EFFECT OF PUBLICLY AND PRIVATELY FINANCED R&D ON TOTAL FACTOR PRODUCTIVITY GROWTH*

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The effects of privately and publicly financed R&D on total factor productivity growth are examined. Total factor productivity (TFP) is decomposed into mark-up, exogenous demand, factor price, and publicly and privately financed R&D effects at the industry level. The constructed dataset consists of 11 Finnish manufacturing industries in 1975–1993. The results suggest that both privately and publicly financed R&D has a considerable effect on the TFP rate of growth but R&D explains only part of the technical progress. On the average, total R&D accounted for about 9 percent of the TFP rate of growth in manufacturing industries while one fourth of the growth could be attributed to the residual technical change. Exogenous demand effect was the biggest component, accounting almost for one third of the TFP rate of growth. (JEL: L6, O38,O47)

1. Introduction

The role of R&D as a means of competition has become increasingly important in recent years. At the same time, R&D has become the primary instrument in public competition policy as governments have abolished traditional industrial subsidies. While there is a body of evidence of the effect of R&D on productivity growth, the determinants of productivity growth have received less attention. Especially the role of publicly financed private R&D should be thoroughly appraised. By breaking down the productivity rate of growth into components, we can estimate the effect of R&D along with other important factors such as demand, factor price and the residual technical change. The result will then show us the relative share of each component in the productivity growth.

Examining the interaction of total factor productivity (TFP) and R&D is in line with the ideas of the new growth theory which seeks to explain the growth that cannot be attributed to the accumulation of traditional inputs – labor and capital. The new growth theory proposes that a stock of general knowledge is the source of economic growth. The usual way is to use R&D as a proxy for the stock of knowledge. A theoretical rationale can also be found for the choice of the TFP as the variable to be explained by R&D investment. Since the TFP measures the proportion of output growth that stems from factors other than the increased use of ordinary inputs, it is a more logical choice in determining the effect of R&D than, for instance, output growth.

Although studies on the effect of public R&D subsidies are hard to find, there is more evi-

* *I would like to thank Pekka Ilmakunnas, Matti Pohjola, Jouko Vilmunen and two anonymous referees for helpful comments.*

dence of the effect of total R&D capital stock on TFP growth, suggesting that privately financed R&D has a positive effect on total factor productivity growth. The early papers include R&D elasticity studies by Mansfield (1965) and Griliches (1980). Subsequently, several panel data studies have confirmed the role of R&D on productivity growth. Coe and Helpman (1995) examined the role of domestic business sector R&D in TFP growth in conjunction with international R&D spillovers. The results indicated that a one percent increase in R&D capital stock raises the average productivity by almost 0.1 percent. Finland was included in the sample but country-specific figures were not given for domestic R&D.

The effect of publicly financed R&D on productivity has been examined less extensively, let alone publicly subsidized private R&D. Finding relevant data on the share of publicly financed R&D has hampered empirical applications. Another issue has been omitted: the estimates for R&D, whether publicly or privately financed, may be biased upwards since important variables characterizing firms or industries have been left out. For instance, Denison (1985) has estimated that R&D accounts for only 20 percent of all technical progress. Therefore, isolating the effect of R&D from the residual technical change may yield better estimates of changes in growth and the rate of productivity.

The total factor productivity decomposition method by Nadiri and Mamuneas (1994) gives an insight into the industry-wide effect of public capital investments. The impact of private R&D is not examined in their study but the model can be modified to incorporate the two sources of financing R&D investments – public, which in Finland is usually distributed by the Technology Development Centre, and private companies. Note that in our model, all R&D is private in the sense that it is performed by firms. The focus is therefore on the source of financing, whether the funds attributed to R&D expenditures come from the firm itself or from external sources in the form of public subsidies.

Technical change is retrieved as a separate item in a similar fashion to the growth-accounting approach of Solow (1957), i.e. technical change is treated as a residual. In addition to public and private R&D effects, the decomposition method also yields estimates for exogenous demand and factor price effects. The former stems from the growth of the economy as a whole while the latter represents the impact of capital and labor price increases on TFP growth. Although Nadiri and Mamuneas (1994) do not give an interpretation for the term involving mark-up change in the decomposition method, we can interpret that term as a measure of oligopoly power or cyclical mark-up change.

In this paper we decompose the TFP into seven components, estimating the relative share of each component. According to our results the TFP rate of growth can be attributed to the components as follows. First, industrial R&D accounts on average for nine percent of the TFP rate of growth, with the subsidized part of R&D being slightly higher than the privately financed part. Privately financed R&D investments appear to have decreased cost of production while publicly financed R&D had an opposite effect. The roles are reversed in productivity growth; public R&D has increased productivity in most industries whereas privately financed R&D offsets part of that effect. The effect of exogenous demand is the largest component with an average share of 29 percent of productivity growth. This leaves the disembodied technical change component an average share of about one fourth of the TFP rate of growth.

The paper is organized as follows. The model is presented in section two, followed by the discussion of the empirical issues and the description of the data in section three. Section four provides the decomposition results. A summary and concluding remarks can be found in section five.

2. *The model*

In the spirit of Nadiri and Mamuneas (1994), the model presented here is a an extended version of the simple production function approach. The idea is to decompose total factor productivity growth into various effects such as exogenous demand, factor price, and R&D effects. As opposed to Nadiri and Mamuneas (1994), the main interest of this study is in the impact of publicly and privately financed R&D on productivity.

