

R&D and Productivity
A broad cross-section cross-country look

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Third draft. Paper presented at the European Economic Association annual conference in Helsinki, 27-29 August, 1993

Abstract

The empirical literature on R&D and productivity has shown that there is indeed a positive influence of R&D investment on output growth. However, the exact relation depends to a large extent on the approach chosen (i.e., functional form). Because most studies concentrate on a limited number of countries or sectors and use their own specific methodology, comparison is difficult. This paper aims at providing a broad overview of cross-country and cross-sector differences in the relation between R&D and output growth, using a common methodology, so that comparison is easier. The functional form used is a translog production function, which is applied to data for 15 manufacturing sectors and 9 principal OECD countries.

Keywords: R&D and productivity, **JEL-codes:** O30, O40, O57

* I thank Franz Palm for helpful suggestions and Zvi Griliches for comments. All errors and the views expressed remain my own responsibility. My research has been made possible by a fellowship of the Royal Netherlands Academy of Arts and Sciences.



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1. Introduction

This paper is concerned with the relation between technological change and output growth. It tries to establish an empirical relation between technological change in the form of cumulated R&D expenditures and the growth rate of value added.

There are many papers in this field, both theoretical and empirical. On the theoretical side, the relation between technological change and growth is prominent in both the evolutionary approaches to the economic process (e.g. Nelson and Winter 1982, Dosi *et al.* 1988, Verspagen 1992a) and the so-called new growth theory (e.g. Romer 1990, Grossman and Helpman 1991, an overview is in Verspagen 1992b). Both of these approaches stress, although in a different way and from different starting points, the influence of technology as a factor related to increasing returns to scale, and being the primary source of economic growth in the long run.

This paper tries to establish this influence of technology in the form of R&D, and tries to find out whether there are differences between countries and/or sectors. Sectoral differences in the influence of R&D (or more general) technology are related to differences in technological opportunities and characteristics. In general, it is assumed that the influence of technology is largest in the 'scientific' sectors, in which the application of recent technologies plays a large role.

The rest of this paper is organized as follows. In section 2, a very broad overview of the main conclusions of the empirical literature on R&D and productivity growth is provided. This section also tries to identify some main gaps in this literature, and thus sets out the main lines along which the paper will be developed, trying to fill these gaps.

Section 3 gives a broad overview of the main trends in the dataset that will be used. It provides some basic descriptive statistics on inputs and outputs and their growth rates. This section also provides a classification of sectors into high-, medium-, and low-tech that will be used in the rest of the paper.

Section 4 contains the actual empirical analysis. It provides a flexible model of output growth (in the form of a translog function), and estimates its parameters from a dataset of nine countries and three different sets of sectors.

The results are summarized in section 5.

2. The empirical literature on R&D and productivity and motivation for the present study

An excellent survey of the literature in which this paper is interested is given in Mohnen (1992). There is no need, nor space, to reproduce such a survey here. However, it is useful to recapitulate the most important conclusions of this literature here.

First, it seems that the conclusions on the influence of R&D on productivity depend to a large extent on the approach (i.e., functional form) used. Even when restricted to one particular type of models (factor demand models based on the duality theory), Mohnen (1992: 15) concludes that "[t]he results seem to depend more on the underlying model than on the country concerned". This indicates the importance of choosing a functional form that is sufficiently flexible, i.e., does not impose any unnecessary conditions with regard to for example elasticities of substitution or returns to scale.

Second, most studies find a positive influence of R&D on productivity. However, the exact influence is hard to establish. In the two tables that summarize Mohnen's survey, the estimated (positive) rate of returns to R&D investment vary from 3 to 274%. Rates of return seem to differ between sectors, more than they differ between countries. Again, this result seems, however, to depend on the approach chosen: "In the cross-section dimension, the elasticities of output with respect to R&D are higher in the scientific (i.e. research intensive) sectors. (...) However, in the time-series dimension, where the elasticities tend to drop, there is not much difference between the two types of sectors" (Mohnen 1992: 13).

Third, the influence of R&D investment is to some extent connected to spillovers, which can be of the inter- and intra-industry and/or -country type. The exact influence of these spillovers seems, however, even harder to identify than the effect of direct R&D: "The rates of return to indirect R&D show a much greater [than direct R&D, author] dispersion, partly due, perhaps, to the different choices of weighting matrices" (Mohnen 1992: 6).

These results seem to indicate the need for a study that considers both the cross-section and cross-country dimension of the relation between R&D and productivity, using a common methodology for all estimates, and applying a flexible approach. It is the aim of this paper to cover this gap.

