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INVESTIGATING THE RELATIONSHIP BETWEEN R&D AND PRODUCTIVITY AT THE FIRM-LEVEL: CASE STUDY OF FINNISH MANUFACTURING INDUSTRY**

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ABSTRACT: This study investigates the relationship between R&D and productivity in Finnish manufacturing firms. The analysis is based on the Cobb-Douglas production function, modified to incorporate a variable describing R&D. The variable for R&D is R&D capital. The panel data exploited in this study cover the period 1987–1993.

The methods used in the measurement of the production function differ in terms of whether the estimates of elasticity are based on time-series or cross-sectional dimension of the data. The effect of the corrections for R&D double-counting on the estimates of R&D elasticity is examined. Also, attention is paid to the effects of alternative depreciation rates of R&D capital on the estimates of R&D elasticity.

The results suggest that industrial R&D has a positive and statistically significant impact on productivity. The estimates of R&D elasticity are in the range of 0.07–0.20. The results are relatively consistent regardless of the methods of measurement employed or of the alternative values of the variables.

The estimations suggest that R&D has a remarkably greater impact on productivity in the hi-tech sector than in other branches. The relationship between R&D and productivity became stronger during the period under review, particularly in the early part of the 1990s. The same trend was evident in both groups of industrial branches. When looking at the relationship between labour and productivity, the situation is opposite. Especially in the high-tech sector, the estimates of labour elasticity declined during the 1990s.

The effect of the depreciation rate of R&D capital on the estimated elasticity of R&D is relatively limited. The effect of the corrections for R&D double-counting on the R&D elasticity estimate is clearer. When the corrections are not made, the R&D elasticity estimate is lower and the statistical significance weaker.

KEYWORDS: R&D, Productivity, Panel data, Manufacturing, Firm level.

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TIIVISTELMÄ: Työ tarkastelee tutkimustoiminnan ja tuottavuuden välistä yhteyttä suomalaisissa tehdasteollisuuden yrityksissä. Tarkastelu perustuu tutkimustoiminnan muuttujalla laajennettuun Cobb-Douglas -tuotantofunktioon. Tutkimustoiminnan muuttujana on tutkimuspääoma. Työssä käytetään yritystason tietoihin perustuvaa paneeliaineistoa, joka kattaa vuodet 1987–1993.

Tuotantofunktion mittaamisessa käytettävät menetelmät eroavat toisistaan sen mukaan, perustuvatko laskelmat aineiston poikkileikkaus- vai aikasarjaulottuvuuteen. Työssä vertaillaan erilaisilla laskentatavoilla saatuja tuloksia. Työssä tarkastellaan myös t&k-toimintaa ja työpanosta kuvaavien muuttujien päällekkäislaskennan vaikutusta t&k:n jouston estimaattiin. Huomiota kiinnitetään lisäksi siihen, miten t&k-pääoman laskennassa käytetyt erilaiset poistokertoimet vaikuttavat t&k:n jouston estimaattiin.

Tulosten mukaan tutkimustoiminnalla on myönteinen ja tilastollisesti merkitsevä tuottavuusvaikutus tehdasteollisuuden yrityksissä. Tutkimuksen jouston estimaatit vaihtelevat välillä 0,07–0,20. Tulokset ovat verrattain yhdenmukaisia vaihtoehtoisista mittaamistavoista ja muuttujille lasketuista arvoista huolimatta.

Tulokset osoittavat, että tutkimustoiminnalla on huomattavasti suurempi vaikutus tuottavuuteen korkean teknologian toimialoilla kuin muilla. Tutkimuksen ja tuottavuuden välinen yhteys voimistui tarkasteltuna aikana. Työpanoksen ja tuottavuuden välisen suhteen kehitys on päinvastainen. Työpanoksen jouston estimaatit pienenivät 1990-luvun alkupuolta koskevissa laskelmissa.

Tutkimuspääoman laskennassa käytettyjen erilaisten poistokertoimien vaikutus tutkimuksen jouston estimaattiin jää suhteellisen vähäiseksi. Sitä vastoin päällekkäislaskenta vaikuttaa t&k:n jouston estimaattiin huomattavammin. Jos päällekkäislaskennan korjausta ei tehdä, tutkimustoiminnan jouston estimaatti on pienempi ja sen tilastollinen merkitsevyys alhaisempi.

ASIASANAT: Tutkimus- ja kehittämistoiminta, tuottavuus, paneeliaineisto, tehdasteollisuus, yritystaso.

INVESTIGATING THE RELATIONSHIP BETWEEN R&D AND PRODUCTIVITY AT THE FIRM-LEVEL: CASE STUDY OF FINNISH MANUFACTURING INDUSTRY

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Yhteenveto - Finnish Summary

Teollisuusyritysten tutkimusmenot ovat kasvaneet Suomessa hyvin nopeasti 1990-luvun alkupuolen lamavuosia lukuun ottamatta. Tutkimustoiminnan välillisistä vaikutuksista antaa viitteitä se, että korkean teknologian tuotteiden tuotannon osuus koko tuotannosta ja korkean teknologian tuotteiden viennin osuus koko viennistä ovat kasvaneet hyvin nopeasti viimeisen neljän vuoden aikana. Tämä ei kuitenkaan kerro tarkemmin sitä, minkälaisia ovat tutkimustoiminnan taloudelliset vaikutukset yritystasolla. Keskeisiä kysymyksiä ovatkin, kuinka voimakas yhteys tutkimuksella on yritysten tuottavuuteen ja kuinka kiinteästi yritysten menestyminen ja t&k-toiminta ovat yhteydessä toisiinsa. Nämä kysymykset ovat nousseet viime vuosina eräiksi keskeisiksi tutkimuskohteiksi teknologiaa ja t&k-toimintaa käsittelevässä taloustieteessä.

Työ tarkastelee tutkimuksen ja tuottavuuden välistä yhteyttä suomalaisissa tehdasteollisuuden yrityksissä. Se pohjautuu yritystason paneeliaineistoon, joka kattaa vuodet 1987–1993. Tarkastelu perustuu Cobb-Douglas -tuotantofunktioon, jota on laajennettu tutkimustoiminnan muuttujalla. T&k-toiminnan muuttuja on tutkimuspääoma, joka on laskettu vuosittaisista tutkimusmenoista nk. kertymämenetelmällä.

Työ tarkastelee myös tutkimusta ja työpanosta kuvaavien muuttujien päällekkäislaskennan vaikutusta t&k-pääoman jouston estimaattiin. Päällekkäislaskenta toteutuu, kun tutkimushenkilöstön määrä on mukana työpanosta kuvaavassa muuttujassa ja tutkimushenkilöstön palkat on luettu tutkimusmenoihin. Huomiota kiinnitetään myös siihen, miten t&k-pääoman laskennassa käytetyt erilaiset poistokertoimet vaikuttavat saatuihin tuloksiin.

Tuotantofunktion mittaamisen menetelmät eroavat toisistaan sen mukaan, perustuvatko laskelmat aineiston poikkileikkaus- vai aikasarjaulottuvuuteen. Tutkimuksessa lasketaan regressiokertoimien estimaatit kolmella tavalla. Poikkileikkausestimaatit perustuvat regressioihin, joissa otetaan huomioon joko yritysten muuttujien arvot tiettynä vuotena ("annual cross-sections") tai muuttujien keskiarvot koko tarkastellulta ajalta ("between-firm" estimates based on a "mean cross-section"). Aikasarjaestimaateissa ("within-firm" estimates) on puolestaan otettu huomioon muuttujien arvojen muutokset kussakin yksittäisessä yrityksessä.

Tulosten mukaan tutkimuksella on selkeästi myönteinen ja merkittävä vaikutus tehdasteollisuuden yritysten tuottavuuteen. Koko yrityspaneelin t&k:n jouston vuosittaiset poikkileikkausestimaatit ovat välillä 0,07–0,20 ja koko tarkasteltua kautta koskevat "between"-estimaatit välillä 0,13–0,16. Aikasarjaestimaatit ovat välillä 0,07–0,10.

Tutkimuksen tuottavuusvaikutus on voimakkaampi korkean teknologian toimialoilla kuin muilla. Tutkimustoiminnan jouston estimaatit ovat korkean teknologian toimialoilla verrattain korkeita ja tilastollisesti erittäin merkitseviä. Muilla toimialoilla t&k:n jouston estimaatit ovat puolestaan suhteellisen matalia eivätkä useinkaan tilastollisesti merkitseviä.

Tulosten mukaan lamavuosina tutkimuksen yhteys tuottavuuteen voimistui ja tutkimusinvestointien taloudellinen vaikutus tehostui. Tutkimuksen tuottavuusvaikutus kasvoi 1990-luvun alussa erityisesti korkean teknologian aloilla. Erot tutkimuksen ja tuottavuuden välisessä yhteydessä näyttävät olevan toimialojen ja yritysten välillä huomattavia. Tulokset ovat verrattain yhdenmukaisia kaikilla laskentatavoilla.

Tutkimuksen ja tuottavuuden välisen yhteyden kehitys oli päinvastainen kuin työpanoksen ja tuottavuuden. Työpanoksen jouston estimaatit pienenivät 1990-luvun alkupuolta koskevissa laskelmissa erityisesti korkean teknologian toimialoilla.

Tutkimuspääoman laskennassa käytettyjen erilaisten poistokertoimien vaikutus tutkimuksen jouston estimaattiin jää suhteellisen vähäiseksi. Sitä vastoin päällekkäislaskenta vaikuttaa t&k:n jouston estimaattiin huomattavammin. Jos päällekkäislaskennan korjausta ei tehdä, tutkimuksen jouston estimaatti on matalampi ja sen tilastollinen merkitsevyys pienempi.

Keskeinen kysymys on se, mitkä estimaatit kuvaavat parhaiten t&k-toiminnan tuottavuusvaikutusta. Poikkileikkaus- ja aikasarjaestimaattien väliset erot tunnetaan verrattain hyvin. Aikasarjaestimaatteja pidetään yleensä parempina, koska niihin ei sisälly yrityskohtaisten ominaisuuksien huomiotta jättämisestä seuraavia vinoutumia.

Sekä poikkileikkaus- että aikasarjaestimaatit ovat informatiivisia t&k-toiminnan ja tuottavuuden suhteen indikaattoreita, vaikka ne kuvaavatkin tutkittavaa ilmiötä eri näkökulmasta. "Within"-estimaatit kuvaavat paremmin sitä, mitä yrityksissä tapahtuu niiden kohdentaessa resursseja t&k-toimintaan. Poikkileikkausestimaatit kuvaavat puolestaan paremmin kansantalouden tasolla tutkimuksen tai esim. julkisten teknologiatukien yhteyttä tuottavuuteen. Vertailtaessa eri tavoin laskettuja estimaatteja on syytä korostaa, että tutkimuksen tuottavuusvaikutusten mittaamiseksi ei ole olemassa vain yhtä oikeaa tai selkeästi muita parempaa tapaa. Erilaiset t&k-muuttujien rakentamis- ja laskentatavat tuovat kaikki monimutkaisen tuottavuusilmiön tutkimisessa tarvittavaa tietoa.