We begin with the following production function

$$(1)\quad Y = F(X, RD_p, RD_g, T)$$

where Y is the output, X denotes the standard inputs capital (K) and labor (L), RD_p is privately financed R&D, RD_g is industrial R&D financed by the government and other public institutions, and T is the disembodied technology level. For total factor productivity, the standard definition is given by the Divisia index:

$$(2)\quad TFP = Y - \sum_i S_i X_i$$

where S_i is the relative share of standard of input i: $S_i = P_i X_i / P_y Y$. P_i stands for input prices of labor and capital, P_L and P_K, respectively. P_y denotes the output price. In the rate of growth form, equation (2) can be written

$$(3)\quad \frac{\dot{TFP}}{TFP} = \frac{\dot{Y}}{Y} - \sum_i S_i \frac{\dot{X}_i}{X_i}$$

Without R&D investment, the firm would minimize the usual cost function $C = \sum_i P_i X_i$. We assume that firms engage in cost reducing R&D which is financed by the firm or the government. The cost function with the publicly and privately financed R&D can be written

$$(4)\quad C^* = C + \sum_{s=p,g} Q_s RD_s$$

where Q_s is the price of the R&D input s. Firms engage in R&D up to the point where the following equilibrium condition holds

$$(5)\quad -\frac{\partial C}{\partial RD_s} = Q_s.$$

A firm in the competitive setting minimizes costs given a certain output level:

$$min\ C^* \qquad s.t.\ Y = F(X, RD_p, RD_g, T)$$

The first order conditions from the minimization of C^* are

$$(6)\quad \frac{\partial F}{\partial X_i} = \frac{P_i}{\lambda}\ \forall i,\quad \frac{\partial F}{\partial RD_s} = \frac{Q_s}{\lambda}\ \forall s,$$

$$\frac{\partial C^*}{\partial Y} = \lambda \text{ and } -\frac{\partial C^*}{\partial T} = \lambda \frac{\partial F}{\partial T}$$

Differentiating the production function (1) with respect to time and dividing the result by Y, we can write it in the rate of growth form:

$$(7)\quad \frac{\dot{Y}}{Y} = \sum_i \frac{\partial F}{\partial X_i}\frac{\dot{X}_i}{Y} + \sum_s \frac{\partial F}{\partial RD_s}\frac{\dot{RD}_s}{Y} + \frac{1}{Y}\frac{\partial F}{\partial T}$$

Eliminating λ, the Lagrangian multiplier, from (6) and substituting the result in (7) as well as using (5), we obtain

$$(8)\quad \frac{\dot{Y}}{Y} = \sum_i \frac{P_i \dot{X}_i}{\frac{\partial C^*}{\partial Y}Y} + \sum_s \frac{-\frac{\partial C}{\partial RD_s}}{\frac{\partial C^*}{\partial Y}Y}\dot{RD}_s + \frac{-\frac{\partial C^*}{\partial T}}{\frac{\partial C^*}{\partial Y}Y}.$$

Assuming constant returns to scale with respect to standard inputs X_i and combining this with the definitions of the total cost elasticity η^* (Nadiri and Mamuneas 1994) and the cost elasticity with respect to R&D inputs η_{RDs}, we get

$$\eta^* = \frac{\partial \ln C^*}{\partial \ln Y} = \frac{\partial \ln C}{\partial \ln Y}\Big/ B = \eta/B, \quad \text{where}$$

$$B = 1 - (\sum_j \partial lnC/\partial lnRD_s) = 1 - \sum_s \eta_{RDs}.$$

The non-R&D returns to scale are, by definition, the proportional increase in output due to the equiproportional increase of non-R&D inputs on a given technology and R&D inputs. Non-R&D returns to scale equal $1/\eta$, while $1/\eta^*$ denotes total returns to scale. This information is used to decompose growth in the TFP into total and R&D scale effects.

Rearranging (8) yields

$$\frac{\dot{Y}}{Y}+\sum_s \frac{\frac{\partial C}{\partial RD_s}\dot{RD}_s}{\frac{\partial C^*}{\partial Y}Y}+\frac{\frac{\partial C^*}{\partial T}}{\frac{\partial C^*}{\partial Y}Y}=\sum_i \frac{P_i\dot{X}_i}{\frac{\partial C^*}{\partial Y}Y}$$

$$\Rightarrow \frac{\partial C^*/\partial Y}{P_Y}\frac{\dot{Y}}{Y}+\frac{1}{P_Y}\sum_s \frac{\frac{\partial C}{\partial RD_s}\dot{RD}_s}{Y}$$

$$+\frac{\partial C^*/\partial T}{P_Y Y}=\sum_i S_i\frac{\dot{X}_i}{X_i}=\frac{\dot{Y}}{Y}-\frac{\dot{TFP}}{TFP}$$

$$(9)\quad \Rightarrow \frac{\dot{TFP}}{TFP}=\left[1-\frac{\partial C^*/\partial Y}{P_Y Y}\right]\frac{\dot{Y}}{Y}$$

$$-\frac{1}{P_Y}\sum_s \frac{\frac{\partial C}{\partial RD_s}\dot{RD}_s}{Y}-\frac{\partial C^*/\partial T}{P_Y Y}$$

Since $\frac{\partial C^*}{\partial Y}=\frac{\partial \ln C^*}{\partial \ln Y}\frac{C^*}{Y}$, (9) can be written

$$\frac{\dot{TFP}}{TFP}=\left[1-\frac{\partial lnC^*/\partial lnY}{P_Y}\frac{C^*}{Y}\right]\frac{\dot{Y}}{Y}$$

$$-\frac{1}{P_Y}\sum_s \frac{\frac{\partial lnC^*}{\partial lnRD_s}\frac{C^*}{RD_s}}{Y}\dot{RD}_s-\frac{\partial lnC^*/\partial lnT}{P_Y Y}\frac{C^*}{T}$$

Defining the rate of cost decrease due to technical change as

$$\frac{\dot{T}}{T}=\frac{\partial \ln C^*}{\partial T}\frac{\partial \ln C}{\partial T}\Big/ B$$

and $\kappa=(P_Y Y)/C^*=P_Y/AC^*$ we get

$$(10)\quad \frac{\dot{TFP}}{TFP}=\left(\frac{\kappa-\eta^*}{\kappa}\right)\frac{\dot{Y}}{Y}-\frac{1}{\kappa B}\sum_s \eta_{RDs}\frac{\dot{RD}_s}{RD_s}-\frac{\dot{T}}{\kappa BT}.$$