3. A descriptive look at the data

The aim of this section is to outline the main trends in growth and R&D in the sectors and countries that will be considered in the next section. The sectors that will be looked at are the following¹:

food products (foo); textiles and related products (tex); wooden products (woo); paper and printing (pap); chemicals (che); refined petroleum (pet); rubber and plastic products (rub); other non-metallic minerals (min); ferrous metals (fme); non-ferrous metals (nme); fabricated metal products (fam); non-electrical machinery computers and office machinery (mac); electrical machinery (elm); transport equipment (tra); instruments (ins); other manufacturing (oth).

For each of these sectors, data on value added, employment, investment and R&D expenditures are available. The latter two variables are used to construct stock variables, by means of a perpetual inventory method (see the data-appendix for details).

¹ Abbreviations between brackets will be used in the graphs below.

Figure 1a

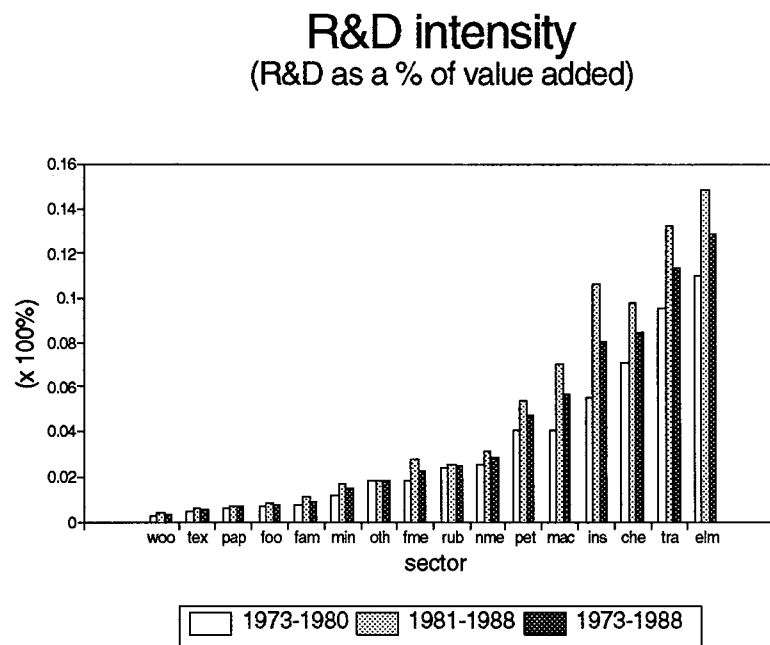


Figure 1b

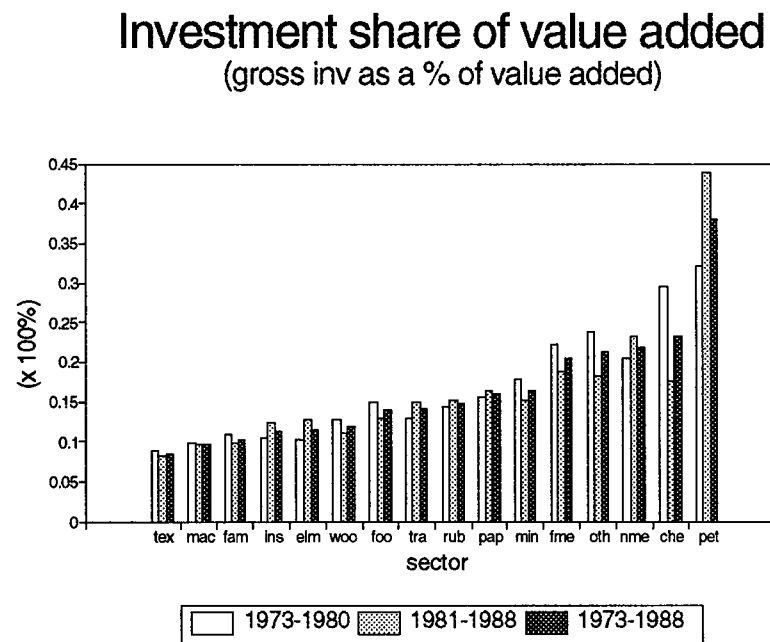
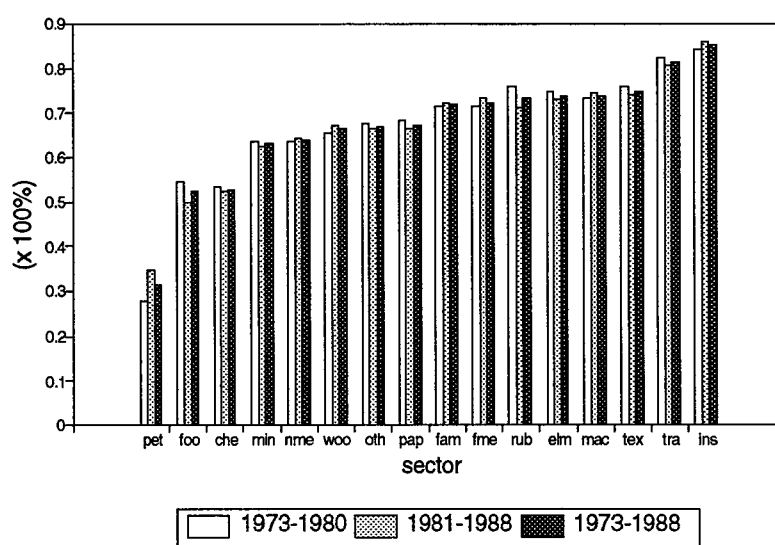


