is the well-known Cobb-Douglas functional form, which in a 3-factor version is written as

(1) $$Y_t = A\exp(\lambda t)C_t^{\alpha} L_t^{\beta} K_t^{\gamma} \exp(\varepsilon_t)$$

where Y is a measure of output (often measured by the production or sales volume). L is a measure of labour input and t is a trend variable. K and C are measures of the cumulated research effort (capital, K) and other physical capital (C) within the firm, i.e. machinery, buildings etc. A, λ, α, β and γ represent the unknown parameters to be estimated in the empirical analysis (all of them expected to be positive). Finally, ε_t reflects all random fluctuations in output.

Transforming (1) into natural logarithm gives the standard empirical form

(2) $$\log Y_t = a + \lambda t + \alpha \log C_t + \beta \log L_t + \gamma \log K_t + \varepsilon_t$$

which has showed up to do rather well in a number of studies. Research capital (K) is normally approximated as a weighted sum of current and past R&D expenditure and as a consequence, γ can be interpreted as the output elasticity of R&D capital.

Equation (2) has been estimated in various forms 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), Lehtoranta (1998) and Smith et al. (1999) using either cross-section data at the firm level or firm panel data. The studies cover France, United States, Japan and Finland.[1]

In general, γ is found to lie between 0.05 and 0.2. In some studies, however, the values of γ are small and statistically insignificant, leaving doubt regarding the magnitude of the productive effect of R&D. Further, more recent estimates seem to be higher than the earlier ones, especially concerning studies of the 1970s and the early 1980s, see Griliches (1995). In fact, the study of Hall and Mairese (1995) using French data for 1980-1987 suggests that γ could be as high as 0.25. Accordingly, there are indications pointing to the fact that the 1970s and the early 1980s were unfavourable time periods for measuring the effect of R&D - mainly because of the stagnation and excess capacity of the OECD economies.[2] Under such sluggish conditions measurement of the effect of R&D becomes difficult.

[1] See Mairesse (1991) and Griliches (1995) for a survey of econometric studies on R&D and productivity. In addition it should be mentioned that Bartelsman et al. (1995) analyse the relationship between R&D and productivity on Dutch firm level data, and the Norwegian evidence is found in Klette and Johansen(1996), using a differing type of model, however.

[2] Lehtoranta (1998) uses data for 186 Finnish firms from the period 1991-1994 which were years of slow economic growth within the Finnish economy. In line with the discussion above γ is found to be close to 0.7 per cent.

Due to empirical data problems concerning the measurement of the R&D capital stock (K), several authors have used an alternative form of equation (2)

$$(3) \qquad \Delta \log Y_t = l + a\Delta \log C_t + b\Delta \log L_t + r\left(\frac{R}{Y}\right)_t + m_t$$

where levels are replaced by growth rates and R denotes the annual expenditure on R&D net of depreciation of the previously accumulated R&D capital. The parameter ρ is often interpreted as the rate of return to investment in R&D capital. Thus, it can be shown that under certain conditions ρ = γ(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 and hence longer time series back in time for R&D is unnecessary concerning the construction of an R&D capital variable. However, the problem of measuring research capitel K correctly has just now been transformed into difficulties of assessing correct values of depreciation in order to measure *net* R&D expenditure.

This form was estimated by Mansfield (1965), Link (1983), Griliches and Mairesse (1984), Clark and Griliches (1984), Odagiri and Iwata (1986), Griliches (1986), Sassenou (1988), Griliches and Mairesse (1990), Hall & Mairesse (1995), Wakelin (1998), Dilling-Hansen et al. (1999) and others using firm data. Further, equation (2) was estimated by Scherer (1982, 1993), Griliches (1979, 1995) and others using aggregate industry data for mainly France, United States, Japan and Belgium. The estimated rates of return lie between 0.2 and 0.5. 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.

Some additional results should be mentioned. Firstly, Griliches (1986) finds that the output elasticity of basic research is significantly higher than the elasticity of other forms of R&D capital, i.e. non-basic R&D-capital. Secondly, the productive effect of company financed R&D is much higher than the corresponding publicly financed R&D capital.

Some unsolved problems in working with econometric models of R&D and productivity should be mentioned. Firstly, there are huge problems of how to measure the R&D capital itself correctly. A rather important problem here is the determination of the lag structure of R&D expenditure when constructing data for research capital, or alternatively, how to decide the depreciation rate of previous R&D capital. Next, R&D investments include human as well as non-human components and there is no obvious way to deal with different forms of R&D capital unless specific knowledge on the R&D environment is present at the firm level.