TFP growth has now been decomposed into a total scale effect, an R&D input effect and a technical change effect. The scale effect can be further decomposed by assuming a mark-up pricing rule $P_Y=(1+\theta)\frac{C}{Y}$, where θ is the mark-up over the marginal cost.[1] Taking logarithms and differentiating the mark-up pricing rule with respect to time yields

$$(11)\quad \frac{\dot{P}_Y}{P_Y}=\frac{(1\dot{+}\theta)}{(1+\theta)}+\frac{\dot{C}}{C}-\frac{\dot{Y}}{Y}$$

In what follows, θ is allowed to change over time since there is no reason to think it would be constant; it would probably be affected by technical change and demand. For example, Rotemberg and Woodford (1991), Forsman *et al.* (1997) and Goldstein (1986) have analyzed cyclical mark-ups. Goldstein (1986) tests the flexible mark-up hypothesis which posits that mark-up changes are positively related to the level of international competition in concentrated industries. Forsman *et al.* (1997) found that mark-ups in Finnish industry have declined over time since the beginning of 1980s.

Time differentiating cost function C and using Shephard’s lemma, we get

$$(12)\quad \frac{\dot{C}}{C}=\frac{\dot{Y}}{Y}+\sum_i S_i\frac{\dot{P}_i}{P_i}+\sum_s \eta_{RDs}\frac{\dot{RD}_s}{RD_s}+\frac{\dot{T}}{T}$$

Nadiri and Mamuneas (1994) assume a log-linear demand function in the growth rate form. Their demand function consists of aggregate income, population and a demand time trend. For the Finnish economy, we can think of alternative ways of modeling the demand. For instance, exports or the GDP of the European countries can be more suitable than aggregate domestic income. Let Z be the variable of choice for the Finnish economy. N and τ denote population and a demand time trend, respective-

[1] *It should be noted that in the theoretical model, κ is also a mark-up factor since it is related to θ as $1+\theta=\kappa C^*/C$. In the empirical application below, the model is simplified by assuming $\kappa=1$.*

ly. The homogeneity of demand is not imposed. The coefficients of Z and N add up to one which can be interpreted so that the elasticity of demand with respect to income per capita (Z/N) is β:

$$(13)\quad \frac{\dot{Y}}{Y} = \tau + \alpha\frac{\dot{P}_Y}{P_Y} + \beta\frac{\dot{Z}}{Z} + (1-\beta)\frac{\dot{N}}{N}.$$

Finally, (11) and (12) are substituted in (13) which is then plugged in (10) to obtain a reduced form function for the TFP rate of growth:

$$(14)\quad \frac{\dot{TFP}}{TFP} = A\alpha\frac{(1\dot{+}\theta)}{(1+\theta)} + A\alpha\sum_i S_i\frac{\dot{P}_i}{P_i}$$
$$+ A\left[\tau + \beta\frac{\dot{Z}}{Z} + (1-\beta)\frac{\dot{N}}{N}\right]$$
$$+ A\alpha\sum_s \eta_{RDj}\frac{\dot{RD}_s}{RD_s} - \frac{1}{\kappa B}\sum_s \eta_{RDs}\frac{\dot{RD}_s}{RD_s}$$
$$+ A\alpha\frac{\dot{T}}{T} - \frac{1}{\kappa B}\frac{\dot{T}}{T}$$

where $A = \dfrac{\kappa - \eta^*}{\kappa}$.

Equation (14) now consists of five effects:

$A\alpha\dfrac{(1\dot{+}\theta)}{(1+\theta)}$ [mark-up effect]

$A\alpha\sum_i S_i\dfrac{\dot{P}_i}{P_i}$ [factor price effect]

$A\left[\lambda + \beta\dfrac{\dot{Z}}{Z} + (1-\beta)\dfrac{\dot{N}}{N}\right]$ [exogenous demand effect]

$\left[A\alpha - \dfrac{1}{\kappa B}\right]\sum_s \eta_{RDs}\dfrac{\dot{RD}_s}{RD_s}$ [public and private R&D effect]

$\left[A\alpha - \dfrac{1}{\kappa B}\right]\dfrac{\dot{T}}{T}$ [disembodied technical change].

The direct effect is the R&D induced reduction in the non-R&D cost of production which results in higher output growth at a lower output price: $(\eta_{RDs}/\kappa B)\dfrac{\dot{RD}_s}{RD_s}$. The indirect effect $A\alpha\eta_{RDs}\dfrac{\dot{RD}_s}{RD_s}$ relates to output growth and leads to further changes in $\dot{TFP}$ ($s = p,g$).

3. Data

In the following analysis, the effect of publicly and privately financed R&D on productivity is estimated for eleven Finnish manufacturing industries. A special dataset is created for this study by collecting data on the industry-level R&D investment and financing from the Science and Technology Yearbooks of Statistics Finland. This information was combined with a time series of labor, output, price indexes, etc. from the Etla (The Research Institute of the Finnish Economy) database. To our knowledge this kind of dataset has not been produced before at the industry level in Finland.

The industries were chosen on the basis of the continuity of R&D information. The industrial classification system has been changed twice by Statistics Finland during our estimation period 1974–1993. Since we use growth rates, 1975 is the first period in the analysis. Although the classification in our sample had to be modified due to the changes in classification, all manufacturing industries at the two digit level are included in the sample. In addition, a few R&D intensive three digit industries could also have been included.

Private R&D expenditures can be retrieved from the data in a relatively straightforward manner while the classification of public R&D subsidies has changed considerably over the years. Furthermore, the level of R&D investment has increased rapidly since the 1970s: the average annual growth rate has been 8.0 percent in privately financed R&D expenditures (9.5 percent in publicly financed R&D) in the 19-year period from 1975 to 1993, and 4.1 percent (9.3 percent) during the latter half of the measuring period. This means that the starting values were at a very low level in many subcategories (by sources and types) of public subsidies. Thus, a dichotomy between publicly and privately financed R&D has been used instead of a more detailed breakdown.