Figure 1c

Labour share in value added



The first series of graphs, 1a-1c, presents some data on the importance of spending categories (investment, labour costs and R&D expenditures) in total value added². The numbers depicted are (unweighted) averages over all countries for which data is available. Principally, these countries are Canada, Germany, France, Japan, Italy, Norway, Sweden, United Kingdom and the USA. However, since data can be missing for some sectors, the averages presented may exclude some countries.

Figure 1a presents average R&D intensities (R&D as a percentage of value added). Overall, it appears that the sectors which are usually identified as 'high-tech' appear to have the highest values, indicating that the pay-offs to R&D are highest in these sectors. These sectors are machinery, instruments, chemicals, transport equipment and electrical machinery. Within four of these sectors, one can identify 'core-R&D' areas in the form of 4-digit ISIC subsectors. These are pharmaceuticals (within chemicals), computers and office machinery (within machinery), electronic components and communication equipment (within electrical machinery), and aircraft (within transport

² One should note that since R&D consists mainly of labour costs, a large part of R&D expenditures are also included in labour share.

equipment).

Petroleum appears as a somewhat intermediate sector between the high-tech and medium-tech segments of the graph. Because of the highly natural resource based character of this industry, it is not classified into high-, medium- or low-tech, and is not considered in the regressions below. The medium-tech group consists of non-metallic minerals, other manufacturing, ferrous and non-ferrous metals, and rubber and plastic products. The other industries, with R&D intensities well below 2%, can be regarded as low tech.

Another feature that emerges from the graph is that in most cases, there is a distinction between the two periods. The first one (1973-1980) is characterized by lower R&D intensities than the second one (1981-1988). This holds for all sectors, except other manufacturing, and is in line with evidence at the aggregate level (see below).

Turning to the graph for investment as a percentage of value added, it is clear that the medium-tech sectors are mostly found at the part of the graph displaying higher values, whereas most high-tech sectors (with the exception of chemicals, and, to a lesser extent transport equipment) are found in the lower-value areas. Thus, it appears that R&D and investment in fixed capital are not very closely connected, something which is not contradictory to broad theories of the product life cycle (Abernathy 1978).

With regard to differences between the two periods, the picture is less clear in the case of investment. Of course, investment in both periods is influenced heavily by the recessions that occurred in each of them (the same goes, to some extent for R&D). On the whole, the number of sectors in which the investment value added ratio decreased is a bit larger than the ones in which it increased (nine against seven), but it appears sectoral effects are more important than aggregate effects.

