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R&D AND PRODUCTIVITY: EVIDENCE FOR EUROPEAN AND US FIRMS IN THE 1990s

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Abstract

This paper analyses the contribution of R&D to productivity growth using an unbalanced sample of 2167 large, publicly traded firms in Europe and the US. The framework for the analysis is a modified version of the `R&D capital in the production function´ model. Instead of estimating the elasticity of R&D capital, we estimate the `rate of return´ to R&D by regressing output growth on the R&D intensity of the firm. As our dataset is particularly prone to selectivity bias we use the heckman correction procedure to control for non-random missing observations. The main result points to a positive and significant contribution of R&D to productivity growth, for both the US and the European firms in our sample. However, the estimated rate of return for the pooled sample is about 12% which is at the lower end of previoulsy reported estimates. Despite the fact that the dataset used is problematic (unbalanced panel, selection bias), different specifications and methods lead to very robust findings with regard to the estimated rate of return to R&D.

1. Introduction[1]

Research into the role of technological change in econommic growth indicates that technological change is one of the key explanatory factors in productivity growth (*Solow*, 1957). Investment in R&D is seen as one of the factors that could explain the productivity residual (*Griliches*, 1998). There has been a lot of work at different levels of aggregation (economy, industry, firm level) which analysis the relationship between R&D and productivity growth. However, the analysis of this relationship is particularly difficult for a number of reasons. In many sectors where R&D investments play a major role, such as health, the military sector or the computer industry, either output is difficult to measure or its measure has not been adequately updated in order to account for the fast changes in technology (*Griliches*, 1994). Furthermore, there are major problems in the measurement of R&D capital as an input factor to the production process. Actually we know little about the appropriate lag structure, about the rate of depreciation of R&D, and about possible spillover effects within R&D activities (*Griliches*, 1979). Additionally, we have to deal with econometric isssues, the most serious one being the simultaneity problem. Future output depends on past investment in R&D and, at the same time, R&D investment depends on past and expected output (*Griliches*, 1979).

In this paper we are interested in the relationship between R&D and productivity at the firm level. Due to data constraints, most studies so far have focused on very few countries, mostly France, Japan and USA. Occasionally, one can find studies with firm level data for other countries (i.e., *Fecher* (1990) for Belgium, *Harhoff* (1994) for Germany, *Bartelsman at. al.* (1996) for the Netherlands, *Cincera* (1998) for Europe, US and Japan, *O´Mahoney* and *Vecchi* (2000) for UK, Germany and Italy, and *Wakelin* (2000) for UK). The overall evidence confirms a positive role for R&D in explaining productivity growth. The aim of this paper is to present further results on this subject.

2. The empirical framework

The model used to estimate the contribution of R&D to productivity is a version of the Cobb-Douglas production function in its growth rate form. The production function is given by:

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

where: Q is output (production, value added or net sales), L is a measure of labour (often number of employees); C is physical (or tangible) capital; K is research capital; X measures external stocks of R&D available (spillover pool); A is a constant; i and t

[1] I should like to thank M. Pfaffermayr and R. Winter-Ebmer for helpful suggestions.

denote firms and time periods (years); λ is the rate of disembodied or autonomous technical change; ε is a multiplicative error term, reflecting the effects of unknown factors, approximations and other disturbances; α, β, γ are the parameters of interest, i.e. the elasticities of output with respect to each of the inputs.

By taking logarithms of the variables and first differencing, the relationship can be expressed as a linear one in terms of the change in output:

$$\Delta q_{it} = \lambda + \alpha \Delta c_{it} + \beta \Delta l_{it} + \gamma \Delta k_{it} + \eta \Delta x_{it} + \Delta \varepsilon_{it} \qquad (2)$$

where lower case letters denote logarithms of variables.

We would be interested in the elasticities of the R&D capital stock, and the R&D spillover pool, respectively. Unfortunately, we do not have R&D expenditure data available for enough years to calculate the R&D capital stock for the firms. However, equation (2) can be transformed by taking the rate of return to R&D as the parameter of interest rather than the elasticity.

From equation (1) we obtain:

$$\gamma = \frac{\partial Q_{it}}{\partial K_{it}} \frac{K_{it}}{Q_{it}} = \rho_1 \frac{K_{it}}{Q_{it}} \qquad (3)$$

where ρ is the marginal productivity of R&D.