The industrial statistics are collected annually by Statistics Finland. The data are very comprehensive, consisting of all manufacturing establishments with a personnel of five or more. In addition, the data include all establishments with less than five employees if the turnover corresponds to the average level of turnover of the enterprises with a personnel of five to ten employees.

In the construction of the dataset, the following definitions of variables have been used. Output was measured by gross industrial output at producer prices. This output measure is used in estimating the demand function. For TFP computations, output was denoted by value added at producer prices which is the standard measure in growth accounting. Labor costs consist of wages of blue and white collar workers including social security costs.

The TFP was calculated as follows. First, the income share for labor was calculated as a ratio of labor costs and value added, both expressed in current prices. The income share for capital was retrieved as residual: one minus the income share of labor. Second, the annual logarithmic change in the input was multiplied by its income share to obtain weighted growth rates of inputs. Third, growth rates of inputs were subtracted from the output rate of growth. This yields the total factor productivity rate of growth.

All indexes were normalized to be equal to one in 1990. If readily deflated time series were not available, the industrial producer price index was applied. R&D and valued added were deflated this way. Exports were deflated by the export price index. The gross domestic product of the OECD countries was already given in 1990 USD prices, as was the gross domestic product of Finland.

Capital was approximated by the value of net capital stock. Privately financed R&D consists of R&D investments which are paid for by the firm or other firms and R&D financed by other private funding. Public financing includes loans or direct subsidies from the Ministry of Trade and Industry, the Technology Development Centre, municipal governments, other ministries and some smaller public entities.

R&D capital stocks were calculated from R&D expenditures using the perpetual inventory model. Unlike physical capital, R&D capital cannot be found in the accounting data. We have used the perpetual inventory method to generate the R&D capital stock from the past expenditure:

$$RDK_t = RD_t + (1-d)RD_{t-1} + (1-d)^2 RD_{t-2} + \ldots RD_t + (1-d)RDK_{t-1}$$

where RDK_t is the R&D capital at time t, RD_t denotes R&D expenditures at time t in real terms and d is the depreciation rate. The value of the *RDK* in the first year of the data was calculated as $RDK_0 = RD_0/(g + d)$ where g is the average annual growth of R&D expenditures over the whole observation period and RD_0 is the value of R&D expenditures in the first year (Griliches, 1986). Since R&D expenditure figures in our data are available only for odd years, the interim years are calculated as arithmetic means: $(RD_t + RD_{t-2})/2$. There is no theoretical or empirical rule for setting the value for the depreciation rate d. In this study we use the value of 10 percent for d.

Table 1 presents the sample statistics. The average annual growth of the TFP has been measured as the average logarithmic change between 1975 and 1993. Year-by-year fluctuations have been considerable in most industries but as a whole, productivity has grown across the industries. The TFP has been positive in each industry, with wood processing, basic metals and the electronics industry achieving the highest productivity growth. The average annual TFP rate of growth has been 3.2 percent in manufacturing in 1975–1993.

As noted above, R&D investment has grown very rapidly. Both publicly and privately financed R&D stocks have grown nearly at the same annual rate of approximately 10 percent. The absolute stock values of the latter are still over ten times higher. The difference is greatest in food processing and chemicals where privately financed R&D stocks are 25 and 19 times bigger, respectively, than publicly financed R&D stock. Public financing has been relatively highest in machinery, non-metallic mineral and fabricated metal industries where

Table 1 Descriptive Statistics of the Sample

Constant price values of the variables in 1993, millions of Markka. Average annual growth rates in percent.

SIC	*description of the industry*	$\dot{TFP}$	Y[1]	$\dot{Y}$	L	$\dot{L}$	K[2]	$\dot{K}$	π[3]	$\dot{\pi}$	RD_p[4]	$\dot{RD}_p$	RD_g[4]	$\dot{RD}_g$
31	*food manufacturing*	2.5	12 783	2.9	5 944	–0.9	25 552	1.9	4 397	3.5	277	9.9	9	11.6
32	*textile, wearing apparel, leather*	2.5	3 013	–3.3	1 757	–7.6	4 428	–2.0	470	–4.0	26	6.1	3	9.4
33	*wood and wood products*	6.5	5 750	4.7	3 535	–3.2	10 881	1.2	1 881	7.9	45	6.5	3	7.5
34	*paper and paper products*	2.9	21 329	3.4	11 163	–0.3	68 053	2.0	3 408	5.9	258	2.9	24	5.8
35	*chemicals, oil, coal, rubber, plastics*	2.2	10 981	3.1	5 074	0.2	28 821	1.7	3 657	3.6	831	7.8	81	10.7
36	*non-metallic mineral products*	2.0	2 978	0.9	1 628	–3.3	8 920	1.9	600	0.5	102	8.5	33	17.5
37	*basic metal industries*	4.4	6 134	4.1	2 467	0.0	14 803	1.0	2 632	6.5	272	8.2	36	12.4
381	*fabricated metal products, excl. machinery*	3.2	5 073	3.0	3 034	–1.2	7 246	2.0	1 501	4.0	81	7.5	13	8.9
382	*machinery, excl. electrical*	3.2	11 094	2.3	5 986	–1.9	11 797	1.5	3 143	3.3	615	7.4	53	4.7
383,5	*electrical machinery and instruments*	4.3	10 331	5.8	4 302	–0.1	8 006	4.4	4 457	10.8	1 893	11.1	161	10.8
384	*transport equipment*	1.9	4 003	–0.4	3 205	–2.5	9 439	0.9	623	–2.6	108	12.2	14	5.2

[1] value added [2] net capital stock [3] surplus of the industry [4] R&D expenditures

the ratio of privately financed to publicly financed R&D stocks ranges from 9 to 6. The average value in manufacturing is around 13.

The decline of two industries, namely textile manufacturing and transport equipment, can be seen in the growth rates of value added and surplus. A low or even negative trend in inputs reflects the same issue. As a whole, the real labor costs have decreased in manufacturing industries. This is due to a shift in production towards more capital-intensive manufacturing. More importantly, the number of industrial workers has declined from 554 000 in 1974 to 361 000 in 1993.