Figure 2a

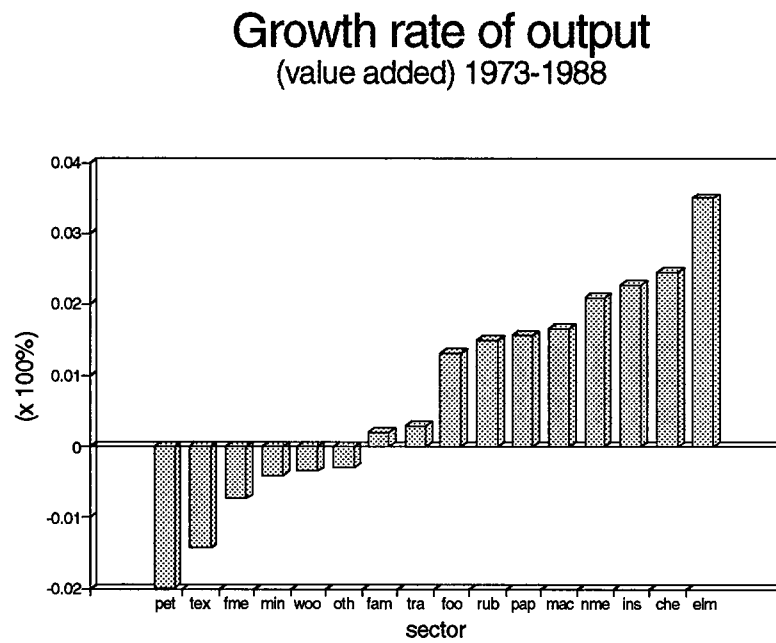


Figure 2b

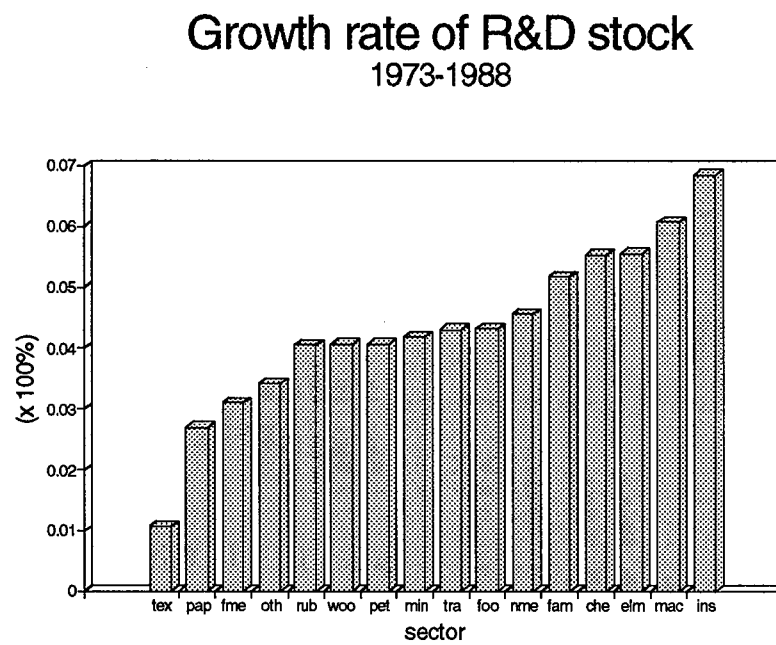


Figure 2c

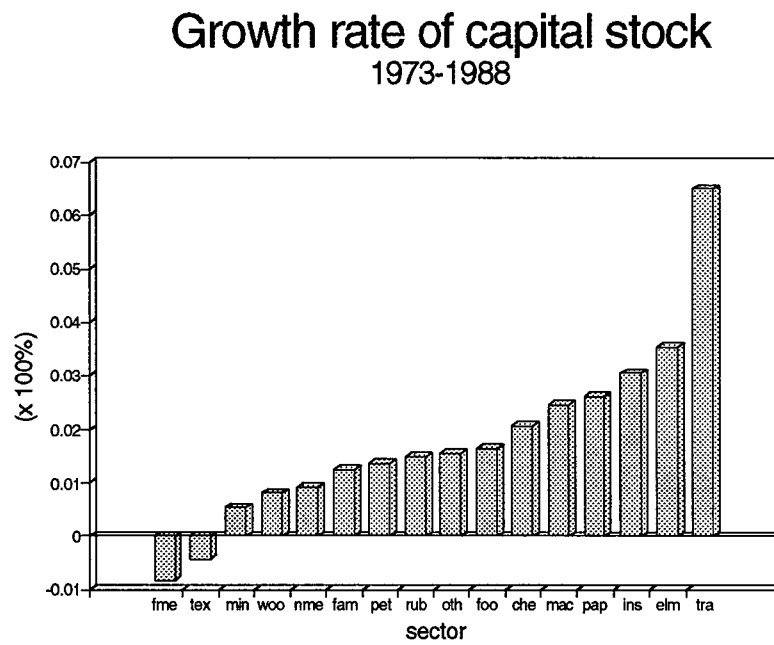
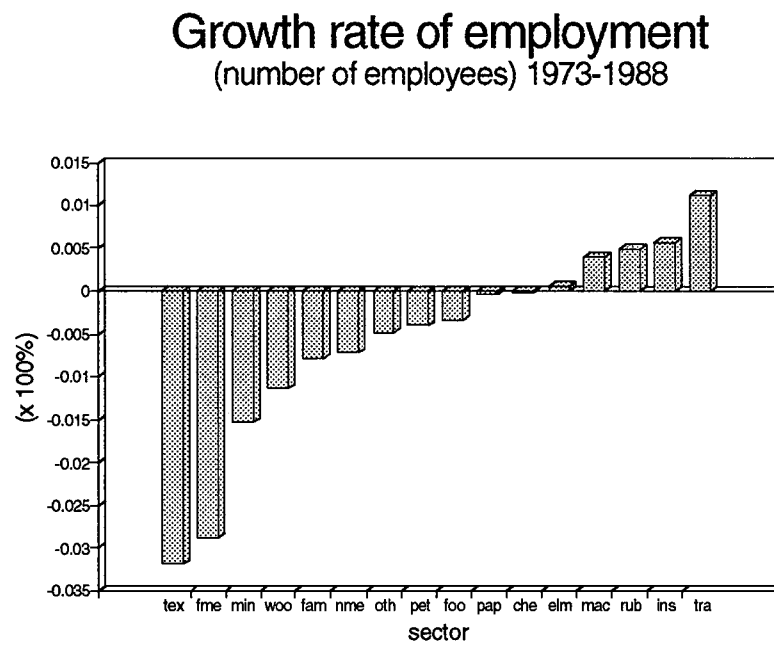