Secondly, R&D spillover effects – the fact that ideas are 'borrowed' by research teams of an industry or a firm from the results of other industries/firms – are very difficult to measure correctly with respect to both timing and magnitudes. How much of the R&D in a particular industry is 'spillable' and which firms/industries are potential receivers? How long does it take to adapt the R&D of other firms/industries and to what extent do spillover effects affect the productive effects of own R&D efforts. There are several studies trying to control for spillover effects, see Griliches (1995) and Wakelin (1998) for an overview. However, the variability of the rates of return to external R&D is quite large, suggesting that this problem has not yet been solved satisfactorily.

Positive R&D spillover effects betwen firms or industries may result in divergence between private and social returns to R&D. Thus social returns would normally be larger than private returns to R&D capital. Jones & Williams (1998) analyse this problem within an endogenous growth framework and find that the estimates of returns to R&D within the productivity literature as represented with equation (3) represent lower bounds on the social returns to R&D which potentially could reach 30%.

Equation (3) can be reformulated in terms of total factor productivity

(4) $?\log TFP_t = a + \rho (R/Y)_t + \mu_t$

Jones & Williams (1998) argue that equation (4) is misspecified and that the correct estimation form taking into account positive spillovers from R&D investments should be

(5) $$\Delta \log TFP_t = a + r'(R/Y)_t + j \log\left(Y_t / \overline{Y}_t\right) + s \log\left(TFP_t / \overline{TFP}_t\right) + m_t'$$

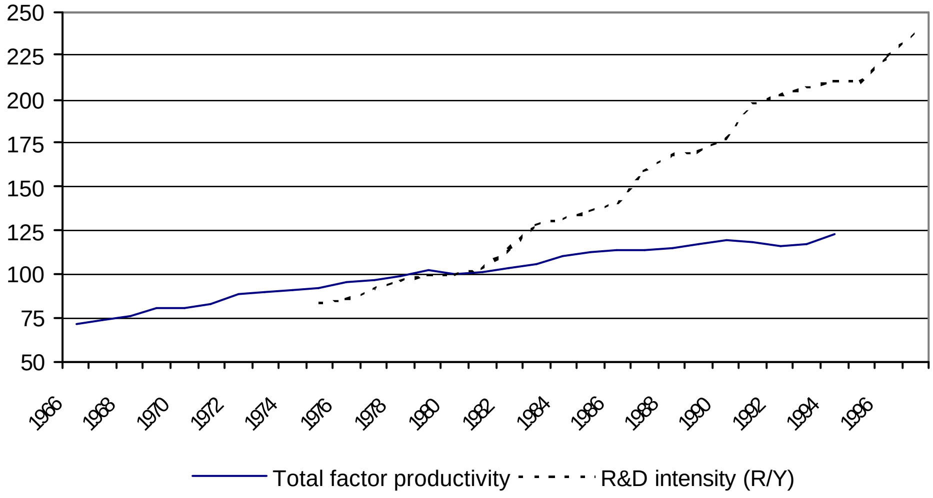
where the two additional regressors are the per cent deviation of output and total factor productivity from their steady state levels $\overline{Y}_t$ and $\overline{TFP}_t$. It is demonstrated that ρ in equation (4) underestimates the true social rate of return to R&D with a maximum bias equal to the rate of output growth. Finally, the framework allows for a direct mapping from the rate of return to the degree of underinvestment in R&D due to the larger social returns. Jones & Williams (1998) argue that optimal R&D investment is at least 2-4 times the actual investment in R&D.

In the empirical part of this paper the starting point will also be the form shown in equation (5). However a prerequisite for using the data is to test the series for their order of integration which is discussed in the next section.

3. The development in total factor productivity and R&D expenditure

The data used in the present analysis come from various issues of the official Danish R&D statistics and from Statistics Denmark. More precisely, the R&D data are collected on a biannual basis and hence the data for even years are interpolated using an exponential smoothing technique and finally, the data set is deflated by use of the implicit GDP-deflator. Data for value-added output and total factor productivity derive from various issues of *The National Account* and *Input-Output Tables* from Statistics Denmark. The data set to be used in the analysis covers the period from 1975 to 1995 and is presented in figure 2.

Figure 2. Total factor productivity and the R&D intensity in the Danish business sector, 1966-1997, (indices 1980=100).