4. Decomposition of the TFP rate of growth

The idea of the TFP decomposition is to compute all the components on the right-hand side of (14) except technical change which is then retrieved as a residual. The estimation of equation (14) requires a number of parameters. The left-hand side is calculated using the definition $\frac{\dot{TFP}}{TFP} = \frac{\dot{Y}}{Y} - \sum_i \frac{S_i \dot{X}_i}{S_i X_i}$ as defined above. On the right-hand side, an array of cost elasticities is needed. The theoretical model distinguishes between η^* (total cost elasticity), η (non-R&D cost elasticity) and η_{RDs} (cost elasticities with respect to R&D$_\mathbf{s}$, where s = **p**rivate or **g**overnment). These are obtained by estimating the cost function with the appropriate share equations. Average translog cost function is employed:

$$
\begin{aligned}
(15)\quad \ln C_i - \ln Y_i = {} & \alpha + \sum_{j=L,K} \beta_j^1 \ln w_j + \sum_i \beta_i^2 T \\
& + \sum_{k=L,K} \sum_{j=L,K} \beta_{jk}^3 \ln w_j \ln w_k + \sum_{j=L,K} \beta_j^4 \ln w_j T \\
& + \sum_{s=p,g} \varphi_{is}^1 \ln RD_s^i + \sum_{s=p,g} \sum_{j=L,K} \varphi_{jis}^2 \ln w_j \ln RD_s^i
\end{aligned}
$$

where i = (31, …, 384) indicates the industry.

In the above equation, all variables have been deflated to the base year of 1990. The technology variable T has been interpreted as a time index, increasing from the first year of the sample by steps of one. R&D stocks are used as described above. The specification implies constant returns to scale with respect to the non-R&D cost elasticity. W_j stands for the input price index. Since the index for investment goods is not available for the whole observation period, we chose the wholesale price index for W_K until 1982 and the investment goods index from 1983 to 1993. For W_L we have the wage index available for the whole observation period. In order to be consistent with the value added based production function, costs C_i are defined net of materials and Y_i as value added.

The possible endogeneity of the right-hand side variables is tested using the Hausman specification test. Hausman's specification test is a general test for testing the hypothesis of no misspecification in the model. The Hausman test can be considered as an endogeneity test. The null hypothesis is that the RHS terms and the residual are independent. A Wald test is undertaken on the difference of the coefficients derived from a consistent estimation method (2SLS instrumental regression) and from OLS.

The Hausman statistic is distributed as chi-squared, with degrees of freedom equal to the number of parameters tested. A value that is insignificant implies no specification error. We carried out the endogeneity test separately for each right-hand side variable. None of the variables turned out to be endogenous. The probability values of the test statistic were statistically insignificant, ranging from 0.17 to 0.92. Testing the R&D-related explanatory variables jointly gave an insignificant value with a probability of 1.00. We can, therefore, conclude that endogeneity is not involved and proceed with the above systems estimation.

We have pooled the industry time-series data. However, a considerable latitude is allowed for industry effects by creating cross-terms of the variables and industry dummies. Different coefficients for each industry are allowed in the variables of interest. In equation (15), the coefficients with industry dummies include the subscript i. In order to save degrees of freedom, the industry effect is estimated for R&D stock (RD) and technical change (T) variables.

The share equations for the translog cost function (15) can be obtained by using Shephard's lemma, that is, differentiating the cost function with respect to input prices w_j:

$$(16)\quad S(j) = \beta_j^1 + \sum_{k=L,K} \beta_{jk}^3 \ln w_k + \beta_j^4 T + \sum_{s=p,g} \varphi_{is}^2 \ln RD_s^i$$

The above system of translog cost function (15) and two share equations S(K) and S(L) is estimated as a nonlinear seemingly unrelated regressions (SURE) system. The parameters have been restricted to satisfy the following conditions:

$$(17)\quad \sum_{j=L,K} \beta_j^1 = 1; \qquad \beta_{LK}^3 = \beta_{KL}^3;\ \textit{and}$$
$$\sum_{j=L,K} \beta_{jk}^3 = 0, \qquad \textit{for}\ k = L,K.$$

The restrictions (17) together with the structure of (15) ensure that C is linearly homogenous in prices and output, that is, the corresponding production function is linearly homogenous (see e.g. Diewert, 1984).

The parameters are first estimated for each equation separately. Then system estimation is carried out, with a covariance matrix derived from the initial parameter estimates. This yields a total of 75 parameters for the system (15)–(16). For the sake of brevity, only the average η coefficients are reported in table 2. They are calculated from the parameters estimated in the above system by differentiating C with respect to RD_s:

$$(18)\quad \eta_{RD_{is}} = \varphi_{is}^1 + \sum_{j=L,K} \varphi_{is}^2 \ln w_j$$

As a whole, a large number of φ coefficients were not statistically significant at a 5 percent confidence level; the number of observations should be larger for better estimates. On the other hand, all η^* coefficients were statistically significant whereas η_{RD} parameters were not. Given that the time series analysis is not the main issue, the fit of the model is quite good. Table 2 lists the obtained cost elasticities for publicly and privately financed R&D by indus-

Table 2 Cost Elasticities from the Trans-log Cost Function

	31	32	33	34	35	36	37	381	382	383,5	384	*average*
η_{RDP}	–0.11 (–0.09)	–0.02 (–0.02)	0.41 (0.32)	–1.03 (–0.14)	–0.24 (–0.24)	–0.12 (–0.10)	–0.15 (–0.04)	0.32 (0.13)	–0.50 (–0.12)	0.08 (0.04)	–0.48 (–0.20)	–0,17
η_{RDG}	0.13 (0.08)	0.02 (0.02)	–0.50 (–0.29)	1.30 (0.14)	0.28 (0.21)	0.15 (0.09)	0.19 (0.04)	–0.38 (–0.12)	0.58 (0.12)	–0.12 (–0.05)	0.51 (0.21)	0,20
η^*	1.02 (1.59)	1.01 (2.27)	0.92 (1.90)	1.38 (0.34)	1.04 (2.96)	1.02 (2.41)	1.04 (1.07)	0.94 (1.56)	1.08 (1.20)	0.96 (2.15)	1.04 (5.11)	1,04

t-statistics in parenthesis.