Figure 2d



Turning finally to labour costs, it is found that the intersectoral differences in this variable appear less dramatic than in the case of the two other variables. There are three sectors in which labour share is low (petroleum, food products and chemicals), and two sectors in which it is high (instruments and transport equipment), and the other sectors have somewhat of an intermediate position. On the whole, high-tech sectors appear to have higher labour shares (with the exception of chemicals), while medium-tech sectors have intermediate values. In light of the Schumpeterian hypotheses on market structure and innovativeness (see Kamien and Schwartz 1982, or Scherer and Ross 1990), this might seem surprising, if one takes labour share as an inverse indicator of the profit rate. This body of theory suggests that innovation provides the entrepreneur with monopoly power, and therefore gives her the opportunity to achieve above normal profits.

The next series of graphs, 2a-2d, gives an overview of the growth rates of inputs and output (value added) for each of the sectors. The presented results are again unweighted sample averages. Starting with value added, it appears that a considerable number of sectors have realized negative growth rates, while a number of others have realized positive growth rates. This points to the relevance of the argument of structural change (Pasinetti 1981, Verspagen 1992a).

Maintaining the distinction between high-, medium- and low-tech industries, it is interesting to see that the high-tech industries are the only category which has realized exclusively positive growth rates. Moreover, four of the five high-tech sectors rank among the five fastest growing sectors (transport equipment grows at a somewhat slower pace). This illustrates the strategic importance of these sectors in the production structure of a country.

The importance of high-tech sectors for R&D activities also comes out of the graph for the growth rate of the R&D stock (Figure 2b). As could be expected, four of the five high-tech sectors rank on top of the list of growth rates. Only transport equipment ranks somewhere in the middle. Contrary to output, growth rates of this variable are positive in all sectors.

Figure 2c shows that the importance of high-tech sectors also holds for the growth rate of the capital stock. The five high-tech sectors now all rank among the six highest values. Another interesting observation is that overall, the growth rate of the capital stock seems to be less than the growth rate of the R&D stock, indicating a slowly growing importance of knowledge in the production of goods.

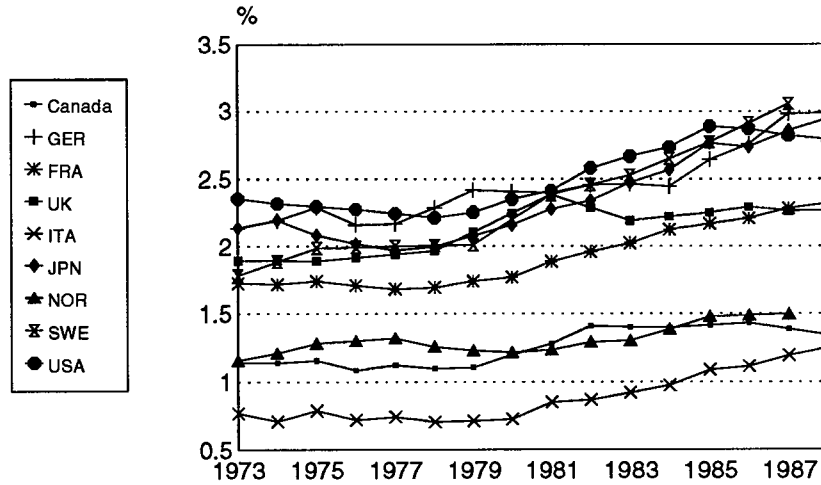
The mostly positive growth rates of the inputs that have been considered so far, in combination with some of the negative rates of output growth in Figure 2a, must lead to the expectation of a large number of cases in which labour input has decreased. Figure 2d illustrates this process, showing that only five of the sectors considered have shown a positive growth rate of employment over the period considered.

The fact that four of these five sectors are high-tech (the other high-tech sector, chemicals, ranks as the one closest to zero on the negative side), shows again the strategic importance of these sectors. While the decline in employment in the other sectors might be partly due to the introduction of labour saving techniques, the so-called compensation effects (see for example Freeman and Soete 1987, Katsoulacos 1986) in the form of new demand seem to be present in the countries under consideration here.

Finally, Figure 3 gives a cross-country look at R&D trends, at the aggregate level rather than the sectoral level. The figure gives business R&D expenditures as a percentage of GDP. Two things emerge. First, over the period as a whole, there has been a significant increase in R&D intensity, as has already been observed at the sectoral level. Second, there is a clear distinction between countries, with one group having relatively low, and the other one having relatively high, R&D intensities. The group with the lower values consists of Norway, Canada and Italy. The absolute top of R&D intensity is formed by the USA, Japan and Germany.