Tutkimustoiminnan luonteen ja sen monimutkaisten vaikutussuhteiden vuoksi on tutkimustoiminnan jouston estimaattia tarkasteltaessa muistettava mm. seuraavat analyysiin sisäänrakennetut ongelmat; a) tutkimus on usein pitkäjänteistä, eivätkä uusimmat investoinnit näy nopeasti jalostusarvossa tai tuottavuudessa; b) tutkimuspääoman määrää mitattaessa on huomattava, että aiemmin tehdyt investoinnit voivat kulua hyvinkin nopeasti, eikä pääoman varannon nettokasvu ole samanarvoinen viimeaikaisten pääomaa kasvattavien tutkimusmenojen bruttoarvon kanssa sekä; c) teknologista osaamista heijastavan tutkimuspääoman määrää ei voida yksiselitteisesti johtaa tarkasteltavien yritysten omasta tutkimustoiminnasta. Siihen vaikuttaa myös teknologian diffuusio mm. tahattomina teknologiavirtoina.

Investigating the Relationship Between R&D and Productivity at the Firm-Level: Case Study of Finnish Manufacturing Industry

1. R&D and Firm Performance

This study is concerned with the dynamic performance of an information-intensive economy and, in particular, with the contribution of research and development (R&D) to the economic performance of Finnish manufacturing firms. The ongoing process of economic restructuration is reflected, specifically, in changing production methods as well as in regional, industrial and firm-level changes in organisational structures. The major features linked with these changes are the increasing importance attached to the role of R&D and innovativeness, as well as the broad and rapid introduction of new technologies.

Manufacturing firms vary widely in terms of success and productivity and in terms of how they experience and respond to economic fluctuations. During the past decade, high-tech firms (businesses engaged e.g. in information technologies, new materials technologies, and biotechnologies) have represented a major growth sector. In Finland, manufacturing industries have shown a considerable improvement in their performance since the early 1980s, as is evident from the surplus in the balance of trade in high-tech products (e.g. Husso 1996).

At the same time as the number of high-tech manufacturing firms and research activities has been growing, the issue of the impact of R&D on company productivity and competitiveness has gained more attention. Although not all manufacturing firms operate in technology-intensive sectors, there are many good reasons for firms to emphasise the role of R&D. According to Rosenberg (1990: 171), there are numerous activities that are crucial to business success and that depend heavily upon a research capability. This may be the case even if that capability does not play a direct role in solving industrial problems.

The dynamic role of research capability can be described as follows. Firstly, in order to evaluate the potential benefit of a given technology, firms need to obtain information about that technology. However, it is important that firms are capable both of understanding the value of the information that is available and of processing that information for their own purposes. And secondly, in order to be able to adopt and introduce a certain technology and in order to be able to manage the application of that technology, firms often need a vast pool of knowledge and R&D resources.

The point that needs to be stressed here is that R&D not only generates product and process innovations, but it also generates new information which enhances the firm's ability to make the best possible use of the knowledge available from the techno-economic environment (see Cohen & Levinthal 1989: 569). In short, it is essential for manufacturing firms to acknowledge the central long-term strategic productivity-related function of internal R&D. The effect of R&D on the overall activities of manufacturing firms can thus be very far-reaching.

2. Framework

The increasing use of new key technologies, the growing need for a highly skilled and competent workforce, and the growing requirements of conducting intramural R&D have all generated a renewed and growing research interest in productivity at the level of manufacturing firm (see Science and Technology... 1994). It has become clear that we need more information about the fundamental preconditions for doing research and about its various effects.

The theoretical framework for this study is provided by the Cobb-Douglas production function. The purpose is to investigate;

- the relationship between R&D and productivity and changes in this relationship in Finnish manufacturing firms during the period between 1987 and 1993;

- the effect of the rate of depreciation on the estimates of R&D elasticity; and

- the effect of the correction for R&D double-counting on the estimates of R&D elasticity (i.e., to make comparisons with the situations where the number of researchers is or is not subtracted from the total number of personnel).

The focus of the study is thus on the R&D variable of a production function model and on estimating the R&D elasticity. Both cross-sectional and time-series estimates of R&D elasticity will be presented. The study is based on a new firm-level panel data compiled at Statistics Finland. The data include information on production, labour force, physical capital and R&D activities in Finnish manufacturing firms. The panel data cover the period from 1987 to 1993.

3. The Formalization of the Model and the Methods of Estimation

3.1. Model

For purposes of studying the impact of R&D on firm output or productivity, we need to modify the traditional Cobb-Douglas function by incorporating a variable that describes R&D capital (see Mairesse & Sassenou 1991: 11–12; Hall & Mairesse 1995: 268–269). The baseline assumption is that the production function of manufacturing firms can be written on the basis of the Cobb-Douglas function so that firm output or productivity Y_{it} (e.g. value added or value added/labour input) is explained by three factors: L is labour input (e.g. the number of workers, person-years or working hours put in), C is physical capital and K is the amount of annual R&D expenditure or cumulative R&D capital. The function can be expressed as follows:

$$Y_{it} = Ae^{\lambda t} C_{it}^{\alpha} L_{it}^{\beta} K_{it}^{\gamma} e^{\varepsilon_{it}} \quad i=1,...,N;\ t=1,...,T, \qquad (1.)$$

where A is constant and α, β and γ are the elasticity coefficients of physical capital, labour input and R&D capital. λ refers to the rate of disembodied technological change. ε is the error term of the equation, including any errors in the specification of the model as well as other disturbance factors (see Griliches & Mairesse 1984: 344; Mairesse 1990; Baltagi 1995). The error term follows a normal distribution with a mean of zero and a variance of δ^2. Subscripts i and t refer to the industrial firm and time. If the three dependent variables in the model follow constant returns to scale, the sum total μ of their elasticity coefficients is 1 (i.e., $\alpha + \beta + \gamma = 1$).

An important advantage of the Cobb-Douglas function is that by taking logarithms from the variables, the function can be estimated as a linear regression equation:

$$y_{it} = a_{it} + \alpha c_{it} + \beta l_{it} + \gamma k_{it} + \varepsilon_{it}, \quad (2.)$$

where the small letter stands for the variable's logarithm. The term $a_{it} = a_i + \lambda t$ is a firm- and time-specific indicator of technological level and other firm characteristics. In a panel material, this can be taken into account by calculating the "within-firm estimates" based on firm-specific effects.

In the models above the realisation of constant returns to scale can be studied on the basis of the sum total of the estimated elasticities of production factors. If we assume that the constant returns of scale do not materialise, equation 2 can be so modified that the effect of the labour input variable l is subtracted from both sides of the equation (see e.g. Cuneo & Mairesse 1984; Griliches & Mairesse 1984, 1990; Hall & Mairesse 1995):

$$(y_{it} - l_{it}) = a + \lambda t + \alpha(c_{it} - l_{it}) + \gamma(k_{it} - l_{it}) + (\mu - 1)l_{it} + e_{it} \qquad (3.)$$

The writing of the production function as in equation 3 is generally justified for interpretative reasons. If we subtract the effect of the labour input variable from both sides of the equation, we can explicitly measure any deviation from constant returns to scale. In this case, the coefficient (μ - 1) of the logarithm of the labour input variable indicates the extent of the deviation from constant returns to scale. In the assumption of constant returns to scale (μ - 1) is left open or given the value 0. In this study, the theoretical framework for the analysis of the productivity of R&D is provided by models 2 and 3. In the results reported here, the estimates of labour elasticity refer to a situation where the coefficient of the logarithm of labour is (μ - 1).

Although the analysis here focuses on the variables' elasticity coefficients, it is important to recognise the meaning of the error term ε_{it}. The error term is usually interpreted to comprise all errors linked to the model's variables. These errors are based: a) on errors of measurement, b) on the different production functions of different firms; and c) on inadequate analysis and specification of the variables. However, a more detailed analysis of the contents of the information provided by the error term is a complex process. The most central component of the magnitude of ε_{it} is probably related to the heterogeneity of the technologies and modes of production employed by the firms concerned. This firm-level difference which remains unmeasured is directly reflected in the model's disturbance or error component. Another important element with regard to the magnitude of ε_{it} has to do with changes in productivity over time, which are common to all firms. In the analysis of the error term we must also take account of the errors related to the price deflators used as well as the effects of other factors that have a bearing on the real quantities of measured outputs and inputs (see e.g. Mairesse 1990; Hall & Mairesse 1995).

Calculations based on cross-sectional dimension of panel data sets have usually used the one-way error component model to take account of error and disturbance factors (see Baltagi 1995: 9–10). In this case the error term of consists of two separate components:

$$\varepsilon_{it} = \mu_i + \upsilon_{it}, \qquad (4.)$$

where the term μ_i is invariant in relation to time and refers to such firm-specific characteristics that have not been taken into account in the structure of the model. The component can be interpreted as describing such factors as management skills and strategic vision within the firm or its ability to make good use of communication channels outside the firm that are supportive of its R&D activities. υ_{it} describes the remaining perturbation and it varies in relation to firm and time. It may also be interpreted to comprise short-term changes in capacity utilisation (Griliches & Mairesse 1984: 344). With the exception of the within-estimates based on time-series, we have used model 4 in this study. In the case of within-estimates, we employ a two-way model in which the structure of the error term is as follows (see e.g. Baltagi 1992: 206–209; Baltagi 1995: 27–46, 219–220):

$$\varepsilon_{it} = \mu_i + \lambda_t + \upsilon_{it} \quad (5.)$$

The error term in the model is divided into three components, of which μ_i is time invariant and describes unnoticed firm-specific characteristics. λ_t is invariant in relation to firms and it comprises an unnoticed time effect; it is thus the period-specific component. ν_{it} is the remaining stochastic error term, which can be regarded as the two-dimensional part of the measurement error. These error components are independent of each other. Based on model 5, the variability can be decomposed as follows:

$\sum_i \sum_t (x_{it} - \bar{x}_i)$ is the within-firm variability referring to μ_i,

$\sum_i \sum_t (x_{it} - \bar{x}_t)$ is the within-period variability referring to λ_t,

$\sum_i \sum_t (x_{it} - \bar{x}_i - \bar{x}_t - \bar{x})$ is the within period-firm variability referring to υ_{it},

where

$\bar{x}_i = \frac{1}{T} \sum_t x_{it}$ is the mean of the firm i,

$\bar{x}_t = \frac{1}{N} \sum_i x_{it}$ is the mean of the period t,

$\bar{x} = \frac{1}{NT} \sum_i \sum_t x_{it}$ is the overall mean.