SURE system estimated with two share equations S(L) and S(K).	S(L) share equation	S(K) share equation
Convergence achieved after 3 iterations:	Mean of LHS. Var. : 0.6471	Mean of LHS. Var. : 0.3529
Log-L = 130.5818	Std. of LHS Var. : 0.1446	Std. of LHS Var. : 0.1446
No. of obs. = 209	Std error of est : 0.0687	Std error of est : 0.0690
	R-Squared : 0.7743	R-Squared : 0.7726

try along with the total cost elasticity η^*. T-statistics have been calculated with the Wald test. The remaining cost elasticities can be derived from the R&D elasticities. Since the non-R&D cost elasticity η equals unity by construction, $\eta^* = 1/(1-\sum \eta_{RD_s})$.

Total cost elasticity coefficients mainly have values at or slightly above unity. This implies constant or decreasing returns to scale except in the wood processing and electronics industries where η^* is below unity. The average total cost elasticity is 1.04.

The cost elasticity of privately financed R&D is negative in most industries. The absolute value of η_{RDP} is highest in paper manufacturing and machinery. Negative coefficients can be found also in the elasticities of publicly financed R&D although η_{RDG} is generally positive and of higher absolute value than the privately financed R&D cost elasticity.

Negative coefficients imply that privately financed R&D input has indeed decreased costs in industry. This effect is offset in most industries by a positive value of η_{RDG}. This could result from R&D being used to improve the efficiency of the ordinary inputs (capital and labor), and the inclusion of both R&D and ordinary inputs in the estimation equation may reduce the effect of R&D stocks. Another explanation is related to cost reducing process innovations (‘development’) and riskier innovations aimed at creating novel products (‘research’). It is plausible that private funding is directed mainly at the former types of innovations while public money is used for investments of a higher risk profile. This would explain the opposite signs of the elasticities.

Examining the trend of the R&D cost elasticities over time, it is noticeable that the absolute values have grown with the sign remaining usually unchanged. In other words, the cost reducing effect of R&D has intensified in the industry where R&D reduced costs at the beginning of the observation period.

Mark-up θ can be expressed as follows:

$$P_Y = (1+\theta)\frac{C}{Y}$$ and $\pi = P_Y Y - C$, where π denotes profit and C is marginal cost

$$\Rightarrow \theta = \frac{P_Y Y - C}{C} = \frac{\pi}{P_Y - \pi}$$

For π we use surplus in industry, as measured by Statistics Finland. The mark-ups range from 5 to 22 percent with the average being 14 percent. The mark-up over the marginal cost is highest in non-metallic minerals and electronics. The wood and wood products industry has the lowest value.

The log-linear demand function (13) is estimated to obtain parameters α, β and τ. As noted above, there exist many alternatives to approximate the variable Z. We tried four variables: OECD gross domestic product (GDP), GDP of European OECD countries, Finnish exports and Finnish GDP. Of these variables, the

Table 3 Demand Function Parameter Estimates

	31	32	33	34	35	36	37	381	382	383,5	384
τ	0,017	–0,063	0,010	0,017	–0,037	–0,017	0,032	0,018	–0,007	0,081	–0,018
	(0,595)	(2,189)	(0,346)	(0,607)	(1,288)	(0,596)	(1,129)	(0,615)	(0,239)	(2,814)	(0,645)
α	–0,146	0,076	–0,303	–0,230	0,977	–0,302	–0,339	–0,275	0,142	–0,646	–0,259
	(0,314)	(0,163)	(0,652)	(0,495)	(2,104)	(0,648)	(0,728)	(0,592)	(0,304)	(1,389)	(0,556)
β	0,225	1,201	1,967	1,214	0,520	2,489	1,222	2,200	1,722	1,091	1,616
	(0,393)	(2,093)	(3,429)	(2,115)	(0,936)	(4,176)	(2,129)	(3,835)	(3,001)	(1,902)	(2,817)
1-β	0,775	–0,201	–0,967	–0,214	0,480	–1,489	–0,222	–1,200	–0,722	–0,091	–0,616
	(1,350)	(0,350)	(1,686)	(0,372)	(0,863)	(2,498)	(0,386)	(2,092)	(1,258)	(0,159)	(1,074)

t-statistics in parenthesis.

Linearly restricted regression
Adjusted R-squared = 0.28681
No. of obs. 198, Model test: F[32,165] = 3.48,
Prob value = 0.00000 degr. of fr. 154
Log-L = 244.0771, Restricted(á = 0) Log-L = 193.0657

model estimated with Finnish GDP turned out to fit the data best. Nine out of eleven parameter estimates of β are statistically significant at a 5 percent confidence level.

Table 3 presents the results of the demand function. Output was measured by industry output in 1990 prices. Exports were deflated by the export price index. The figures for OECD are available in 1990 US dollars, taking exchange rates into account. Finnish GDP is also available in time series deflated to 1990 prices. The population was approximated by population at the end of the given year. As above in the case of the demand function, data were pooled with industry dummies created for each parameter.

The time trend of demand, τ , is statistically zero in all industries barring textiles where it is negative and electronics which has a positive and statistically significant coefficient. Given the development of these two industries, the result is expected. The coefficient for population growth, *1-*β, is statistically significant only in two industries. The same holds for α, the coefficient of the price level rate of change, which is statistically insignificant in all but one industry. However, as noted above, domestic GDP has a positive and statistically significant effect on demand in most industries.

Finally, κ is assumed to equal one. In other words, the value of the industry output is assumed to equal the payments to the factors of production and the public R&D investment. This is by and large consistent with the estimates of total cost elasticities which were approximately one. Now all the necessary parameters for the decomposition of total factor productivity have been obtained and can be substituted in equation (14).