Figure 3

Aggregate R&D intensity (R&D as a % of GDP)



4. A formal model

In order to assess the impact of R&D on productivity and production, the procedure in Nadiri and Prucha (1992) is followed. This means that a translog production function (and its first order conditions) will be estimated. The production function will not include foreign R&D or R&D carried out in other sectors, because of the difficulties associated with this (see the survey by Mohnen 1992).

While the methodology of the translog production function offers great flexibility, it also has a number of drawbacks. These relate to the quality of the price data used in the estimations, the exogeneity of output, and many other factors. A more complete discussion is in Mohnen (1992).

The models used can be specified as follows. Denote output, labour, the capital stock, and the R&D stock by Q , L , K , R , respectively. T will denote a time trend, related to disembodied technological change. A subscript t denotes time. The function looks as follows

$$\begin{aligned}
\ln Q_t = & \alpha_0 + \alpha_L \ln L_t + \alpha_K \ln K_t + \alpha_R \ln R_t + \alpha_T T_t + \\
& \frac{1}{2} \alpha_{LL} (\ln L_t)^2 + \alpha_{LK} \ln L_t \ln K_t + \alpha_{LR} \ln L_t \ln R_t + \alpha_{LT} \ln L_t T_t + \\
& \frac{1}{2} \alpha_{KK} (\ln K_t)^2 + \alpha_{KR} \ln K_t \ln R_t + \alpha_{KT} T_t + \\
& \frac{1}{2} \alpha_{RR} (\ln R_t)^2 + \alpha_{RT} \ln R_t T_t + \frac{1}{2} \alpha_{TT} T_t^2.
\end{aligned} \tag{1}$$

The α 's are parameters to be estimated later on. Denoting the (rental) price of factor I by P_I and the price of output by P , the first order conditions can be written as

$$\frac{P_{Lt} L_t}{P_t Q_t} = \alpha_L + \alpha_{LL} \ln L_t + \alpha_{LK} \ln K_t + \alpha_{LR} \ln R_t + \alpha_{LT} T_t \tag{2}$$

$$\frac{P_{Kt} K_t}{P_t Q_t} = \alpha_K + \alpha_{LK} \ln L_t + \alpha_{KK} \ln K_t + \alpha_{KR} \ln R_t + \alpha_{KT} T_t \tag{3}$$

$$\frac{P_{Rt} R_t}{P_t Q_t} = \alpha_R + \alpha_{LR} \ln L_t + \alpha_{KR} \ln K_t + \alpha_{RR} \ln R_t + \alpha_{RT} T_t.$$

The greater flexibility of the translog function only comes at the expense of a relatively large number of parameters to be estimated, in this case 15. Moreover, the value of the parameters themselves are not very interesting from a theoretical point of view. Instead, it is more useful to look at the elasticity of output with respect to each of the factors.

This latter quantity can be obtained by differentiating production function (1) with respect to each of the factors, which results in the following expression for factor I

$$e_{Qit} = \alpha_i + \sum_l \alpha_{il} \ln I_{it} \quad (5)$$

Using the data from the previous section, equations (1)-(4) are estimated by 3SLS, using lagged (once and twice) values of the variables (including prices, but not factor shares) as instruments.

Because there are 15 datapoints for each sector at the most, and 15 parameters have to be estimated, some kind of pooling will have to be applied. Along the lines sketched above, pooling will be done over sectors, splitting the total sample into three different groups: high-tech, medium-tech and low-tech sectors.

Because of space considerations, the regression results will be limited to reporting on the calculated output elasticities and their standard errors. The elasticities are obtained by substituting the sample means of the independent variables in equation (5), and the standard errors are calculated using the variance-covariance matrix of the parameter estimates obtained in the 3SLS procedure.

The results for the high-tech sectors are documented in Table 1. In general, the results indicate that R&D, as well as the more traditional production factors labour and capital, are highly significant in explaining the growth rate of output. This holds for all countries in the table, except for the case of R&D for Canada and Norway. Although the estimated elasticities for these countries are positive, the one for Norway is smaller than for the other countries, and standard errors are relatively large for both Norway and Canada. The time trend is significant for Japan and Germany only (in the latter case, the trend is negative, which is hard to interpret. Leaving out the time trend does not change the results drastically, except for the case of Norway, where the estimated standard error of the elasticity of R&D is reduced significantly³.

First, the results for R&D in this table indicate the general finding that R&D is

³ Results not documented, but available on request.

important in the high-tech sectors. They also seem to indicate that there are differences between countries, in contrast to what Mohnen (1992) reports (see above). The estimated elasticities is highest in the USA, than Japan, after which the larger European countries follow. The two countries which do not seem to operate on the frontier of technological advance (Norway and Canada) have lower values of the elasticity and/or higher standard errors. The values of the elasticities are somewhat higher than in Nadiri and Prucha (1992), who apply the same methodology at the aggregate level. They find elasticities between 2 and 3%.