3.2. The Accumulation of R&D Capital

A perpetual inventory method used for the measurement of physical capital is often applied for purposes of determining the amount of R&D or information capital in a given firm (e.g. Griliches 1979; Hall & Mairesse 1995). The equation for determining capital K for R&D activities is as follows:

$$K_t = R_t + (1-\delta)R_{t-1} + (1-\delta)^2 R_{t-2} + \ldots = R_t + (1-\delta)K_{t-1} \qquad (6.)$$

where K_t is the value of R&D capital in year t, R_t is the deflated R&D expenditure during year t and δ is the annual rate of depreciation for R&D capital. The method is useful enough for panel studies but it requires data on R&D expenditure over a very long period of time as well as appropriate indices for deriving real values of R&D capital and suitable depreciation rates. If data on R&D expenditure commence from year t = 1, for instance, the amount of cumulated R&D capital is obtained from equation 6. However, the problem here is that comprehensive data are not available on R&D expenditure over long periods. If data can be obtained on R&D expenses from the beginning of the time period concerned and R&D expenses have increased during the time preceding a certain measurement period at a rate of g, then the amount of R&D capital for the first year can be determined on the basis of the following equation:

$$K_1 = R_0 + (1-\delta)R_{-1} + (1-\delta)^2 R_{-2} + \ldots = \sum_{s=0}^{\infty} R_{-s}(1-\delta)^s = R_0 \sum_{s=0}^{\infty}\left[\frac{1-\delta}{1+g}\right]^s = \frac{R_1}{g+\delta} \qquad (7.)$$

However, the measurement of the R&D capital variables involves certain problems associated with the characteristics of the variable that must be taken into account in interpreting the results. Firstly, research is very often a long-term process, and investments in research are not reflected in productivity very rapidly. Secondly, no exact data are available on the depreciation of R&D investments. Thirdly, it must also be observed that the net increase in R&D capital reserves is not identical to the gross value of recent investments adding to capital reserves. And fourthly, when we consider a firm's intramural R&D expenditure as a measure of the R&D variable, this implies the assumption that the relationship between the firm's R&D and productivity depends on its own R&D expenditure, not on the amount it spends on foreign technology or on the amount spent on R&D elsewhere. Consequently, the amount of information in different companies and in different lines of industry cannot be directly inferred from the volume of their own R&D activities because it is very much influenced by technological diffusion in its various forms. All in all, the problems related to the determination of R&D capital are very complex indeed. Other methods and applications apart from those used in the present study for determining the level of R&D capital are also available (see e.g. Bartelsman, van Leeuwen, Nieuwenhuijsen & Zeelenberg 1995; Klette & Johansen 1996).

3.3. Operationalization of Variables

The R&D capital stock (K) is calculated on the basis of Statistics Finland's figures for annual R&D expenditure. This still leaves us with the problem of the stock for the initial year. That can be estimated in accordance with equation 7 by using the long-term growth percentage g and depreciation coefficient δ. In principle, the depreciation rate is determined on the basis of the estimated average service life of the technology concerned as well as the form of its survival function (see Virtaharju & Åkerblom 1993: 28–33; Hall & Mairesse 1995: 287). However, there exists no unambiguous theoretical or empirical basis for setting this value. In addition, it may be assumed that depreciation rates will vary between individual firms. Therefore researchers have usually operated with assumptions that they have considered most appropriate. In this study, we have used the values of 0.1 and 0.3 for δ and compared the results obtained with these coefficients.

Data on R&D expenditure are available from 1971 onwards. The value used here for growth rate g is the same as the average real annual growth recorded for R&D expenditure in the private sector between 1971 and 1985, which was eight per cent. Since the figure for R&D expenditure R is only obtained for every other year, the interim years were estimated on the basis of the mean figure

$(R_t+R_{t-2})/2$. For the operationalization of the other variables, there is the option of using either Statistics Finland's industrial statistics or final statements statistics (see Husso, Leppälahti, Niininen 1996: 20–21). In this study the variables for value added (*Y*), labour input (*L*) and physical capital (*C*) are obtained from the industrial statistics. This is how the variables are defined:

Industrial statistics:

Y = gross value of production - value of production inputs,

L = number of personnel,

C = value of physical capital.

The problem here is that the value of physical capital is not obtained directly but it has to be estimated on the basis of acquisitions of machinery and equipment. Figures are only available on annual expenditure, i.e., investment in machinery and equipment. Since the value of the stock was not available, that has been estimated in the same manner as research capital. The choice of depreciation rate for physical capital involves similar problems as in the case of research capital: there are no straightforward grounds for the value of the physical capital coefficient, and researchers therefore often have to content themselves with picking a coefficient that seems appropriate. The value used here for the depreciation rate is 0.05. The values for the initial stock are based on data from the 1985 industrial statistics on the replacement value of fixed assets.

The overlap between physical capital and research capital has been regarded as one of the key problems in calculations based on production functions. In this study, the double-counting of physical capital (*C*) and research capital (*K*) was corrected by subtracting from physical capital the acquisition costs of fixed assets included in R&D expenditure. As for labour input (*L*), it has been considered problematic that it is not always possible to subtract R&D personnel from total personnel numbers in the firm. The effects of overlap between the R&D variable and the labour variable were examined here by calculating the elasticity coefficients of R&D capital in corrected form without double-counting and in a situation where this correction was not made.

3.4. Methods of Estimation

Two basic statistical methods were used here to measure the production function. These methods differ from each other in terms of whether the estimates calculated are based on time-series or cross-sectional dimension of the data. The estimates are obtained by using models 2 and 3, while deviations from constant returns to scale are obtained using model 3 (i.e., coefficient μ - 1). The annual cross-sectional estimates are based on regressions which take into account the levels of the variables for each firm during the years under review (e.g. x_{it}, where time is fixed). The estimates based on annual data are at once estimates that are obtained by calculating the so-called between-firm regression, i.e., they are annual between-firm regressions. However, although the basic method of estimation is the same, annual cross-sectional estimates (Chapter 5.1.1.) differ from the between-firm estimates (Chapter 5.1.2.) in that the latter estimates are based on time-series data and cover the whole period 1987–1993. The between-firm estimates are based on a "mean cross-section", i.e., they are performed on the individual firm means of variables over several years, i.e., $x_{i.} = 1/T\sum_{t=1}^{T} x_{it}$.

The estimates are based on between-firm differences in the levels (or values) of variables and they are calculated by the ordinary least squares method. Between-estimates usually come very close to so-called total estimates. On the other hand, they generally differ very clearly from time-series estimates, i.e., so-called within-estimates. This is explained by the fact that total variability comprises variability in the level of variables both within and between firms. Variability in the levels of the variables between firms is usually much greater than the variability within firms.

The estimates of annual cross-section data and the between-estimates for the whole period examined are thus based on differencies in the levels of variables between firms. The within-estimates (Chapter 5.2.), for their part, take into account the changes in the level of variables within each individual firm. This means that the levels of the variables themselves are of no consequence. The estimates take into account the deviations of firm-specific variable levels from the mean figures of each variable for the whole period under review, i.e., $x_{it} - x_{i.}$.

The production function estimates of R&D elasticity were calculated by using the following four alternative construction methods of the R&D variable:

a) corrections for R&D double-counting made, rate of depreciation of R&D capital 0.30;

b) corrections for R&D double-counting made only in part (number of researchers is not subtracted from the total number of employees), rate of depreciation 0.30;

c) corrections for R&D double-counting made, rate of depreciation 0.10; and

d) corrections for R&D double-counting made only in part (number of researchers is not subtracted from the total number of employees), rate of depreciation 0.10.

The purpose of constructing the R&D variable in alternative ways was to ascertain the effects of different rates of depreciation used in the calculation of R&D capital on the estimates of R&D elasticity, and to find out what kind of effect double-counting of the R&D variable and the labour input variable has on the estimate of R&D elasticity.

4. Data

Before we move on to take a closer look at the data set of this study, we shall briefly review the trends and developments in the intramural R&D expenditure and productivity of Finnish manufacturing firms during the period 1987–1993. The data on the firms included in the sample of the study cover this same period.

4.1. R&D and Productivity in Finnish Manufacturing Industries

The trends in labour, capital and total productivity in Finnish manufacturing industries between 1987 and 1993 are shown in Figure 1. The growth of capital productivity was slow throughout the 1980s and sharply declined towards the end of the decade, as did total productivity. However, the productivity of labour did not decline as dramatically as total productivity or the productivity of physical capital. The most outstanding characteristic of the period under review has been the sharp increase in labour productivity and total productivity with the exception of the short period in the early 1990s.

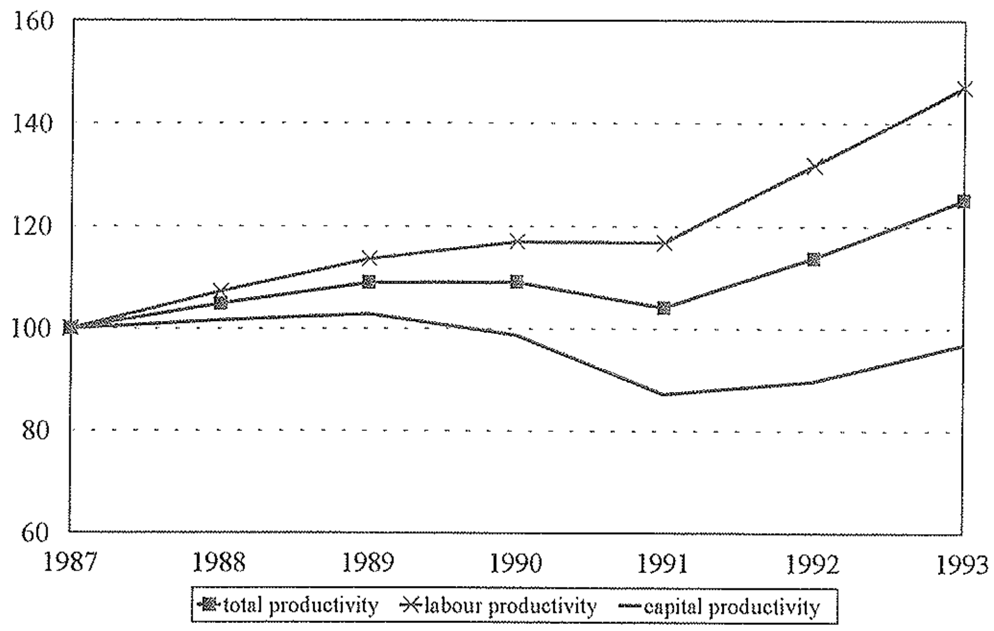

Figure 1. The development of productivity in the manufacturing industry in 1987–1993, index 1987=100 (modified from Lehtoranta 1995: 53–54).

The real R&D expenditure of manufacturing firms increased dramatically in the 1980s. For instance, the annual growth of intramural R&D expenditure between 1983 and 1989 was 11 per cent. From 1989 to 1991, real R&D expenditure by the whole industry declined. However, in the manufacturing industries, real intramural R&D expenditure increased to some extent (Statistics Finland 1993: 5). In terms of R&D expenditures, this suggests that the economic recession had a less restrictive effect on the manufacturing firms than it did on the others. Since 1991, the increase in real intramural R&D expenditure has been gathering pace again within the manufacturing industry (Figure 2).