Note that the above process yields an R&D cost elasticity for every year and each industry, that is, a matrix of elasticity parameters. Therefore, the final result in the decomposition is also a 11 x 18 matrix for each component. The use of growth rates decreases the number of years to 18. Since all the components measure the percentage effect on total factor productivity on a particular year, an average compounded change can be computed. This reduces the matrices to 11 x 1 vectors, making the information comprehensible. Table 4 presents the results. Negative figures indicate that a component has had an adverse effect on the rate of growth of total factor productivity.[2]

[2] *Following Nadiri and Mamuneas (1994) and Mamuneas (1999), standard errors for average components have not been computed. Apart from lengthy calculations, the main reason is based on the theory of statistics. In this case, we have parameters from two independent regressions – average cost and demand functions. The variance of the product for two independent variables is* $var(xy) = \mu_y^2 var(x) + \mu_x^2 var(y) + var(x) var(y)$ *where* μ_x *is the point estimate of x (see e.g. Mood et al., 1974: 180–181). Therefore, the variance of the product is likely to be high, making the product xy statistically insignificant even if both variables x and y are statistically significant. Mamuneas (1999) even omits the standard errors for elasticity parameters.*

Table 4 Decomposition of the TFP Rate of Growth

industry	31	32	33	34	35	36	37	381	382	383,5	384
TFP	2.51	2.52	6.54	2.86	2.23	2.00	4.43	3.23	3.21	4.27	1.89
Mark-up	0.00	0.00	–0.03	0.02	0.00	0.00	0.00	0.00	0.00	–0.01	0.00
Factor Price	0.02	0.00	–0.20	0.66	–0.25	0.05	0.10	–0.12	–0.09	–0.19	0.08
Exog.demand	2.78	–3.87	5.39	4.72	–0.06	2.79	7.15	6.67	1.82	16.44	1.02
R&D (private)	–1.37	–0.16	3.33	–5.33	–2.14	–1.30	–1.32	2.96	–4.53	0.82	–8.60
direct	–1.36	–0.16	3.43	–5.01	–2.22	–1.29	–1.30	3.01	–4.58	0.84	–8.51
indirect	0.00	0.00	–0.10	–0.32	0.07	–0.01	–0.02	–0.05	0.05	–0.02	–0.08
R&D (public)	1.99	0.26	–4.47	9.64	2.58	2.34	2.43	–4.31	3.67	–1.27	3.43
direct	1.99	0.26	–4.60	9.06	2.67	2.33	2.40	–4.38	3.71	–1.30	3.40
indirect	0.00	0.00	0.13	0.58	–0.09	0.01	0.03	0.07	–0.04	0.03	0.03
R&D total	0.63	0.10	–1.14	4.31	0.44	1.04	1.11	–1.35	–0.85	–0.44	–5.17
resid. T	–0.91	6.30	2.53	–6.84	2.11	–1.88	–3.93	–1.97	2.34	–11.53	5.96

TFP figures in percent p.a. 1975–1993 (average annual changes). Component figures in percentage points
Depreciation rate for R&D stocks = 10 percent.

The TFP rate of growth is positive in all industries, reaching the highest values in wood processing (SIC 33) and electronics (SIC 383, 385). The industrial average is 3.2 percent in 1975–1993.

Looking at the absolute values, it is apparent that the rate of growth in exogenous demand is the largest single component in explaining the TFP rate of growth. In many industries, it even exceeds the productivity growth. The decline of the textile industry is visible again in the demand component which has a large negative value.

The mark-up and factor price effects have only a negligible impact on productivity growth, mainly less than a tenth of a percentage point. The fact that mark-up effect has no effect on the TFP rate of growth says nothing about the existence of oligopoly power. If it exists, it has no effect on productivity growth. The R&D components vary a lot between industries. The public R&D component seems to have had a positive effect on productivity growth more often than the private R&D component. This relationship is the reverse of the one observed with cost elasticities. It appears that the public R&D component, albeit having on average a positive cost elasticity, has in the long term had a positive effect on productivity. This could stem from publicly financed new product innovations which increase the production cost but which are sold at a higher margin. Also, the opposite signs of publicly and privately financed R&D components may indicate that the public R&D has crowded out private R&D. Firms may have used public funding for projects that they would have financed themselves anyway. Although there is some offsetting between the privately and publicly financed R&D components, the total R&D effect is positive except in the textile and metal industries.

The direct effect of R&D – the change in the TFP contributed by a change in production costs – explains most of the R&D effect. Private R&D explains about three percentage points of productivity growth in the wood processing and fabricated metal products industries. It has a large opposite effect in the machinery and paper industries which also have large publicly financed R&D effects. Since technical change is calculated by definition as residual, it fluctuates a lot over the industries. The average effect is –0.7 percentage points.

The relative forces for each component can be calculated, for example, by adding up the absolute values of each component and comparing each component against the sum of absolute values. Table 5 shows more clearly the most potent components in the TFP growth. Minus signs have been omitted in this table as we compare absolute values.

The average share of factor price effect over the industries is one percent. Exogenous demand accounts, on the average, for about 30 percent of the TFP rate of growth. The average share of the privately financed R&D effect has