By disregarding R&D depreciation, ΔK is equal to present R&D expenditures RD, i.e. $\Delta k = \Delta K / K = RD / K$. Applying the same transformations to the R&D Spillover-stock X, we can re-write equation (2):

$$\Delta q_{it} = \lambda + \alpha \Delta c_{it} + \beta \Delta l_{it} + \eta \Delta x_{it} + \rho_1 (RD / Q)_{it} + \rho_2 (XD / Q)_{it} + \theta_{it} \qquad (4)$$

This is the relationship we will test using the data discussed in the next section. The parameter ρ_1 is often interpreted as the \`rate of return´ to investment in R&D capital. The main advantage of this formulation is that productivity growth is directly related to some measure of R&D expenditures, which are readily available from the company accounts. That is, we do not have to calculate the firms R&D capital which avoids several huge problems. One important problem is the determination of the lag structure of R&D expenditure, or alternatively, how to decide on the depreciation rate of previous R&D capital.[2] Another problem stems from the fact that the R&D capital stock of a firm includes 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.

A second well-known issue encountered when estimating the contribution of R&D relates to the problem of *double counting*. Irrespective of whether R&D is measured as a stock, expenditure or intensity figure, expenditures on labour and physical capital used in R&D should be removed from the measures of labour and physical capital used in production. *Schankerman* (1981) clearly demonstrates that the failure to remove this double counting biases the estimated R&D coefficients downwards[3]. That is, the true returns are likely to be *higher* than those estimated. When the coefficients (elasticities) are converted to marginal products, this difference is magnified even more[4].

A third major issue concerns *spillovers*, the effect of knowledge capital outside the firm or industry in question on the within-industry productivity[5]. Most empirical studies do not account for potential spillover benefits between and within industries. The reason is that spillover effects are very difficult to measure correctly with respect to both timing and magnitude. Those studies, which try to control for spillover effects use some weighted measure of the firms stocks of R&D capital to derive a pool of potential spillover benefits. The weights indicate how relevant the R&D of one industry is likely to be to the current industry. *Griliches* (1992) gives an overview on the measurement issues involved. In the empirical part of the paper we use a rather crude measure of spillover effects which gives an identical weight to the R&D of all other firms operating in the same industry sector.

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[2] The most commonly used method for constructing the firms R&D capital stock is the perpetual inventory method, which was originally proposed by *Griliches* (1979). This method assumes that the current state of knowledge is a result of present and past R&D expenditures discounted by a certain rate of depreciation. However, as *Mairesse* and *Sassenou* (1991) demonstrate, the problem of the assesment of R&D depreciation also affects the approach considered in equation (4). The estimated rate of return is in most cases viewed as a \`gross´ rate of return. A \`net´rate of return has to be calculated by subtracting the rate of depreciation (or obsolescence) δ of R&D: $\rho_{net}=\rho_{gross}-\delta$. If the rate of depreciation δ is not negligible or low, the estimate of ρ may in fact be stronlgy biased, as the variable of gross R&D intensity (RD/Q) replaces the true variable (RD-δK)/Q.

3 This finding has been confirmed by a number of other studies, including *Cuneo* and *Mairesse* (1984), *Griliches* and *Mairesse* (1984), *Hall* and *Mairesse* (1993) and *Mairesse* and *Hall* (1996).

4 Most econometric studies do not adjust for this double counting and, based on *Schankerman* (1981), their estimates are likely to be lower than if they had done so (all other things being equal). However, many of these studies are subjected to countervailing biases, so the net effect is less certain. For example, due to their use of R&D expenditure figures, most of the TFP studies do not allow for depreciation. This would lead to an overestimation of the return to R&D, in comparison to the situation had depreciation been taken into account.

5. As *Griliches* (1979, p. 103) comments: \`The level of productivity achieved by one firm or industry depends not only on its own research efforts but also on the level of the pool of general knowledge accessible to it. Looking at a cross section of firms within a particular industry, one will not be able to distinguish such effects. If the pools of knowledge differ for different industries or areas, some of it could be deduced from inter-industry comparisons over time and space. Moreover, the productivity of own research may be effected by the size of the pool or pools it can draw upon.´

Besides these measurement problems, there are also econometric problems related to the estimation of equation (4), namely simultaneity and selectivity. The simultaneity problem is related to the ednogeneity of R&D expenditures. It refers to the question of whether R&D, for instance, depends on past, current or future values of output, i.e. expectations of the dependent variables, or conversely. Among the different solutions proposed to circumvent this simultaneity problem, semi-reduced forms of equation (2) can be estimated (*Griliches* and *Mairesse*, 1984). *Mairesse* and *Hall* (1995) consider beginning of years capital stocks rather than end of years to attenuate the possible simultaneity biases. *Griliches, Hall* and *Pakes* (1991) `enrich' the R&D-productivity model by considering additional information on the investment policy adopted by the firm, the number of patents it has received or its stock market value. An alternative approach that allows for all these issues to be present, i.e. correlated fixed effects, measurement errors and simultaneity, relies on a General Method of Moments (GMM) estimator.[6] However, as is obvious from the discussion in *Griliches* and *Mairesse* (1998), the results are often very sensitive to the estimation method employed and attempts to correct for simultaneity can introduce more problems than they solve. Because these methods are restricted to balanced panels, and our dataset is `too unbalanced´, at least at the european front, we did not employ these methods here.