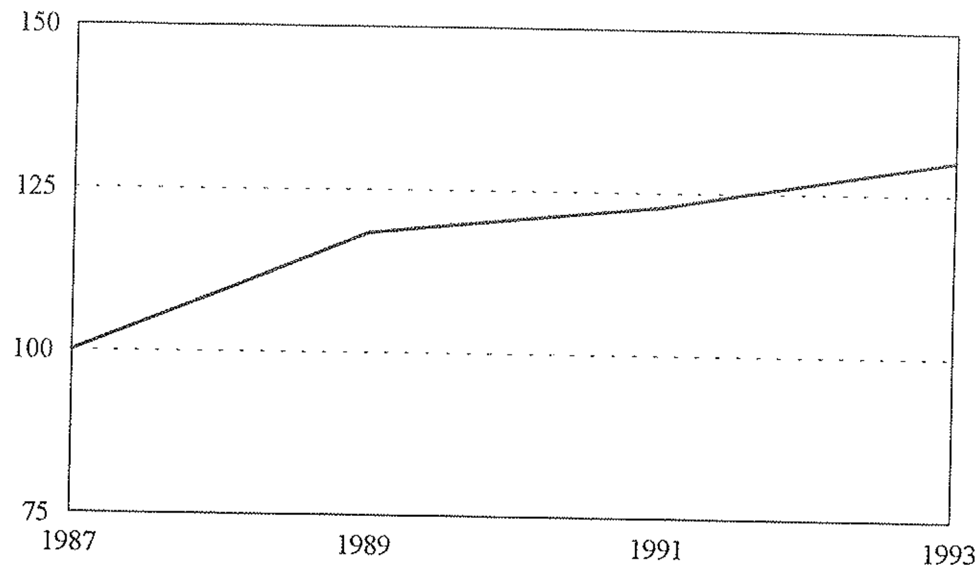

Figure 2. Development of real intramural R&D expenditure in the manufacturing industry in 1987–1993, index 1987=100 (source: Statistics Finland's R&D statistics).

The significance of R&D activities to individual firms within the manufacturing industry can be assessed by looking at the level of expenditure as a proportion of value added (Figure 3). During the period under review the proportion has increased from less than four to over five per cent. Although the growth of intramural R&D expenditure in 1989–1991 came virtually to a standstill, its share of value added increased noticeably. However, the situation changed in 1991. Although the increase in research expenditure gathered some pace after 1991, the amount of expenditure as a proportion of value added began to decline.

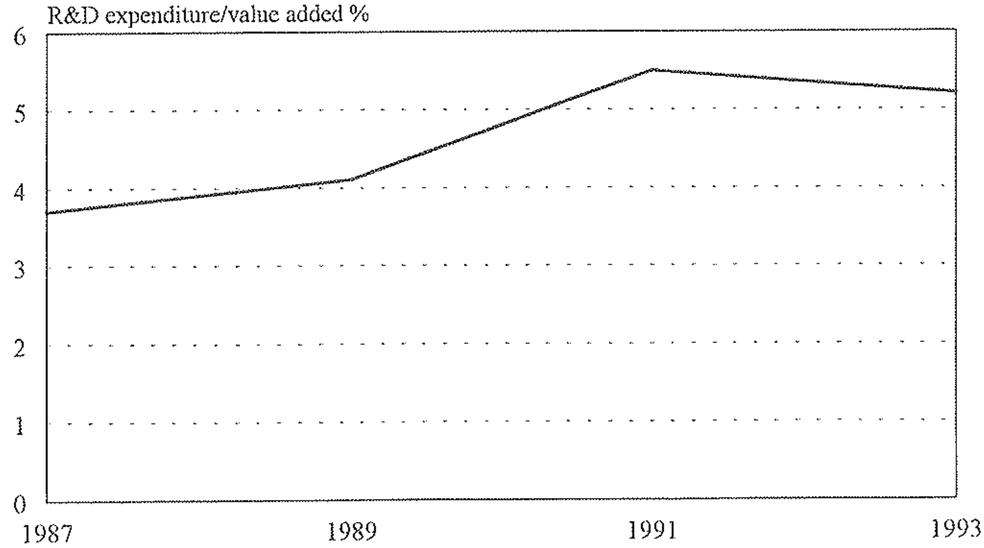

Figure 3. Intramural R&D expenditure as a proportion of value added in the manufacturing industry in 1987–1993, index 1987=100 (source: Statistics Finland's R&D statistics and industrial statistics).

4.2. Description of the Panel Data

The research material for this study comprises Statistics Finland's R&D and industrial statistics for the period 1987–1993. These statistics have been linked together at the firm-level. The data sets formed on this basis are divided into two main groups. A so-called balanced firm panel has been formed of the statistics so that both cross-sectional estimates and time-series estimates can be calculated. Since the questionnaires carried out in the 1980s for the R&D statistics involved only limited overlap in terms of the firms included, the number of firms in the panel is comparatively small. Because of the size of the panel data set, the firms were crudely divided into only two groups, viz. firms in high-tech branches and other industries. High-tech manufacturing industries included the manufacture of chemicals and chemical products (NACE Rev. 1, mainly class 24), the manufacture of machinery and equipment (mainly class 29), the manufacture of electrical machinery and instruments (mainly classes 30, 31, 32 and 33), and the manufacture of transport equipment (mainly class 35). All other branches were combined into the single category of other industrial branches.

The panel material was so processed that outlier firms were excluded. To identify deviant observations and outliers, we examined the residuals of estimated regression equations, scatter plots, studentized residuals and Cook's D-magnitudes. However, no firms were excluded from the material simply on the basis of statistical analysis – the residual analyses were simply used as indications that there is reason to suspect the validity of each observation. The firm was eventually excluded if it met any one of the following criteria:

- value added was zero or negative;

- R&D capital was zero during any panel year;

- fixed assets acquisition costs under internal R&D expenditure exceeded the book value of machinery, equipment and means of transport at the beginning of each financial period;

- firm activities showed unusually rapid growth or decline, which changed significantly a firm's nature; ordinarily, these changes are due to the sale or purchase of firms or parts of firms;

- full information was not available on the firm for the whole period of analysis; and

- variable values did not indicate normal productive business activities; typically, this will apply to research centres or holding companies of major concerns; clear indicators of this are situations where R&D expenditure considerably exceeds value added or where very substantial value added figures are recorded with very small labour inputs from just a few persons.

A more detailed description of the firms included in the panel and of the exclusion of outlier firms is presented in the study by Husso, Leppälahti and Niininen (1996: 78–86), which uses the same data set.

The panel comprises a total of 74 companies, of which 40 operate in high-tech industries and 34 in other branches. Tables 1 and 2 provide some basic data on the panel firms. As we can see in Table 1, the median and mean of the group of firms differ markedly from each other. Middle-sized and large firms are clearly overrepresented in the panel, indicating a skewed distribution. There are also

Table 1. Panel firm parameters for cross-section years 1987, 1989, 1991 and 1993.

Year	1987		1989		1991		1993		1987–1993 changes	
	median	mean	median	mean	median	mean	median	mean	median %	mean %
Value added (FIM 1000)	67 735	264 585	75 044	305 366	62 986	229 729	63 596	226 820	-6.1	-14.3
firms in hi-tech branches	42 800	280 267	62 743	311 509	51 183	255 471	54 896	242 519	+28.3	-13.5
firms in other branches	75 457	246 136	81 866	298 139	75 850	199 445	75 508	208 350	+0.0	-15.4
Personnel	288	935	330	937	282	849	256	722	-11.1	-22.8
firms in hi-tech branches	196	902	254	908	203	817	182	711	-7.1	-21.2
firms in other branches	383	973	422	972	397	887	315	734	-17.8	-24.6
Physical capital (machinery and equipment FIM 1000)	55 229	757 508	66 701	790 838	77 528	800 529	73 799	774 013	+33.6	+2.2
firms in hi-tech branches	25 558	773 368	33 844	791 973	36 025	765 450	38 826	730 786	+51.9	-5.5
firms in other branches	114 857	738 850	117 931	789 502	126 442	841 789	125 210	824 868	+9.0	+11.6
R&D capital (FIM 1000) ($\delta = 0.10$)	9 775	78 818	10 844	97 850	12 404	111 625	14 348	120 846	+46.8	+53.3
firms in hi-tech branches	12 996	125 042	14 151	155 811	15 890	177 664	23 362	192 616	+79.8	+54.0
firms in other branches	7 992	24 436	10 219	29 659	10 297	33 931	11 460	36 410	+43.4	+49.0
R&D expenditures (FIM 1000)	1 760	14 188	2 179	19 050	1 857	16 410	2 117	15 568	+20.3	+9.7
firms in hi-tech branches	2 340	22 510	3 070	30 619	2 811	25 984	2 655	25 258	+13.5	+12.2
firms in other branches	1 439	4 399	1 543	5 440	1 192	5 144	1 338	4 167	-7.0	-5.3

Value added, physical capital, R&D capital and annual intramural r&d expenditures calculated in 1990 currency. Personnel number is the average payroll for each financial period during the panel. R&D capital is calculated here only with the depreciation rate of 0.10.

Table 2. Total personnel, value added, physical capital, R&D capital calculated with the depreciation rates of 0.10 and 0.30, and annual intramural R&D expenditure in panel firms. Real change in production factors and output compared to previous point of measurement in parentheses.

Year	1987	1989	1991	1993	1987–1993
Firm personnel total (N)	69 188	69 365 (+0.3%)	62 833 (-9.4%)	53 391 (-15.0%)	-22.8%
as proportion of total in industry	14.8%	15.5%	15.6%	15.6%	15.4%
Firm value added total (FIM 1000)	19 579 270	22 597 064 (+15.4%)	16 999 966 (-24.8%)	16 784 665 (-1.3%)	-14.3%
as proportion of total in industry	19.9%	21.0%	19.4%	17.7%	19.5%
Firm physical capital total (FIM 1000)	56 055 611	58 521 981 (+4.4%)	59 239 124 (+1.2%)	57 276 959 (-3.3%)	+2.2%
Firm R&D capital total (FIM 1000) ($\delta = 0.10$)	5 832 527	7 240 871 (+24.1%)	8 260 213 (+14.1%)	8 942 606 (+8.3%)	+53.3%
Firm R&D capital total (FIM 1000) ($\delta = 0.30$)	2 761 394	3 623 653 (+31.2%)	3 908 295 (+7.9%)	3 922 487 (+0.4%)	+42.0%
Firm R&D expenditure total (FIM 1000)	1 049 947	1 409 728 (+34.3%)	1 214 296 (-13.9%)	1 151 988 (-5.1)%	+9.7%
as proportion of total in industry	27.4%	31.1%	25.8%	23.1%	26.6%

Value added, physical capital, R&D capital and annual intramural R&D expenditures calculated in 1990 currency. The last column on the line describing the total personnel, value added and physical and R&D capital of the panel firms indicates the real change in per cent between the values for the first and last year. The last figure on the line describing the firms' personnel as a proportion of the manufacturing industry as a whole indicates the sum total of the personnel in the panel firms for all years as a proportion of the manufacturing industry for the same period of time. The firms' combined value added and the R&D expenditure as a proportion of the manufacturing industry for 1987-1993 has been calculated in the same way.

clear differences in the volume and nature of company activities in different branches. In high-tech firms, R&D capital and R&D investment are at a higher level than in other companies. This, at least as far as R&D variables are concerned, was consistent with expectations. Firms in other industries, for their part, are clearly bigger when measured in terms of valued added, staff numbers and physical capital.