Table 1. Estimated output elasticities in the high-tech sectors (machinery, transport equipment, instruments, chemicals), 1973-1988*

Country	<i>L</i>	<i>K</i>	<i>R</i>	<i>T</i>	<i>n</i> ^{**}
USA	0.730 (0.017)	0.152 (0.029)	0.111 (0.059)	0.0017 (0.0064)	60
Japan	0.545 (0.007)	0.146 (0.026)	0.088 (0.034)	0.050 (0.004)	60
Germany	0.742 (0.010)	0.137 (0.043)	0.074 (0.012)	-0.0050 (0.0015)	40
UK	0.840 (0.062)	0.197 (0.059)	0.077 (0.026)	0.050 (0.005)	45
Canada	0.638 (0.025)	0.150 (0.069)	0.075 (0.074)	-0.0066 (0.0052)	45
Norway	0.724 (0.068)	0.252 (0.035)	0.051 (0.053)	0.002 (0.009)	45

* Numbers between brackets are standard errors.

** Number of observations in the regressions.

It is also interesting to note that with regard to labour and capital there are differences between countries. Japan and Canada stand out with regard to low labour elasticities, while the UK has a high value of this quantity. The elasticity of capital input is relatively high in Norway and the UK.

The same regressions were carried out for the medium-tech sectors. The output

elasticities and their estimated standard errors are in Table 2. With regard to R&D, it now appears that the estimated elasticities are lower (as expected) and also less significant in most cases. In fact, Norway and Sweden are the only two countries in which a clearly significant influence of R&D in these sectors is detectable, with France as a borderline case. Italy and Germany stand out with negative (although insignificant) values⁴. This shows that the influence of R&D in these sectors is smaller, but can still be positive.

The Scandinavian case is an interesting one. One of these countries has been characterized as medium-tech at the aggregate level above. Although Sweden's R&D intensity is up to the level of the major technological countries, its role as a creator of new technology is more modest than Germany, Japan or the USA. Thus, while the high-tech countries all showed significantly positive elasticities in case of the high-tech sectors (contrary to the medium-tech countries in Table 1), the only countries in which a significant influence of R&D is established in the medium-tech sectors are indeed the more medium-tech countries. It thus seems there is an economic reason why these countries should invest in R&D in a 'moderate' way.

Table 2. Estimated output elasticities in the medium-tech sectors (non-metallic minerals, rubber and plastic products, basic metals, other manufacturing), 1973-1988*

Country	<i>L</i>	<i>K</i>	<i>R</i>	<i>T</i>	<i>n</i> ^{**}
USA	0.730 (0.026)	0.177 (0.028)	0.014 (0.052)	0.017 (0.0057)	75
Japan	0.570 (0.001)	0.188 (0.016)	0.022 (0.032)	0.011 (0.005)	75
Germany	0.685 (0.021)	0.277 (0.049)	-0.032 (0.031)	0.021 (0.006)	75
France	0.670 (0.014)	0.322 (0.037)	0.038 (0.026)	0.014 (0.008)	46
Italy	0.697 (0.049)	0.318 (0.084)	-0.090 (0.067)	0.022 (0.014)	73

⁴ In case of Germany, the negative elasticity vanishes if a time trend is no longer included.

Canada	0.715 (0.010)	0.169 (0.042)	0.061 (0.043)	0.010 (0.005)	75
Norway	0.720 (0.027)	0.213 (0.039)	0.068 (0.031)	-0.003 (0.004)	75
Sweden	0.837 (0.024)	0.305 (0.024)	0.042 (0.016)	0.011 (0.004)	60

* Numbers between brackets are standard errors.

** Number of observations in the regressions.

With regard to the other factors, it seems like the elasticities with regard to labour are slightly smaller in this group of sectors, while the estimates for capital are somewhat higher overall. Again, these two variables are highly significant, as could be expected.

Table 3. Estimated output elasticities in the low-tech sectors (food products, textiles, wooden products, paper and printing, fabricated metal), 1973-1988*

Country	<i>L</i>	<i>K</i>	<i>R</i>	<i>T</i>	<i>n</i> ^{**}
USA	0.665 (0.015)	0.112 (0.037)	-0.003 (0.021)	0.009 (0.004)	75
Japan	0.570 (0.009)	0.144 (0.034)	-0.019 (0.030)	0.026 (0.005)	75
Germany	0.662 (0.024)	0.213 (0.044)	-0.036 (0.033)	-0.005 (0.005)	75
France	0.706 (0.030)	0.215 (0.035)	-0.022 (0.029)	0.0003 (0.004)	75
UK	0.876 (0.010)	0.142 (0.025)	0.012 (0.006)	0.027 (0.008)	75
Italy	0.545 (0.036)	0.152 (0.074)	0.013 (0.017)	0.013 (0.095)	60
Canada	0.699 (0.011)	0.175 (0.046)	-0.021 (0.041)	0.002 (0.006)	75
Norway	0.786 (0.031)	0.211 (0.043)	0.023 (0.032)	0.009 (0.007)	75

Sweden	0.674 (0.025)	0.198 (0.057)	0.025 (0.040)	0.002 (0.007)	60
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* Numbers between brackets are standard errors.