Another important econometric problem in panel data estimation is related to the *selectivity bias*. Included in the estimation are those companies which perform and record R&D investments. Companies that either do not perform or do not record them are not in the sample. If they are not randomly missing, that is, if the selection rule is non-ignorable, inference based on the resulting panel may be misleading because it is no longer representative of the population. One has to take into account the mechanism that causes the missing observations in order to obtain consistent estimates of the parameters of interest. As our dataset used in the empirical analysis is particularly prone to selectivity bias, *Heckman´s* (1976) selectivity bias correction is employed to obtain more consistent estimates.

Equation (4) was estimated before by *Link* (1983), *Griliches* and *Mairesse* (1984), *Clark* and *Griliches* (1984), *Odagiri* and *Iwata* (1986), *Griliches* (1986), *Sassenou* (1988), *Griliches* and *Mairesse* (1990), *Hall* and *Mairesse* (1995), *Wakelin* (2000) and others. The estimated rates of return in most of the studies lie between 20% and 50%.[7]

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[6] See *Mairesse* and *Hall* (1996) for a general description of this methodology (which is based on that of *Arellano* and *Bond* (1991)).

[7] See *Mairesse* and *Sassenou* (1991), *Nadiri* (1993), *Mairesse* and *Mohnen* (1995), and *Wieser* (2001) for reviews on the empirical evidence on R&D and productivity at the firm level.

3. The sample and Data

The company accounts database employed in the analysis, Global Vantage, includes consolidated company accounts information for approximately 12,000 companies world-wide for 10 years from 1989 to 1998. From this we have extracted information for the United States and twelve European Union countries.[8] Companies are sampled from a wide range of manufacturing sectors.

We started with the information for 2681 (EU 1482; US: 1199) manufacturing firms over the period 1990-1998. Because of missing observations on employment and of questionable data on other variables, we first had to limit the sample to 2649 (EU 1481; US 1168), and then, in response to merger and acquisition problems (outliers), to restrict it further to 2167 firms (EU 1365; US 833). The cleaning procedure is based on the following criteria:

Any observation for which the growth rate of net sales, capital stock, and employment is less than minus 80% or greater than 100% has been removed.

Any observation for which R&D intensity is greater than 50% has been removed.

Any observation for which net sales per worker (productivity), capital stock per worker and R&D capital per worker is above or below three times the interdecile range of the median has been removed.

The resulting samples and their corresponding sub-samples of R&D reporting firms[9] are presented in Table 1. Just over 48% of firms report R&D expenditure of which about 56% are from the US, 15% are from the UK and 29% are from the other European countries.

Several variables have been constructed for the purpose of the subsequent empirical analysis. These variables are the firm´s R&D intensity and the R&D spillover stock available to the firm. Furthermore, in order to proxy industry and geographic specific effects, several sets of dummy variables have also been constructed. For a comparison of all these variables across industries, countries and over time, several deflators have been considered and all nominal variables have been converted into 1995 constant dollars.

The *physical capital stock* measure corresponds to the net property, plant and equipment of firms. `Net´ means that accumulated reserves for depreciation, depletion and

[8] There is no information on R&D expenditures for firms in Spain, Luxembourg and Portugal.

[9] For the purpose of the following descriptive analysis, we make no distinction between firms whose R&D is reported as `zero´ and firms whose R&D is just `missing´. All such firms are treated as not reporting positive R&D. However, there may be a selection bias in our data, and we account for this in the econometric model.

amortisation are not included. Information on annual capital expenditures is available as well. Hence, it may be possible to construct a capital stock according to the perpetual inventory method. However, this approach requires knowledge of the rates of depreciation of physical capital which vary across firms and over time. Since this information is unavailable and capital expenditures are missing for some firms and years, we did not choose this approach.