Figures 4 and 5 describe the real development of key variables during the panel period. The decline in industrial output and above all the clear decrease in the use of labour inputs are also clearly in evidence in the panel. The combined value added of the firms decreased by 14.3 per cent from 1987 to 1993. This decrease was particularly sharp during 1989–1991. The decrease in staff numbers was even more dramatic, falling by 22.8 per cent. The trend in the number of R&D personnel deviated throughout the period concerned from the trend in total personnel numbers, which remained unchanged until 1989, after which they began to fall. On the other hand, staff numbers in R&D increased until 1989. The figures then began to fall, but the decrease was not as dramatic as in the case of total personnel numbers. In 1993, the number of R&D personnel was 3.8 per cent higher than in 1987.

During the period under review the panel firms became much more intensive in terms of R&D capital. Calculated on the basis of a 0.10 depreciation rate, R&D capital increased from 1987 to 1993 by around 53 per cent, averaging 7.4 per cent a year. When the depreciation rate of 0.30 was used, R&D capital in the panel firms increased by around 42 per cent; average growth per annum was 6.0 per cent. During this period R&D expenditure increased by 9.7 per cent. Expenditure increased sharply until 1989, and then the real volume started to decline. Physical capital increased by only 2.2 per cent during the period under review. Overall, the period can certainly not be described as one of steady growth, but rather as a more or less troubled period characterised by quite dramatic cyclic fluctuations. This is also reflected in the panel firm's variables. Detailed annual data on the panel firms and their development are shown in Table 1.

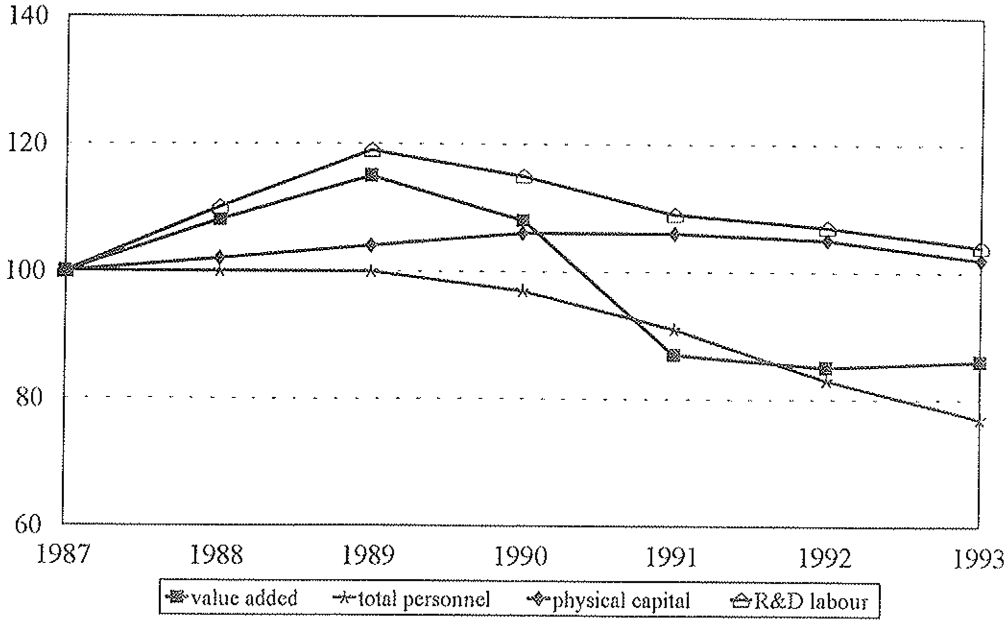

Figure 4. Real development of panel variables, index 1987=100.

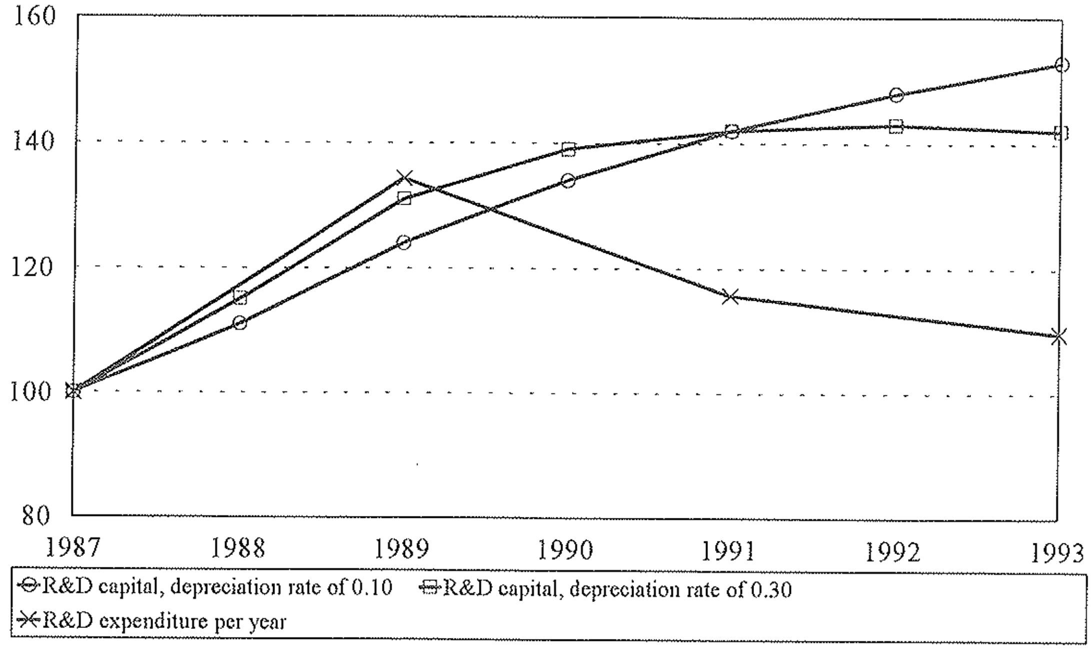

Figure 5. Real development of R&D capital and annual R&D expenditure of the panel firms. Capital is calculated on the basis of depreciation rates of 0.10 and 0.30.

Figures 6 and 7 describe the development of productivity and R&D intensity (R&D expenditure/value added) in the panel firms and in the whole industry. The information from these Figures may be summarised as follows:

- The average real productivity of labour has increased significantly during the period under review. Throughout this time labour productivity in the panel firms has been higher than in the manufacturing industry as a whole. Productivity decreased in the manufacturing industry between 1989 and 1991, but then started to improve again. However, the trends in productivity have been consistent with those for the whole industry. In the panel data, the difference in the productivity between high-tech and other industries increased in the early 1990s with the onset of the recession.

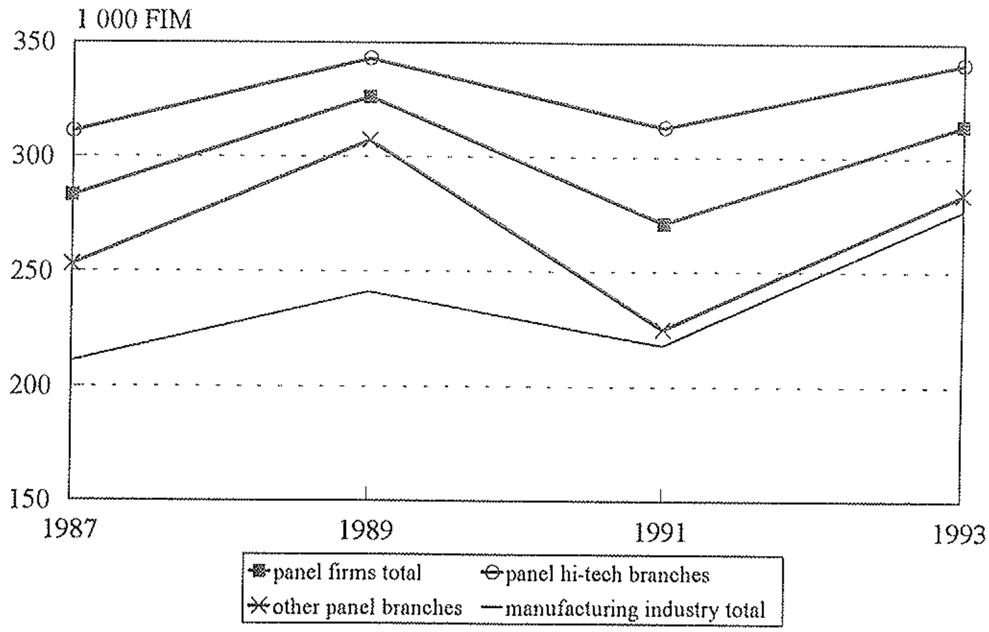

Figure 6. Real average labour productivity in the panel firms and in the manufacturing industry.

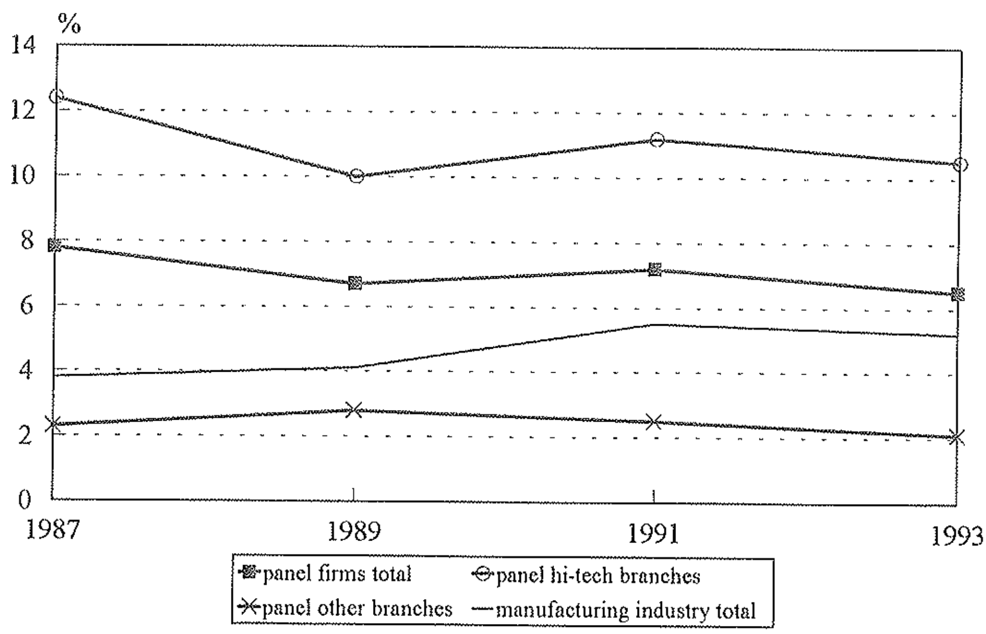

Figure 7. R&D intensity in the panel firms and in the manufacturing industry.