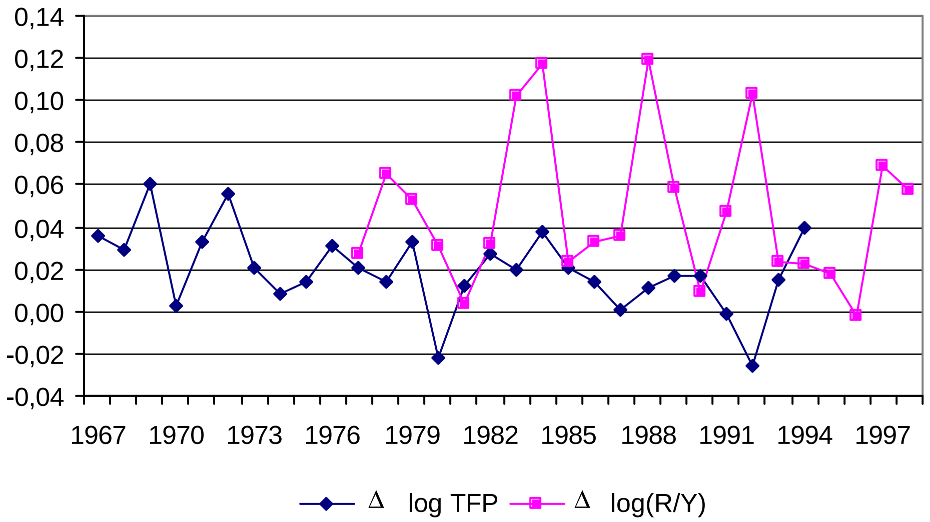


Sources: National Accounts, Input-Output Tables, various issues, Statistics Denmark. The Danish Business Sector R&D Statistics, various issues, The Danish Institute for Studies in Research and Research Policy.

Over the entire period the total factor productivity has increased by nearly 75 per cent, which amounts to an annual growth rate of 1.7 per cent, whereas the R&D intensity, which has been defined as the annual R&D investment divided by value-added output is growing more rapidly. However, there are significant variations in the growth rate from year to year as can be seen in figure 3.

Figure 3 gives a picture of the growth rates of the basic series exhibited in level values in figure 2. Growth in total factor productivity was negative in 1980 and again in 1992, whereas the R&D intensity has been growing almost every year in the sample period, however, with varying strength.

Figure 3. Total factor productivity and the R&D intensity, growth rates 1967-1997.



Sources: as in figure 2.

4. Empirical analysis

A prerequisite for the empirical analysis is to test the series for their order of integration. Accordingly, value-added output (Y), R&D expenditure (BERD), total factor productivity (TFP) and the R&D intensity (BERD/Y) are all tested by applying the Dickey-Fuller unit root test, with results as presented in table 1.

Table 1 clearly indicates that all of the variables are non-stationary. The critical value at the 5 per cent level of significance (–3.66) is notable above the ADF test statistics (in absolute values) concerning the level variables. Next, the first differences of the variables turn out to be stationary, which means that the series shown in the table are most likely I(1) variables. As a consequence, if these variables are to be used in any kind of model or analysis they have to be integrated of the same order and cointegrate, i.e. form a stable long-run relationship, in order to avoid the so-called spurious regression problem.

Table 1. Unit root tests.

	Variable	ADF
Total factor Productivity	Log TFP	-2.17{0}
Value added output	LogY	-2.96{1}
R&D expenditure	Log BERD	-2.99{1}
R&D intensity	Log(BERD/Y)	-2.55{1}
Total factor productivity, diff.	ΔLog TFP	-4.99{0}
Value added, diff.	ΔLogY	-4.34{0}
R&D expenditure, diff.	ΔLog BERD	-4.23{1}
R&D intensity, diff.	ΔLog(BERD/Y)	-4.66{1}

Notes. The critical value is –3.66 at the 5% level of significance, based on MacKinnon (1991). The tests include a deterministic trend to allow for an alternative hypothesis of trend stationarity. {} denots the included lags in the DF-test. The business sector R&D is denoted by BERD.

Turning back to equation (5) it is obvious that there is a conflict between the equation form and the proporties of the series included in the equation. Thus, the dependent variable is I(0) but the explanatory variables are all I(1). That is the case for both the R&D-intensity and the other variables which measure deviations from trends, i.e. $\log(Y_t/\overline{Y}_t)$ and $\log(TFP_t/\overline{TFP}_t)$. In this analysis the long-run trends are approximated by using the Hodrick-Prescott filter approach, which has gained popularity concerning decomposing time-series data into a business cycle component and a long-run trend. As a consequence, the estimation form in equation (5) is not fully compatible with the data. Ignoring these problems and estimating equation (5) as a preliminary experiment, the parameters and the test-values do not verify the model of Jones and Williams (1998). The results in table 2 clearly give an indication of the inconsistency between the data and the model. Only one parameter is significantly different from zero and the model residuals are highly autocorrelated.

Table 2. Estimation of equation (5).

	Constant	Log (BERD/Y)	log($Y_t / \bar{Y}_t$)	log($TFP_t / \overline{TFP}_t$)	R^2	DW
Parameter	0.0022 (0.0141)	0.0065 (0.0118)	-0.3337 (0.1912)	0.8637 (0.2987)	0.38	1.19

Note: Estimation period 1978-1994. Standard error in parenthesis.