In order to pick up unobserved market factors or *industry specific effects* as well as *geographic effects*, two sets of dummy variables have been constructed by assigning each firm to its main industrial sector and the geographic area in which the firm is domiciled. As far as the industry dummies are concerned, the industry sectors corresponding to these variables have been chosen so as to allow for a concordance between the SIC (industrial classification retained in the Global Vantage database) and the NACE (industrial classification retained in the EU databases).

TABLE 1: Number of firms included in the sample (1990-1998)[a]

	All firms		R&D firmsb		Non R&D firms	
	absolute	*% of sample*	absolute	*% of sub-sample*	absolute	*% of sub-sample*
Total	2198	*100.0*	1034	*100.0*	1164	*100.0*
US	833	*37.9*	581	*56.2*	252	*21.6*
EU-12	1365	*62.1*	453	*43.8*	912	*78.4*
Austria	34	*1.5*	11	*1.1*	23	*2.0*
Belgium	39	*1.8*	6	*0.6*	33	*2.8*
Denmark	48	*2.2*	13	*1.3*	35	*3.0*
France	214	*9.7*	54	*5.2*	160	*13.7*
Finland	51	*2.3*	36	*3.5*	15	*1.3*
Germany	266	*12.1*	96	*9.3*	170	*14.6*
Greece	25	*1.1*	8	*0.8*	17	*1.5*
Irland	154	*7.0*	10	*1.0*	144	*12.4*
Italy	82	*3.7*	7	*0.7*	75	*6.4*
Netherlands	73	*3.3*	18	*1.7*	55	*4.7*
Sweden	74	*3.4*	39	*3.8*	35	*3.0*
UK	305	*13.9*	155	*15.0*	150	*12.9*

[a] The sample excludes firms with large jumps in the data, generally caused by mergers

[b] All firms that reported nonzero R&D expenditures in one or more years in the 1990-98 period

Several approaches have been developed in the literature in order to measure the potential pool of *R&D spillovers* (Griliches, 1992) . In the present work, we rely on a rather simple approach. The spillover variable is constructed as the manufacturing sector-based amount of R&D reported in ANBERD database less the firm´s own R&D investment. This approach gives an identical weight to the R&D of all other firms operating in the same industry sector and only considers intra-sector spillovers. In a similar manner, more aggregated R&D spillover stocks can be constructed, the intra-industry national stocks, the intra-industry international stock, the inter-industry national stock and finally the inter-industry international stock.

The firm´s *R&D intensity* is measured as the ratio between the level of R&D expenditures and the firm´s output, i.e. net sales. R&D expenditures have been deflated using the GDP *deflators* of the respective countries, while the deflator of physical capital has been used for the capital stock. Regarding net sales, value added deflators had to be estimated for all countries and industries (NACE-3 digits), respectively. A substantial number of firms in the sample might have more than one product line at the SIC two digit level, and might be multinational, that is, a substantial part of their activities is performed outside the domestic market. Therefore, the use of domestic output price indexes for each country may not seem to be a relevant approach for deflating sales. Unfortunately, shares of sales performed in the home country and abroad are not available, and a more general price index could not be computed. Results based on real values should therefore be interpreted with caution.

Table 2 shows 1994/95 levels of average employment, sales, gross physical capital, R&D expenditures and R&D intensities for the European and US firms in the sample. We also show the lower quartile, the median and the upper quartile for these variables. First, the European firms in the full sample are on average only (slightly) smaller than the US firms. This is true in terms of average employment, average sales and average physical capital stock as well. Second, the European firms which report R&D expenditures are much larger than the US R&D firms. European R&D firms have on average 25,600 employees, whereas US R&D firms have on average 14,600 employees. Furthermore, European R&D firms are more than twice as large as non R&D firms, whereas in the US sample R&D firms and firms that do not report R&D expenditures are approximately similar in size. Additionally, average R&D expenditures of European R&D firms are considerably higher than those of US R&D firms. These three observations suggest that small innovation active European firms are not adequately represented in the subsample of R&D reporting firms. Third, average R&D intensity (R&D/sales) is much higher in the US (4.8% compared to 3.6% in Europe). However, if the disclosure decision depends positively on the importance of R&D activities to the firm (measured by the R&D-to-sales ratio), than the `true´ average R&D intensity of the European firms might be even smaller. Fourth, the size distributions in both samples are highly skewed. In most cases the means are above the third quartile. Hence, even after outlier corrections the samples are heavely dominated by large firms in both countries.