- In high-tech branches, R&D intensity has remained at over 10 per cent throughout the panel. In other branches it has been at a clearly lower level, i.e., between 2–3 per cent. The difference between panel firms and the whole industry has decreased during the period under review.

Depending on the year, the panel firms account for 14.8–15.6 per cent of the entire industry's workforce, 23.1–31.1 per cent of its R&D expenditure and 17.7–21.0 per cent of its value added (Table 2). Although the number of firms is relatively small, they cover a fairly large share of the industry's activities, at least in the light of these indicators. It has not been possible to present reliable calculations of the share of physical capital and R&D capital because comparable statistics on the whole industry are not available.

Judging by the parameters discussed, the panel firms differ from the manufacturing industry as a whole in terms of their higher R&D expenditure and intensity as well as in terms of their higher labour productivity. Large and medium-sized firms with R&D activities are overrepresented in the panel. Compared with the manufacturing industry as a whole, the volume of R&D activities is above average. Generally, however, the panel firms have responded to the changes taking lace in the economy in a very similar fashion as other industrial companies. This is clearly seen when we look at the trends in staff numbers, value added, labour productivity and R&D activities in the panel firms and in the industry as a whole.

5. Results

5.1. Cross-sectional Estimates of R&D Elasticity

The relationship between production factors and productivity was examined by two different kinds of cross-sectional calculations. Chapter 5.1.1. presents the estimates that are based on cross-sections from different years of the panel. The cross-section years reviewed were 1987, 1989, 1991 and

1993. Chapter 5.1.2. presents cross-section estimates that cover the whole panel period from 1987 to 1993, i.e., the between-firm estimates based on a "mean cross-section" method.

Two separate calculations were also made for the between-estimates (and for the within-estimates in Chapter 5.2.), of which the former covered the period between 1987 and 1990 and the latter the period from 1990 to 1993. The aim was to shed light on how the link between R&D and output, and, followingly, between R&D and productivity changed in the panel firms during these two, very different kinds of periods. The year 1990 was a sort of watershed in terms of economic development in the sense that in 1990 Finland was still enjoying an ongoing economic upswing, even though there were already signs of an imminent downturn.

5.1.1. Estimates Based on Annual Cross-sections

We shall begin by looking at the results of the production function based on a R&D capital depreciation rate of 0.30 and with corrections for R&D double-counting made (see Table 3, left side). The estimate of R&D elasticity during the cross-section years was within the range of 0.10–0.20. In 1987 and in 1989, the estimates of R&D elasticity for the whole panel were around 0.10. In 1991, the estimate value was 0.16 and in 1993 considerably higher at 0.20. In high-tech branches, the estimates of R&D elasticity were in the range of 0.10–0.29. In other branches, the figures were between 0.03 and 0.19. In high-tech firms, the estimates of R&D elasticity were higher than in other branches in all the years studied.

There were certain features in the trends in R&D elasticity estimates that were shared by the whole panel as well as by high-tech industries and other industries. Estimates of R&D elasticity increased throughout the panel period, i.e., from 1987 to 1993. The rise was particularly sharp in 1991 and 1993; in other words, the results clearly indicate that the relationship between R&D and productivity became stronger during the 1990s. Especially in high-tech branches, the productivity of R&D

Table 3. Production function estimates for panel cross-section years 1987, 1989, 1991 and 1993. On the left side, corrections for R&D double-counting are made, i.e., the number of researchers is subtracted from the total number of employees and physical capital devoted to R&D activities is deducted from total physical capital. On the right side, corrections for R&D double-counting are made only in part, i.e., the number of researchers is not subtracted from the total number of employees. The rate of depreciation of R&D capital is 0.30.

Dependent variable: Value added/Employee

Year	1987	1989	1991	1993	1987	1989	1991	1993
	Corrections for double-counting are made				Corrections for double-counting are made only in part			
Labour log(L)	**0.784 (0.061)****	**0.839 (0.068)****	**0.805 (0.076)****	**0.674 (0.070)****	**0.811 (0.062)****	**0.882 (0.065)****	**0.852 (0.076)****	**0.688 (0.069)****
hi-tech branches	0.798 (0.085)**	0.829 (0.089)**	0.725 (0.102)**	0.561 (0.100)**	0.842 (0.088)**	0.890 0.084)**	0.786 (0.107)**	0.574 (0.100)**
other branches	0.747 (0.099)**	0.811 (0.117)**	0.875 (0.126)**	0.748 (0.107)**	0.761 (0.099)**	0.845 (0.117)**	0.900 (0.125)**	0.774 (0.109)**
...								
Physical capital log(C/L)	**0.161 (0.040)****	**0.154 (0.044)****	**0.088 (0.052)**	**0.134 (0.047)****	**0.165 (0.039)****	**0.147 (0.041)****	**0.082 (0.050)**	**0.137 (0.046)****
hi-tech branches	0.156 (0.055)**	0.139 (0.054)*	0.105 (0.066)	0.132 (0.063)*	0.157 (0.054)**	0.130 (0.049)*	0.099 (0.065)	0.137 (0.061)*
other branches	0.176 (0.068)*	0.241 (0.085)**	0.124 (0.095)	0.096 (0.083)	0.176 (0.067)*	0.231 (0.083)**	0.119 (0.093)	0.091 (0.082)
...								
R&D capital log(K/L)	**0.098 (0.025)****	**0.096 (0.027)****	**0.163 (0.032)****	**0.195 (0.032)****	**0.072 (0.025)****	**0.066 (0.026)***	**0.130 (0.032)****	**0.174 (0.032)****
hi-tech branches	0.100 (0.043)*	0.115 (0.044)*	0.214 (0.057)**	0.288 (0.058)**	0.061 (0.044)	0.070 (0.042)	0.168 (0.059)**	0.263 (0.059)**
other branches	0.092 (0.039)*	0.032 (0.050)	0.068 (0.058)	0.187 (0.060)**	0.082 (0.039)*	0.017 (0.048)	0.051 (0.056)	0.172 (0.059)**
...								
Deviation from CRS#	**0.042**	**0.089**	**0.056**	**0.003**	**0.048**	**0.095**	**0.064**	**-0.001**
hi-tech branches	0.054	0.083	0.044	-0.019	0.060	0.090	0.053	-0.026
other branches	0.015	0.084	0.067	0.031	0.019	0.093	0.070	0.037
...								
R^2	**0.945 (0.354)**	**0.946 (0.355)**	**0.932 (0.388)**	**0.934 (0.368)**	**0.946 (0.352)**	**0.952 (0.333)**	**0.936 (0.377)**	**0.936 (0.362)**
hi-tech branches	0.949 (0.394)	0.960 (0.345)	0.946 (0.395)	0.944 (0.386)	0.950 (0.391)	0.967 (0.315)	0.948 (0.388)	0.946 (0.381)
other branches	0.931 (0.325)	0.924 (0.369)	0.914 (0.374)	0.924 (0.338)	0.933 (0.322)	0.928 (0.358)	0.917 (0.367)	0.926 (0.334)

Elasticity estimates and standard errors for all panel firms and for hi-tech firms and other branches separately.

** p-value < 0,01   * 0,05 ≥ p-value ≥ 0,01   in other cases the estimate is not statistically significant at below 5 % risk level.

R^2 = coefficient of determination; root mean standard error in parentheses.

= Deviation from constant return to scale (CRS) refers to the difference of the sum of factor elasticities ($\alpha+\beta+\gamma$) from CRS value 1.

The basic figure for the variable to be explained in the model (Y) is value added, which has been obtained from Statistics Finland's industrial statistics. The independent variables are as follows: labour input (L) is a firm's personnel (industrial statistics and R&D statistics); the variable describing physical capital (C) is based on cumulated value of machinery and equipment acquisitions (industrial statistics); and the variable describing R&D capital (K) is based on cumulated intramural R&D expenditure (R&D statistics).

capital increased markedly during the period under review. For instance, while the estimate of R&D elasticity in 1989 was 0.12, the figure for 1991 was 0.21. The estimate of R&D elasticity was particularly high in 1993 at 0.29.

In the cross-sections of the 1980s, the estimates of R&D elasticity in high-tech branches were lower than the estimates for physical capital. In the 1990s, the situation was opposite. The relationship between R&D and productivity was stronger than that between physical capital and productivity. In other industries, the situation was different: with the exception of 1993, the R&D elasticity estimate was considerably lower than the estimate of physical capital elasticity. Especially in the cross-section years of the 1980s, the difference between the estimates for R&D capital (0.09 and 0.03) and the estimates for physical capital (0.17 and 0.24) in other branches was considerable.

As the estimates of R&D elasticity increased in the cross-sections of the 1990s, their statistical significance increased at the same time (see *p*-values). However, it must be noted that in other than high-tech branches the estimates fluctuated throughout the panel period, and these estimates were not always statistically significant. In fact the only estimate of R&D elasticity in other industries which was statistically highly significant was that for 1993.

The estimates of physical capital elasticity for the whole panel were between 0.13 and 0.16 with the exception of 1991, when the figure dropped to a very low level (0.09). In high-tech branches, the elasticity of physical capital ranged between 0.11 and 0.16, while in other branches the figures were between 0.10 and 0.24. In high-tech branches, the estimates were more often lower than in other branches. The estimate was comparatively high in 1989 for other industries. However, with the exception of the single year of 1989, the differences in the elasticities of physical capital between high-tech and other branches were not very significant: for the main part the difference between different branches was in the region of 0.02–0.04. A notable exception was the year 1993, when the elasticity of physical capital in high-tech sectors rose beyond the elasticity of other sectors.

The estimates of labour elasticity for the entire set of firms were in the range of 0.67–0.84. Thus, depending on the year examined, the magnitude of the estimate varied considerably. The most significant result was that the productivity effect of labour input declined in 1993, when the estimate of labour elasticity was at its lowest level. In high-tech branches the estimates were relatively high during the 1980s (0.80 and 0.83), but declined sharply during the 1990s. In the 1993 cross-section, the estimate of labour elasticity was only 0.56. According to the 1980s results, in high-tech branches, the productivity of labour was greater than in other branches. However, as the labour elasticity estimates declined in 1993, the decline was clearly the sharpest in the high-tech sector. The decrease in the estimate of labour elasticity in the 1990s is seen in all the cross-sectional estimates of this study. This, however, is not apparent in the time-series results examined in Chapter 5.2.

It is interesting to consider the question of how far the results were affected by the different R&D capital depreciation rates and by the way in which the R&D variable was constructed. To establish the extent of that effect, we carried out experiments with a different depreciation rate and a different way of constructing the variable. The results shown in the right side of Table 3 are based on a situation where the double-counting between the R&D variable and labour input has not been removed. The depreciation rate for R&D capital stock was the same. The results shown in Table 4 are in turn based on the same kind of calculations (referring double-counting) as in Table 3, but where the R&D capital depreciation rate is 0.10.