Following the results of the stationarity tests in table 1 a solution to the problem might be using first-difference variables. However, various estimations (not reported) using equation (4) and equation (5) gave no significant parameters and the returns to R&D were small and negligible. Therefore, the following ad hoc model was estimated. The experiments ended up in the ad hoc model

(6) $$\Delta \log TFP_t = \mathrm{a} + r\Delta \log\left(BERD / Y\right)_{t-2} + d_1 D_{8092} + d_2 D_{85\_93} + m_t$$

where D_{8092} is a dummy variable for the negative outliers in the productivity growth for 1980 and 1992. In addition, D_{85_93} is a dummy variable controlling for the entire stagnation period in the Danish economy in the period 1985-1993. The estimates of δ_1 and δ_2 are both expected to be negative whereas ρ', of course, is positive. The change in the R&D-intensity is included with a time lag of 2 periods allowing for potential delays in the influence from R&D on the output and production processes within the firm.

Table 3. Estimation of equation (6).

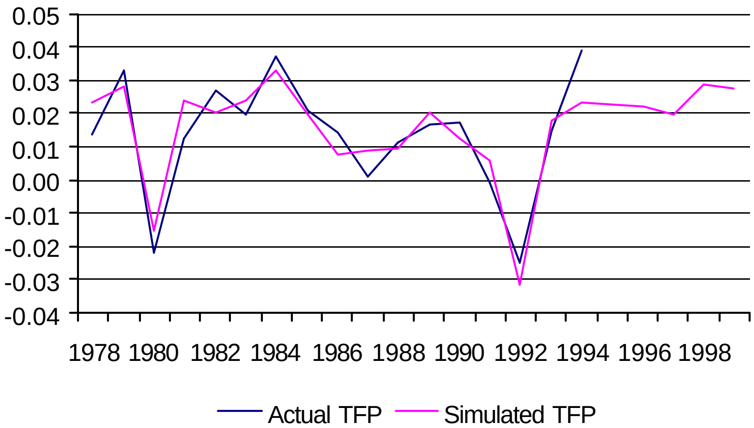
	Constant	Δlog (BERD/Y)$_{t-2}$	D_{8092}	D_{85_93}	R^2	DW
Parameter	0.0200 (0.0039)	0.1269 (0.0578)	-0.0421 (0.0062)	-0.0153 (0.0041)	0.82	2.40

Note: The estimation period is 1978-1994. Standard error in parenthesis.

Table 3 shows that the estimated parameters for all variables in the model are highly significant. In particular the parameter of the two-period-lag change in the R&D intensity is positive, significant and of a noteworthy size. Thus an increase of 1 per cent in the R&D-intensity will lead to an increase in total factor productivity of 0.12 per cent after a time lag of two years, assuming that new R&D capital becomes productive after a delay of 2 years, which seems reasonable. In the experimental phase of the project the R&D intensity was included with different lag length, i.e. no lag 1 or 3 years. However in all those cases the overall model fit was poorer and the estimated returns to R&D significantly lower.

Finally, figure 4 shows the predicted values against the actual values for the total factor productivity using the estimated parameters reported in table 3.

Figure 4. Simulated and actual values for total factor productivity, 1978-1999.



Note: Equation (6) with parameter estimates from table 3 used when calculating the simulated TFP.

The figure gives an alternative indication of the overall model fit. It is easily seen that except for the very last year in the historical period[3], where the predicted value undershoots the actual value significantly the model fit is quite satisfactory for the historical time period.

[3] With a real growth rate of 5.8 per cent the year 1994 was the starting point for a significant upturn in the Danish economy.

5. Conclusion

The purpose of this paper has been to analyse the influence of the R&D on productivity within the Danish business enterprise sector. In accordance with Jones & Williams (1998) an empirical model that accounts for spillover effects was formulated and tested on annual time series data for the period 1978 to 1994. However, the empirical form suggested by Jones and Williams (1998) is not compatible with the Danish data, mainly because of differences in the order of integration of the series used in the model. When ignoring the problems of integration and spurious regressions, estimating the model from Jones and Williams (1998) results in poor parameter estimates.

As a consequence and in line with the properties of the data series an ad hoc model was formulated where the change in total factor productivity was explained by the change in the R&D intensity, which secured consistent orders of integration among the included variables. The alternative model reports a significant and positive influence from R&D on total factor productivity with a time lag of two periods, which is also in accordance with a priori expectations. Finally, it should be noted, that the estimated model did quite well in simulations and the overall degree of explanation is rather high.

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