TABLE 2: Sample Characeristics: 1994/95[a] Levels of Major Variables

	EU-12			USA		
Variable	All firms	R&D firms	Non R&D firms	All firms	R&D firms	Non R&D firms
N	1365	453	912	833	581	252
Average employment˜,						
in thousands	12.3	25.6	5.9	12.5	14.6	7.8
Q1	0.8	1.1	0.7	1,0	1,0	1.2
Me	2.2	5.2	1.9	3,1	3.3	2.8
Q3	8.7	21.8	6.5	10.0	12.0	6.9
Average sales						
in millions of dollars	2160	4570	1050	2274	2766	1210
Q1	103	156	106	152	146	157
Me	307	728	278	473	501	414
Q3	1324	3605	1011	1539	1870	909
Average phys. Cap.˜						
in millions of dollars	821	1747	402	853	1035	436
Q1	26	40	28	34	33	39
Me	89	206	83	128	142	112
Q3	398	1454	328	512	623	328
Average R&D˜						
in millions of dollars		199			119	
Q1		3			4	
Me		13			14	
Q3		71			45	
Average R&D/sales						
ratio		3.6			4.8	
Q1		1.0			1.2	
Me		2.2			2.8	
Q3		4.7			6.4	

˜ average 1994/95
˜ average number of employees
˜ property, plant and equipment (gross depreciation)
˜ research and development expense
Q1: lower quartile, Me: median, Q3: upper quartile

Bearing in mind the limitations of our R&D data (domination of large firms; underrepresentation of small European R&D firms), we look now at the performance record of the firms in our sample for both countries during the 1990s. Table 3 shows median growth rates per year for major variables of R&D firms and firms which do not report R&D in the European countries, as well as in the US. If we compare the performance of R&D firms to other firms in both countries, we observe that the former show higher labour productivity growth as well as more capital deepening compared to Non R&D firms in both countries. While the physical capital stock grew significantly faster in R&D firms, there was no statistically significant difference in employment growth.[10] This suggests that

[10] We applied a non parametric test (Mann-Whitney U) on the significance of observable differences in the growth rates of the variables. The *Mann-Whitney U* test statistic is based on the mean ranks of different samples.

part of the higher productivity growth of R&D firms is due to more capital deepening. Alternatively, it could be the case that R&D firms are subject to more pronounced (international) competition, which forced them to faster rationalisation.

TABLE 3: Median growth rates (per year)
Non parametric tests for significant differences in variables

	EU-12		USA	
Variable	Non R&D	R&D	Non R&D	R&D
sales	2.6	4.0	5.3	6.8
US vs. EU	*	*	*	*
Non R&D vs. R&D	*	*	*	*
employees	1.9	1.3	2.3	2.3
US vs. EU	n.s.	*	n.s.	*
Non R&D vs. R&D	n.s.	n.s.	n.s.	n.s.
phys. capital	3.2	4.6	5.8	7.0
US vs. EU	*	*	*	*
Non R&D vs. R&D	*	*	*	*
sales/employee	1.1	2.7	3.3	4.3
US vs. EU	*	*	*	*
Non R&D vs. R&D	*	*	*	*
phys. cap./empl.	1.1	2.7	3.4	4.0
US vs. EU	*	*	*	*
Non R&D vs. R&D	*	*	*	*
R&D		4.1		7.8
US vs. EU		*		*

* = statistically significant at the 5% level; n.s. = not significant

Another important observation in Table 3 is that R&D firms in the U.S. show more rapid growth in all variables compared to European R&D firms in all periods under investigation. Growth in R&D expenditures by US firms has been almost twice as high compared to European firms, and labour productivity increased by 1.6% per year faster in the U.S.

4. R&D Intensity and output growth: Basic results with Heckman selection model

In order to assess the contribution of R&D to output growth, we consider in this section the R&D intensity version of the Cobb Douglas Production function (equation 4) with output growth being a function of the growth rates of physical capital and labour as well as the R&D intensity at the beginning of the period. Our measure of output is `net sales or revenue´, physical capital is `net property, plant and equipment´, `employment is average number of employees´ and R&D intensity is `research and development expenses divided by sales´.

The selection problem

One important econometric problem in estimating the relationship between R&D and productivity is related to the selectivity bias. If data on R&D expenditures by firms are not missing at random, OLS estimates may be biased. Unfortunately, our dataset is particularly prone to selectivity bias. The large number of European firms that do not report R&D expenditures raises the likelihood that, at least in the European sample, some kind of sample selection might be at work. One reason is that European firms are in most cases not forced to disclose their R&D activities in their official accounts.[11] Another reason might be that firms which do not report R&D expenditures are actually thos firms which have very low values anyway. If we do not acknowledge these observations, we lose valuable information that may explain part of the relationship between R&D and productivity in our sample.