When the correction for R&D double-counting (the number of researchers subtracted from the total number of employees) was not made, the estimate of R&D elasticity for all branches was within the range of 0.07 and 0.17, depending on the year (right side in Table 3). The elasticity of R&D in high-tech branches was between 0.06 and 0.26 and in other branches between 0.02 and 0.17. The central result was that when the correction for R&D double-counting was not made, the estimates of R&D elasticity were clearly lower compared to the estimates derived from the situation where the correction was made. Because of the "overlap" between the R&D variable and the labour input variable, the estimate of R&D elasticity for the entire set of firms was about 0.03 lower. In high-tech industries, the estimate of R&D elasticity dropped by 0.03–0.05 and in other branches by 0.01–0.02. As expected, disregarding the double-counting had the clearest effect in high-tech branches, i.e., chiefly in those fields where the number of research staff as a proportion of total personnel was higher than in other branches.

However, the relative changes in the magnitudes of R&D elasticity estimates between different years and the general trend throughout the panel period were parallel to those occurring in the situation where the double-counting was taken into account. For instance, the estimates of R&D elasticity in 1991 and 1993 were considerably higher than in the 1980s cross-section years. The estimates of physical capital elasticity showed hardly any change at all regardless of whether the effect of R&D double-counting had been removed or not – the differences between the estimates of physical capital elasticity remained within the range of ± 0.01.

The effect of double-counting on the labour elasticity estimates seem to be quite unambiguous. A central result was that, when the correction for double-counting of R&D was not made, the estimate of the labour elasticity tended to be somewhat higher than otherwise. Depending on the year and group of firms examined, the labour elasticity estimates were 0.01–0.06 higher when the correction for double-counting was not made. This result was consistent with all the estimates of labour elasticity of this study.

The results in Table 4 are based on calculations using a R&D capital depreciation rate of 0.10. According to these results, the effect of the depreciation rate of R&D capital on the estimate of R&D elasticity was clearly lesser than the effect of double-counting (compare with Table 3). When the effect of double-counting was removed, the R&D elasticity estimate in all the panel firms was between 0.10 and 0.18. In high-tech branches, the estimate of R&D elasticity was 0.10–0.26 and in other branches 0.05–0.15. When the correction for double-counting was not made, the R&D elasticity estimate for all firms was in the range of 0.07–0.16, for high-tech branches in the range of 0.06–0.24, and for other branches in the range of 0.03–0.13.

Table 4. Production function estimates for panel cross-section years 1987, 1989, 1991 and 1993. On the left side, corrections for R&D double-counting are made, i.e., the number of researchers is subtracted from the total number of employees and physical capital devoted to R&D activities is deducted from total physical capital. On the right side, corrections for R&D double-counting are made only in part, i.e., the number of researchers is not subtracted from the total number of employees. The rate of depreciation of R&D capital is 0.10.

Dependent variable: Value added/Employee

Year	1987	1989	1991	1993	1987	1989	1991	1993
	Corrections for double-counting are made				Corrections for double-counting are made only in part			
Labour log(L)	**0.784 (0.061)****	**0.836 (0.068)****	**0.810 (0.077)****	**0.689 (0.072)****	**0.811 (0.062)****	**0.880 (0.065)****	**0.859 (0.078)****	**0.705 (0.071)****
hi-tech branches	0.798 (0085)**	0.838 (0.089)**	0.746 (0.104)**	0.595 (0.101)**	0.842 (0.088)**	0.900 (0.084)**	0.801 (0 108)**	0.610 (0.101)**
other branches	0.747 (0.099)**	0.811 (0.116)**	0.872 (0.126)**	0.759 (0.114)**	0.761 (0.099)**	0.844 (0.116)**	0.899 (0.126)**	0.788 (0.116)**
...								
Physical capital log(C/L)	**0.161 (0.040)****	**0.154 (0.044)****	**0.092 (0.053)**	**0.135 (0.049)****	**0.165 (0.039)****	**0.147 (0.041)****	**0.085 (0.050)**	**0.137 (0.047)****
hi-tech branches	0.156 (0.055)**	0.141 (0.055)*	0.111 (0.068)	0.130 (0.066)	0.157 (0.054)**	0.130 (0.049)*	0.103 (0.066)	0.135 (0.063)*
other branches	0.176 (0.068)*	0.233 (0.084)**	0.136 (0.094)	0.130 (0.087)	0.176 (0.067)*	0.223 (0.081)*	0.128 (0.092)	0.122 (0.086)
...								
R&D capital log(K/L)	**0.098 (0.025)****	**0.099 (0.027)****	**0.153 (0.033)****	**0.184 (0.033)****	**0.072 (0.025)****	**0.068 (0.026)***	**0.120 (0.032)****	**0.161 (0.033)****
hi-tech branches	0.100 (0.043)*	0.108 (0.044)*	0.187 (0.056)**	0.263 (0.059)**	0.061 (0.044)	0.063 (0.041)	0.142 (0.057)*	0.237 (0.060)**
other branches	0.092 (0.039)*	0.045 (0.050)	0.054 (0.058)	0.146 (0.063)*	0.082 (0.039)*	0.030 (0.048)	0.039 (0.056)	0.131 (0.062)*
...								
Deviation from CRS#	**0.043**	**0.089**	**0.055**	**0.008**	**0.048**	**0.095**	**0.064**	**0.003**
hi-tech branches	0.054	0.087	0.044	-0.012	0.060	0.092	0.055	-0.018
other branches	0.015	0.089	0.062	0.035	0.019	0.098	0.066	0.041
...								
R^2	**0.945 (0.354)**	**0.946 (0.354)**	**0.929 (0.396)**	**0.929 (0.381)**	**0.946 (0.352)**	**0.953 (0.332)**	**0.933 (0.383)**	**0.932 (0.374)**
hi-tech branches	0.949 (0.394)	0.959 (0.348)	0.943 (0.407)	0.939 (0.402)	0.950 (0.391)	0.966 (0.317)	0.946 (0.397)	0.942 (0.395)
other branches	0.931 (0.325)	0.925 (0.366)	0.913 (0.377)	0.914 (0.358)	0.933 0.322)	0.929 (0.356)	0.916 (0.369)	0.917 (0.353)

Elasticity estimates and standard errors for all panel firms and for hi-tech firms and other branches separately.

** p-value < 0,01 * 0,05 ≥ p-value ≥ 0,01 in other cases the estimate is not statistically significant at below 5 % risk level.

R^2 = coefficient of determination; root mean standard error in parentheses.

= Deviation from constant returns to scale (CRS) refers to the difference of the sum of factor elasticities ($\alpha+\beta+\gamma$) from CRS value 1.

The basic figure for the variable to be explained in the model (Y) is value added, which has been obtained from Statistics Finland's industrial statistics. The independent variables are as follows: labour input (L) is a firm's personnel (industrial statistics and R&D statistics); the variable describing physical capital (C) is based on cumulated value of machinery and equipment acquisitions (industrial statistics); and the variable describing R&D capital (K) is based on cumulated intramural R&D expenditure (R&D statistics).

The differences in the magnitudes of the R&D elasticity estimates compared with the figures obtained using the depreciation rate of 0.30 were -0.04 and +0.01. In fact, with the exception of the R&D elasticities in high-tech industries in 1991 and 1993 and in other branches in 1993, the differences remained very small. The exceptional figure obtained for R&D elasticity in 1993 in other than high-tech sectors (the difference in comparison with the elasticity obtained with the depreciation rate of 0.30 was -0.04) is probably connected with the behaviour of the estimated elasticity of physical capital. While the difference of the estimates of physical capital elasticity for other branches to the estimates given in Table 3 peaked at ± 0.01, the estimate in 1993 differed clearly from this (+ 0.03).

One of the special characteristics of the perpetual inventory method used for the calculation of the R&D capital stock was that since 1987 was taken as the start-point for the calculation of R&D capital, the estimates for this year showed no differences due to different depreciation rates. The method used for calculating the capital stock also involved another, more interesting characteristic. That is, excepting the estimates for 1987, the results suggest that the longer the time period for which the estimates of elasticity since the start-point of R&D capital calculations are calculated, the greater are the differences between the R&D elasticity estimates calculated with different depreciation rates. These observations are at least partly explained by the way in which the R&D capital depreciation rate works when the perpetual inventory method is used. Although the values of capital stock vary with different depreciation rates, the relative differences between the capital stock figures for observation units in the start-year of the calculation remain constant. The differences between the observation units in the levels of capital value and their relative differences only begin to fluctuate after the start-year when the units' annual R&D expenditures are added cumulatively to the capital stock.

Notwithstanding the different depreciation rates of R&D capital and the different ways in which double-counting was handled, all the cross-sectional calculations shared the following features in common: Firstly, the different depreciation rates and the ways the corrections for double-counting were handled did not have a significant effect on the standard errors of the estimated elasticity coefficients. Secondly, they had hardly any effect on the deviations from constant returns to scale. And thirdly, the degree of explanation remained more or less unchanged (varying ± one percentage points) in spite of the different depreciation rates and methods of double-counting. In addition, the way the R&D variable was constructed had some effect on the magnitude and on the statistical significance of the R&D elasticity estimates; when the depreciation rate was higher, the estimate of the R&D elasticity was often higher, and; statistical significance of the estimate of R&D elasticity tended to be better when the corrections for double-counting were made. These same points also apply to the between-firm estimates discussed below.

5.1.2. Between-Estimates of R&D Elasticity for the Period 1987–1993

The production function between-estimates for the period 1987–1993 are shown in Tables 5 and 6. These estimates are based on a "mean cross-section" method. The results in Table 5 have been obtained using the R&D capital depreciation rate of 0.30, and with and without the correction for R&D double-counting made (compare with Table 3). When the corrections for double-counting were made, the estimate of R&D elasticity for the whole period was 0.16. In high-tech industries, the estimate was comparatively high, i.e., 0.19, whereas in other branches it was 0.11. Judging on the basis of the R&D elasticity of different branches, the relationship between R&D and productivity was considerably stronger in high-tech branches than in other industries. The *p*-values of the estimates were below 0.01, i.e., they were statistically very significant for the whole panel and for high-tech branches, whereas on the basis of the *p*-value (< 0.05), the estimate of R&D elasticity in other branches was statistically significant.

Estimates were also calculated separately for the two shorter periods of 1987–1990 and 1990–1993. R&D elasticity in the whole material for the 1980s period was 0.11 and for the 1990s period 0.19. The estimated elasticity thus increased by 0.08. An increase of the same magnitude also occurred in

Table 5. Between-firm estimates of production function for the 1987–1993 panel firms. Separate estimates are also given for the panel periods 1987–1990 and 1990–1993. On the left side, corrections for R&D double-counting are made, i.e., the number of researchers is subtracted from the total number of employees and physical capital devoted to R&D activities is deducted from total physical capital. On the right side, corrections for R&D double-counting are made only in part, i.e., the number of researchers is not subtracted from the total number of employees. The rate of depreciation of R&D capital is 0.30.