** Number of observations in the regressions.

Finally, Table 3 gives the estimations for the low-tech sectors. The results with regard to labour and capital are basically the same as in the previous two tables, indicating some disparity between countries, but all significantly positive values within the limits of reasonable values. With regard to R&D, the estimates for the high-tech countries are now mostly negative, but not significantly so. For some of the medium-tech countries, estimates are positive (Norway, Sweden, UK), but only in the case of the UK significant.

Overall, the results show that the influence of R&D on productivity is relatively strong in the high-tech sectors and high tech countries, and in some cases also significantly positive in medium-tech sectors in medium-tech countries.

5. Conclusions

This paper has investigated the role of R&D in productivity increases over the period 1973-1988. In a first description of the data, a clear trichotomy between sectors emerged. The first group of sectors, the so-called high-tech sectors (machinery, chemicals, transport equipment and instruments), is characterized by a high ratio of R&D to value added, a more modest ratio of investment to value added, and by high growth rates of output, employment and capital and knowledge inputs. The second group of sectors, the medium-tech sectors (non-metallic minerals, basic metals, rubber and plastic products, other manufacturing) are characterized by average R&D to value added ratios, often high investment to value added ratios, modest growth rates of output and capital and knowledge inputs, and mostly modestly negative growth rates of labour input. The low-tech sectors, food products, textiles, wood, paper and printing, and fabricated metal, generally display slow growth of output, capital and knowledge inputs, and sharply negative growth rates of labour input.

These descriptive statistics illustrate, although in a very basic way, the strategic importance of technology in growth. The technology-intensive sectors are also the ones that contribute most to output and employment growth.

A broad survey of the empirical literature has shown that there is a need for a study that looks at the relationship between R&D and productivity in a broad sample of sectors and countries. Most existing studies are specific to one combination of sector, country and methodology. Thus, the second part of this paper has applied a translog production framework to sectoral data for nine OECD countries (Canada, Germany, France, Japan, Italy, Norway, Sweden, United Kingdom and the USA). For each of these countries, one set of equations was estimated for a pooled sample of five sectors, along the classification of high-, medium-, and low-tech sectors introduced in the first part. The production function used has three inputs: labour, capital and the knowledge stock (cumulated R&D). Additionally, a time trend was included to capture the effects of 'disembodied' technical change.

The results of this exercise are the following. For the high-tech sectors, positive elasticities of output with respect to R&D were found. The values range from 5-11%. However, only for the most advanced countries (with regard to technology), the estimated R&D elasticities were significant. These countries are the USA, Japan, Germany and the UK (no data was available for France, Sweden and Italy). Across these countries, there are significant differences in elasticities.

In the medium-tech sectors, positive elasticities were also obtained, but only in the case of Sweden and Norway, these were significant. Overall, the value was clearly lower than in the high-tech sectors. This seems to indicate that there is evidence for a positive influence of R&D on productivity outside high-tech production, but that this depends on the country. It is not necessarily the case that these elasticities should be highest in the 'high-tech countries'. This finding seems to be consistent with the theory on national systems of innovation (see Lundvall 1992), which stresses that a country's general institutional setting determines where and to what extent technological change will have its influence. The way in which the results here match

this theory, is that some of the medium-tech countries' national systems seem to be geared towards application of new technology in medium-tech sectors rather than in high-tech sectors.

In the low-tech sectors, no significant influence of R&D was found. Moreover, several estimated elasticities were negative in this group of estimations.

The overall conclusion arising from the estimations is thus that the influence of R&D on productivity depends highly on the sectoral and national context.

Appendix. A description of the data and its sources

Source for all the data on values, as well as employment, is OECD. Stocks of R&D and investment in fixed capital are constructed using a perpetual inventory method, with depreciation rates of 0.1 in the case of fixed capital and 0.15 in the case of R&D. Initial stocks are calculated as the value of investment of next year, divided by the depreciation rate plus an assumed growth rate of 0.05.

Sources for price data are as follows. Producer prices which are used to deflate value added are taken from UNIDO. The price index for investment is assumed to be equal across sectors, but not countries, and is taken from the Penn World Tables (mark 5). R&D expenditures are deflated by the GDP price deflator, which is taken from the same source. Rental prices for R&D and fixed capital are assumed to be equal to this price index multiplied by the respective depreciation rate.

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