The usual approach to account for selection bias is to add an explicit selection equation to the model of interest. In the first step, a probit function (selection equation) is estimated for the overall sample to obtain the probability of a firm reporting R&D expenditures. This function depends on observed variables which help identify the selection rule.[12] In addition to capital and labour, we include the following factors as determinants of the observability of R&D expenditures: firm size, cash flow, industry dummies and geographic dummies.[13] Based on the probit estimates, the inverse Mills ratio is calculated, which is used as an additional regressor in the subsequent OLS regression (Heckit method).

We do not report the results of the probit estimation for all the specifications which follow. It serves to mention that the probability of reporting R&D expenditures depends negatively on employment growth and positively on the size of firms. Additionally, we attain significant positive results for industry dummies in the case of research intensive industries and significant negative results for European country group dummies. There is no dependency on the firm´s cash flows. To summarize, disclosure of R&D is more likely for large, slowly growing R&D intensive firms from the

[11] Compared to the EU, the reporting rules for R&D expenses are less liberal in the US. The US Securities and Exchange Commission (SEC) requires reporting of `material´R&D expenditures in the intrim and annual financial statements in Forms 10-Q and 10-K. See *Gaeremynck – Veugelers* (2000) for a discussion of the factors which determine firms´ R&D reporting behaviour in the case of Belgium.

[12] The set of explanatory variables in the model equation must be a strict subset of the observed variables in the selection equation. The error term of the selection equation is assumed to be independent of the observed variables (and therefore of the explanatory variables in the model equation). Correlation of the two error terms causes a sample selection problem. See Wooldridge (2000, Ch. 17) for a treatment of the selection bias in OLS using the Heckman method.

[13] Unfortunately, there is nothing else available in our data which could be used as `identifying´ information.

US. Stated otherwise, what is noticeably missing from our data are small, fast growing European firms with above average productivity, given the level of R&D intensity.

Econometric results

Table 4A documents basic results of the contribution of firms' R&D capital to productivity. In the basic specification 1, the estimates are all statistically significant at the 5% level and show important effects on the left hand side variable of the growth model, i.e. total net sales. The estimated rate of return of R&D is 12%, which is within the limits found by former studies.

Specification 2 includes industry dummies (nace 2 digit) as additional explanatory variables, in order to assess the importance of industry specific effects. As *Griliches* and *Lichtenberg* (1984) and *Jaffe* (1988) underlined, it can be expected that, in a perfect world, total factor productivity is not explained by factors specific to industries. However, in the present context, there are at least two good reasons to take the market factors into account. First, as long as the inputs are not corrected by the utilisation rate of the maximal production capacity, variations of these inputs affect the measurement of productivity. Second, omitting materials when sales are used to proxy the output may lead to some biases. Although the materials share in output may vary a lot across firms, these variations should mainly be observed across industries. If R&D expenditures are correlated with these sectoral effects, then omitting these effects will lead to biased estimates of the rate of return to R&D. However, the results in specification 2 lead to the conclusion that the introduction of industry dummies does not influence the estimates.

Specifications 3 and 4 include variables measuring different spillover pools. In specification 3, the spillover variable is constructed as the industry based amount of R&D reported in ANBERD database in percent of the industries production value. This industry wide R&D Intensity should capture intra-industry spillovers in our model. In specification 4, these industry wide R&D intensities are aggregated for the individual countries to measure inter-industry spillovers. However, as the results show, we could not detect any spillover benefits in these two specifications.

One interesting question concerns the relative impact of R&D activities carried out by firms in the different countries. As can be seen from Table 1, we have little information on R&D activities of firms in some smaller European countries and on firms in Italy, for example. We therefore only explore the difference between the USA and the European countries as a whole. We tried to account for country specific effects by introducing an interactive Dummy for the European firms in the sample. Although the estimated rate of return to R&D seems to be lower for European firms (8% compared to 14% in the US), this coefficient is not statistically significant at the usual levels of significance.