Table 5 Percentage Share of the Components in the TFP Rate of Growth

industry	31	32	33	34	35	36	37	381	382	383,5	384
Mark-up	0.0	0.0	0.2	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0
Factor Price	0.3	0.0	1.2	2.4	3.4	0.6	0.7	0.7	0.7	0.6	0.4
Exog.demand	39.3	36.5	32.9	17.3	0.8	33.4	47.9	41.0	14.4	54.1	5.3
R&D (private)	19.3	1.5	21.5	19.6	30.7	15.5	8.8	18.8	36.6	2.9	45.0
direct	19.3	1.5	20.9	18.4	29.7	15.4	8.7	18.5	36.3	2.8	44.6
indirect	0.0	0.0	0.6	1.2	1.0	0.1	0.1	0.3	0.4	0.1	0.4
R&D (public)	28.2	2.5	28.8	35.4	36.9	28.0	16.3	27.4	29.7	4.4	18.0
direct	28.1	2.5	28.0	33.3	35.7	27.8	16.1	26.9	29.4	4.3	17.8
indirect	0.1	0.0	0.8	2.1	1.2	0.2	0.2	0.4	0.3	0.1	0.2
R&D total	8.9	1.0	7.0	15.8	5.8	12.4	7.4	8.3	6.8	1.5	27.1
resid. T	12.9	59.4	15.4	25.2	28.2	22.5	26.3	12.1	18.5	38.0	31.2

been 20 percent of the TFP rate of growth in the measuring period. The average effect of publicly financed R&D is approximately the same. The share of the total R&D effect is 9.3 percent of the TFP rate of growth due to the offsetting effects. This leaves the technical change a share of 26.3 percent, calculated as an industrial average. Note that the effect of other factors which cannot be measured are included in the residual technical change. These may include, for example, public infrastructure.

The effect of the total R&D stock on the TFP rate of growth is largest in the transport equipment and paper products industries. Other large positive values can be found, for instance, in the non-metallic minerals industry. Somewhat surprisingly R&D does not explain much about the TFP rate of growth in electrical machinery and instrument manufacturing. There the productivity growth can be attributed to exogenous demand and the residual technical change.

5. *Summary and conclusions*

The purpose of this empirical study was to analyze the part of the output growth which cannot be attributed to traditional inputs, labor and capital. This is the definition of total factor productivity which is consistent with the theoretical framework of the new growth theory. We broke down the TFP rate of growth into seven components. The estimated shares of the components were as follows. First, industrial R&D accounts on average for 9 percent of the TFP rate of growth, with the subsidized part of R&D being about the same as the privately financed part. The effect of exogenous demand covers nearly one third of the TFP growth. This leaves the disembodied technical change component an average share of about 26 percent of the TFP rate of growth. The mark-up and factor price components had a negligible effect on productivity growth. The share of total R&D is one fourth of the residual technical change and the R&D components. These figures are in line with Denison's (1985) notion of R&D representing around 20 percent of technical progress.

Although the models are different, a general comparison between the results above and those of Nadiri and Mamuneas (1994) merits a few remarks. First, the rise in real factor prices was captured by both models. In our model, the effect of this component is virtually negligible in most industries. The coefficients remain generally below 0.1 percentage points. The estimates of Nadiri and Mamuneas (1994) were larger but the variation was considerable, possibly suggesting measurement problems: the range of the contribution of this effect on TFP growth was between 8 and 77 percent.

The growth of exogenous demand was included in both models. Its contribution also varied a lot: on Finnish data, the range of the exogenous demand effect was between 1 and 54 percent of the TFP rate of growth while in Nadiri and Mamuneas (1994) it fluctuated between 9 and 41 percent.

The average estimated effects of the publicly financed R&D capital stock were much closer in the studies. In Nadiri and Mamuneas (1994), publicly financed R&D accounted for 10 to 15 percent of the annual TFP growth, barring a few extreme cases. In Finnish industry, the component was 23 percent in average, with 2 out of 11 industries having values less than 10 percent. However, one should be cautious in comparing the R&D components for two reasons. First, Nadiri and Mamuneas (1994) define public R&D to include all the research performed *by* public institutions. Hence, one should expect the relative contribution of public R&D to be higher in their model. Second, the inclusion of public infrastructure capital in their model seems to obscure the effect of the R&D component. As they point out, the magnitude of the former exceeds that of the latter in most industries. Also, the size of the residual technical change component is significant in both studies, with Nadiri and Mamuneas (1994) having somewhat larger values of 40 to 60 percent depending on industry.

References

Coe, D., and E. Helpman (1995). "International R&D Spillovers." *European Economic Review* 39, 859–888.

Denison, E. (1985). *Trends in American Economic Growth, 1929–1982*. Washington, D.C: Brookings Institution.

Diewert, W. (1984). "Duality Approaches to Microeconomic Theory." In *Handbook of Mathematical Economics.* Eds. K. Arrow and M. Intriligator. Amsterdam: North-Holland.

Forsman, P., T. Saarenheimo, and M. Terviö (1997). "Time-varying Markups: Empirical Analysis of Markups in Finnish Industries." Bank of Finland Discussion Papers 16, 1–26.

Goldstein, J. (1986). "Markup Variability and Flexibility: Theory and Empirical Evidence." *Journal of Business* 59, 599–621.

Griliches, Z. (1980). "Returns to Research and Development Expenditures in the Private Sector." In *New Developments in Productivity Measurement and Analysis.* Eds. J.Kendrick and B.Vaccara. Chicago: University of Chicago Press.

– **(1986).** "Productivity, R&D and Basic Research at the Firm Level in the 1970s." *American Economic Review* 76, 141–154.

– **(1997).** "R&D and the Productivity Slowdown: Is Recovery Around the Corner?" Proceedings of the conference on The Economics of Science and Technology: Micro Foundations and Policy. Urbino: June 5–6, 1998.

Mansfield, E. (1965). "Rates of Return from Industrial Research and Development." *American Economic Review* 55, 310–322.

Mood, A., *et al.* (1974). *Introduction to the Theory of Statistics.* New York: McGraw-Hill.

Nadiri, I., and T. Mamuneas (1994). "Infrastructure and Public R&D Investments, and the Growth of Factor Productivity in US Manufacturing Industries." C.V. Starr Center Economic Research Reports 94–26.

Rotemberg, J., and M. Woodford (1991). "Markups and the Business Cycle." *NBER Macroeconomics Annual,* 63–129.

Solow, R. (1957). "Technical Change and the Aggregate Production Function." *Review of Economics and Statistics* 39, 312–320.

Statistics Finland (1973–1995). *Yearbooks of Industrial Statistics, Volume 1*. Helsinki: Statistics Finland.

– **(1971–1995).** *Yearbooks of Science and Technology*. Helsinki: Statistics Finland.