TABLE 4A: Output Growth and R&D Intensity (nominal): heckit results (robust)[z]

Specification	Classification	Description	Coefficients and (Standard Errors) independent Variables[a] c	l	RD/S[b]	IRD/S[c]	CRD/S[d]	EU*RD/S[e]	EU	inv. Mills ratio[f]	Chi^2 - Test[g]
	1 Basis	pooled	.26 (.052)*	.61 (.049)*	.12 (.048)*					-.02 (.016)	2.47 (.116)
	2 Industry Effects	pooled, ID	.26 (.052)*	.60 (.053)*	.12 (.052)*					-.01 (.004)*	8.94 (.003)
	3 Intra-Industry Spillovers	pooled, IRD/S	.26 (.050)*	.61 (.053)*	.11 (.048)*	.02 (.060)				-.01 (.004)*	8.10 (.004)
	4 Inter-Industry Spillovers	pooled, CRD/S	.26 (.062)*	.60 (.071)*	.12 (.061)**		.14 (1.195)			-.02 (.054)	.17 (.680)
	5 Country Effects	EU*RD/S	0.27 (.024)*	.60 (.027)*	.14 (.041)*			-.06 (.105)	-.00 (.007)	-.01 (.011)	1.01 (.313)

* (**) statistically significant at the 5% (10%) level.
[z] Heckman full maximum-likelihood estimation with Huber/White/sandwich estimator of the variance
[a] c and l = mean logarithmic growth rates over the period 1991-1998 of phys. Capital and Employment
[b] Average R&D to Sales ratio: R&D averaged over the years 1991-93, divided by average sales 1991 through 1998.
[c] IRD/S = industry R&D outlays/nominal production (NACE-2 digit) at industry level; average 1990-98; from OECD-ANBERD
[d] CRD/S = industry R&D outlays/nominal production (NACE-2 digit) at country level; average 1990-98; from OECD-ANBERD
[e] EU*RD/S = interactive EU-Dummy, representing R&D from EU firms in the sample
[f] The inverse Mills ratio is an additional regressor (in essence, an omitted variable).
A significant coefficient implies sample selection (see Wooldridge (1999), Ch. 17).
[g] The likelihood ratio test is an equivlaent test for sample selection.

TABLE 4B: Output Growth and R&D Intensity (real): heckit results (robust)[z]

Specification	Classification	Description	Coefficients and (Standard Errors) independent Variables[a] c	l	RD/S[b]	IRD/S[c]	CRD/S[d]	EU*RD/S[e]	EU	inv. Mills ratio[f]	Chi^2 - Test[g]
	1 Basis	pooled	.28 (.057)*	.57 (.060)*	.10 (.049)*					-.03 (.013)*	6.07 (.014)
	2 Industry Effects	pooled, ID	.30 (.057)*	.55 (.059)*	.12 (.055)*					-.03 (.014)*	4.83 (.028)
	3 Intra-Industry Spillovers	pooled, IRD/S	.29 (.058)*	.57 (.062)*	.12 (.050)*	-.00 (.001)				-.03 (.015)*	5.22 (.022)
	4 Inter-Industry Spillovers	pooled, CRD/S	.30 (.057)*	.55 (.061)*	.10 (.050)*		.01 (.005)			-.02 (.018)	.92 (.337)
	5 Country Effects	EU*RD/S	.29 (.029)*	.56 (.033)*	.10 (.051)*			.02 (.128)	-.01 (.011)	-.02 (.020)	1.99 (.156)

* (**) statistically significant at the 5% (10%) level.
[z] Heckman full maximum-likelihood estimation with Huber/White/sandwich estimator of the variance
[a] c and l = mean logarithmic growth rates over the period 1991-1998 of phys. Capital and Employment
[b] Average R&D to Sales ratio: R&D averaged over the years 1991-93, divided by average sales 1991 through 1998.
[c] IRD/S = industry R&D outlays/nominal production (NACE-2 digit) at industry level; average 1990-98; from OECD-ANBERD
[d] CRD/S = industry R&D outlays/nominal production (NACE-2 digit) at country level; average 1990-98; from OECD-ANBERD
[e] EU*RD/S = interactive EU-Dummy, representing R&D from EU firms in the sample
[f] The inverse Mills ratio is an additional regressor (in essence, an omitted variable).
A significant coefficient implies sample selection (see Wooldridge (1999), Ch. 17).
[g] The likelihood ratio test is an equivlaent test for sample selection.
[g] The likelihood ratio test is an equivlaent test for sample selection.

TABLE 5A: Output Growth and R&D Intensity (nominal): OLS results

			Coefficients and (Standard Errors) independent Variables[a]									
Specification	Classification	Description	c	l	RD/S[b]	IRD/S[c]	CRD/S[d]	EU*RD/S[e]	EU	R^2adj.	MSE
	1 Basis	pooled	.28 (.024)*	.58 (.026)*	.16 (.036)*					.81	.037
	2 Industry Effects	pooled, ID	.29 (.024)*	.58 (.026)*	.14 (.042)*					.81	.037
	3 Intra-Industry Spillovers	pooled, IRD/S	.28 (.024)*	.58 (.027)*	.12 (.041)*	.10 (.043)*				.81	.038
	4 Inter-Industry Spillovers	pooled, CRD/S	.28 (.0.24)	.58 (.026)*	.14 (.037)*		.60 (.209)*			.81	.037
	5 Country Effects	EU*RD/S	.27 (.024)*	.59 (.026)*	.15 (.039)*			-.06 (.105)	.03 (.002)*	.81	.037

* (**) statistically significant at the 5% (10%) level.
[a] c and l = mean logarithmic growth rates over the period 1991-1998 of phys. Capital and Employment
[b] Average R&D to Sales ratio: R&D averaged over the years 1991-93, divided by average sales 1991 through 1998.
[c] IRD/S = industry R&D outlays/nominal production (NACE-2 digit) at industry level; average 1990-98; from OECD-ANBERD
[d] CRD/S = industry R&D outlays/nominal production (NACE-2 digit) at country level; average 1990-98; from OECD-ANBERD
[e] EU*RD/S = interactive EU-Dummy, representing R&D from EU firms in the sample

TABLE 5B: Output Growth and R&D Intensity (real): OLS results

			Coefficients and (Standard Errors) independent Variables[a]								
Specification	Classification	Description	c	l	RD/S[b]	IRD/S[c]	CRD/S[d]	EU*RD/S[e]	EU	R^2adj.	MSE
	1 Basis	pooled	.31 (.027)*	.54 (.030)*	.15 (.044)*					.74	.044
	2 Industry Effects	pooled, ID	.32 (.027)*	.53 (.030)*	.13 (.050)*					.76	.043
	3 Intra-Industry Spillovers	pooled, IRD/S	.32 (.028)*	.53 (.030)*	.13 (.048)*	.00 (.001)				.75	.044
	4 Inter-Industry Spillovers	pooled, CRD/S	.31 (.027)*	.54 (.030)*	.12 (.043)*		.01 (.002)*			.75	.044
	5 Country Effects	EU*RD/S	.30 (.027)*	.55 (.030)*	.13 (.047)*			.04 (.128)	-.02 (.005)*	.75	.043

* (**) statistically significant at the 5% (10%) level.
[a] c and l = mean logarithmic growth rates over the period 1991-1998 of phys. Capital and Employment
[b] Average R&D to Sales ratio: R&D averaged over the years 1991-93, divided by average sales 1991 through 1998.
[c] IRD/S = industry R&D outlays/nominal production (NACE-2 digit) at industry level; average 1990-98; from OECD-ANBERD
[d] CRD/S = industry R&D outlays/nominal production (NACE-2 digit) at country level; average 1990-98; from OECD-ANBERD
[e] EU*RD/S = interactive EU-Dummy, representing R&D from EU firms in the sample

Robustness

Table 4B and Tables 5A and 5B present robustness checks, first for real values with heckit and than with OLS. The estimates for the private rates of return remain significant and are of rather comparable magnitude in all specifications. This is also true for the estimates on labour and physical capital input, respectively. Furthermore, no single specification reveals significant country effects. However, the OLS results point to high and significant spillover benefits if output growth is measured in nominal values. Indeed, if measured in real values, inter-industry spillovers are still significant, but their magnitude is negligible.

4. Conclusions

In this paper, we have analyzed the contribution of R&D to the productivity performance of firms using a large unbalanced panel of firms from the US and from Europe. The results let us conclude that both, European and US firms engaged in R&D activities, performed better in terms of productivity growth compared to other firms in the 1990s. However, growth in R&D expenditures by US firms has been almost twice as high compared to that of European R&D firms, and labour productivity of R&D firms increased by 1.6% per year faster in the US.

The econometric section confirms the positive and significant contribution of R&D to productivity growth, both for the US and the European firms in our sample. The estimated rate of return is about 12% which is at the lower end of previously reported estimates. Allthough the estimate for the European firms seems to be lower (8%), it is not statistically significant at the usual levels. Additionally, contrary to what could be expected from the empirical literature, we were not able to detect any spillover effects in our basic specifications.

Overall, however, our results must be interpreted with caution. The dataset used is an unbalanced panel, with more than 70% of the firms which report R&D expenditures in their accounts coming from the US or the UK. Furthermore, for most of the European firms in our sample we have no more than two or three observations regarding R&D expenditures over the whole period. Additionally, there may be some kind of selection bias at work, particularly in the European sample. Although we account for this by employing the Heckman correction procedure, it is questionable, if we have enough identifying information in our data. However, the OLS results point to very robust findings with regard to the estimated rate of return to R&D.

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