Dependent variable: Value added/Employee

Time	1987–1993	1987–1990	1990–1993	1987–1993	1987–1990	1990–1993
	Corrections for double-counting are made			Corrections for double-counting are made only in part		
Labour log(L)	**0.742 (0.059)****	**0.788 (0.061)****	**0.731 (0.062)****	**0.776 (0.058)****	**0.826 (0.059)****	**0.764 (0.062)****
hi-tech branches	0.699 (0.083)**	0.777 (0.082)**	0.647 (0.086)**	0.747 (0.084)**	0.834 (0.081)**	0.690 (0.087)**
other branches	0.766 (0.094)**	0.776 (0.103)**	0.812 (0.103)**	0.789 (0.094)**	0.801 (0.103)**	0.836 (0.104)**
...						
Physical capital log(C/L)	**0.145 (0.039)****	**0.162 (0.040)****	**0.121 (0.042)****	**0.145 (0.037)****	**0.159 (0.038)****	**0.119 (0.040)****
hi-tech branches	0.143 (0.052)**	0.158 (0.051)**	0.134 (0.054)*	0.141 (0.049)**	0.153 (0.048)**	0.132 (0.052)*
other branches	0.171 (0.070)*	0.209 (0.074)**	0.109 (0.078)	0.169 (0.069)*	0.204 (0.073)**	0.106 (0.077)
...						
R&D capital log(K/L)	**0.156 (0.026)****	**0.107 (0.025)****	**0.186 (0.027)****	**0.126 (0.025)****	**0.078 (0.025)****	**0.157 (0.027)****
hi-tech branches	0.194 (0.045)**	0.122 (0.043)**	0.240 (0.049)**	0.152 (0.045)**	0.078 (0.042)	0.203 (0.049)**
other branches	0.109 (0.048)*	0.059 (0.045)	0.142 (0.054)*	0.093 (0.047)	0.046 (0.044)	0.124 (0.053)*
...						
Deviation from CRS#	**0.043**	**0.057**	**0.038**	**0.047**	**0.063**	**0.040**
hi-tech branches	0.036	0.057	0.021	0.040	0.065	0.025
other branches	0.046	0.044	0.063	0.051	0.051	0.066
...						
R^2	**0.959 (0.297)**	**0.954 (0.320)**	**0.953 (0.317)**	**0.962 (0.287)**	**0.959 (0.305)**	**0.956 (0.307)**
hi-tech branches	0.964 (0.316)	0.963 (0.329)	0.962 (0.326)	0.967 (0.303)	0.968 (0.309)	0.964 (0.315)
other branches	0.948 (0.285)	0.936 (0.321)	0.938 (0.312)	0.949 (0.281)	0.939 (0.314)	0.939 (0.308)

Elasticity estimates and standard errors for all panel firms and for hi-tech firms and other branches separately.

** p-value < 0,01   * 0,05 ≥ p-value ≥ 0,01   in other cases the estimate is not statistically significant at below 5 % risk level.

R^2 = coefficient of determination; root mean standard error in parentheses.

\# = Deviation from constant returns to scale (CRS) refers to the difference of the sum of factor elasticities ($\alpha+\beta+\gamma$) from CRS value 1.

The basic figure for the variable to be explained in the model (Y) is value added, which has been obtained from Statistics Finland's industrial statistics. The independent variables are as follows: labour input (L) is a firm's personnel (industrial statistics and R&D statistics); the variable describing physical capital (C) is based on cumulated value of machinery and equipment acquisitions (industrial statistics); and the variable describing R&D capital (K) is based on cumulated intramural R&D expenditure (R&D statistics).

the estimate of R&D elasticity in other industries (from 0.06 to 0.14). The most significant change was seen in the estimate of high-tech branches, with R&D elasticity increasing from 0.12 to 0.24.

The results help to shed further light on the annual cross-section estimates that were calculated using the same depreciation rate and when the corrections for R&D double-counting had been made. In the between-estimates, too, the estimates of R&D elasticity for the 1990s were considerably higher than the corresponding estimates for the 1980s. At the same time, the R&D elasticity for high-tech branches was considerably higher than in other branches. The between-estimates for R&D elasticity were in the range and consistent with those in the annual cross-sections. It is noteworthy that also the between-estimates of physical capital and labour elasticities corresponded fairly well with the results for annual cross-sections.

The results shown on the right side in Table 5 differ from those reported above in that the correction for the R&D double-counting was not made. The estimate of R&D elasticity extending across the whole panel was 0.13 for all firms. In high-tech branches the figure was 0.15 and in other branches 0.09. During the period 1987–1990, R&D elasticity for the whole material was 0.08 and during the period between 1990 and 1993 much higher at 0.16. In high-tech industries, R&D elasticity increased between the two periods even more, i.e., from 0.08 to 0.20. The R&D estimate for other branches increased from 0.05 to 0.12. The development of R&D elasticity was very similar in all cases. The increase in R&D elasticity between the two periods was also of the same magnitude when the correction for R&D double-counting was made. In both cases the R&D elasticity coefficient for the period covering the 1990s was 0.07–0.13 higher than during the earlier period.

When the correction for R&D double-counting was not made, the estimate of R&D elasticity fell by 0.01–0.04 (Table 5, compare left and right side). This decrease in the estimated elasticity was most clearly seen in high-tech branches. The result was thus the same as in the annual cross-sections. In addition to the effect of R&D double-counting on the magnitude of the between-firm estimates of R&D elasticity, the results indicate that when the correction for R&D double-counting was not made, the statistical significance of the estimates of R&D elasticity was lower. This was not apparent in all figures, but in some of them.

Looking at the estimates of labour elasticity, we find that the estimates vary remarkably between the two groups of industrial branches. The estimate of labour elasticity was for high-tech branches clearly lower than for other branches. The general trend was that the labour elasticity for the whole group of firms and for firms in high-tech sector declined during the 1990s. An interesting result was that the trend was opposite for firms in other branches. The estimate of labour elasticity was clearly higher for the 1990s period. The correction for the R&D double-counting affects considerably the magnitude of the estimate of labour elasticity. When the correction was made, the estimate of labour elasticity was 0.02–0.05 lower than in the situation where the correction was not made. The effect of the correction on the magnitude of the estimate was larger in the high-tech sector.

The estimate of R&D elasticity based on the depreciation rate of 0.10 was 0.15 for all branches (left side in Table 6). The estimate for high-tech industries was slightly higher at 0.17, in other industries 0.10. The p-values of the R&D estimates for all panel firms as well as for high-tech firms were below 0.01, and they were statistically highly significant. In other industries, the only estimate of R&D elasticity that was highly significant (as judged on the basis of its p-value) was that for 1987–1990.

R&D elasticity for the whole group of panel firms during the 1980s period was 0.11; and for the 1990s period 0.17. The rise in the estimate of R&D elasticity was roughly of the same order as in the case of other industries (from 0.06 to 0.11). The most significant change (+0.10) occurred in the R&D elasticities of high-tech firms. The estimate of R&D elasticity increased from 0.11 to 0.21. The rise in R&D elasticity between the two periods was similar to the situation where the depreciation rate in constructing R&D capital was 0.30. However, the choice of depreciation rate had some effect on the magnitude of the R&D elasticity estimates. Compared with the results based on the depreciation rate of 0.30, the estimate of R&D elasticity fell for all firms by no more than 0.02. In

Table 6. Between-firm estimates of production function for the 1987–1993 panel firms. Separate estimates are also given for the panel periods 1987–1990 and 1990–1993. On the left side, corrections for R&D double-counting are made, i.e., the number of researchers is subtracted from the total number of employees and physical capital devoted to R&D activities is deducted from total physical capital. On the right side, corrections for R&D double-counting are made only in part, i.e., the number of researchers is not subtracted from the total number of employees. The rate of depreciation of R&D capital is 0.10.

Dependent variable: Value added/Employee

Time	1987–1993	1987–1990	1990–1993	1987–1993	1987–1990	1990–1993
	Corrections for double-counting are made			Corrections for double-counting are made only in part		
Labour log(L)	**0.749 (0.060)****	**0.789 (0.060)****	**0.742 (0.064)****	**0.784 (0.059)****	**0.827 (0.059)****	**0.777 (0.064)****
hi-tech branches	0.714 (0.085)**	0.786 (0.082)**	0.671 (0.089)**	0.763 (0.085)**	0.842 (0.080)**	0.716 (0.089)**
other branches	0.769 (0.095)**	0.775 (0.103)**	0.815 (0.106)**	0.792 (0.095)**	0.800 (0.102)**	0.841 (0.107)**

Physical capital log(C/L)	**0.149 (0.040)****	**0.163 (0.040)****	**0.125 (0.043)****	**0.147 (0.038)****	**0.159 (0.038)****	**0.122 (0.041)****
hi-tech branches	0.148 (0.053)**	0.160 (0.052)**	0.140 (0.056)*	0.144 (0.050)**	0.154 (0.048)**	0.136 (0.054)*
other branches	0.181 (0.070)*	0.206 (0.073)**	0.131 (0.080)	0.177 (0.068)*	0.202 (0.072)**	0.126 (0.079)

R&D capital log(K/L)	**0.145 (0.025)****	**0.105 (0.025)****	**0.171 (0.028)****	**0.116 (0.025)****	**0.076 (0.024)****	**0.142 (0.028)****
hi-tech branches	0.174 (0.044)**	0.113 (0.041)**	0.212 (0.049)**	0.134 (0.044)**	0.070 (0.040)	0.175 (0.049)**
other branches	0.095 (0.046)*	0.064 (0.044)	0.112 (0.054)*	0.080 (0.045)	0.051 (0.043)	0.096 (0.053)

Deviation from CRS#	**0.043**	**0.057**	**0.038**	**0.047**	**0.062**	**0.041**
hi-tech branches	0.036	0.059	0.023	0.041	0.066	0.027
other branches	0.045	0.045	0.058	0.049	0.053	0.063

R^2	**0.957 (0.304)**	**0.954 (0.320)**	**0.949 (0.330)**	**0.960 (0.292)**	**0.959 (0.305)**	**0.952 (0.318)**
hi-tech branches	0.962 (0.325)	0.963 (0.332)	0.958 (0.342)	0.966 (0.310)	0.967 (0.310)	0.961 (0.328)
other branches	0.946 (0.289)	0.937 (0.319)	0.933 (0.323)	0.948 (0.284)	0.940 (0.312)	0.935 (0.318)

Elasticity estimates and standard errors for all panel firms and for hi-tech firms and other branches separately.

** p-value < 0,01 * 0,05 ≥ p-value ≥ 0,01 in other cases the estimate is not statistically significant at below 5 % risk level.

R^2 = coefficient of determination; root mean standard error in parentheses.

= Deviation from constant returns to scale (CRS) refers to the difference of the sum of factor elasticities ($\alpha+\beta+\gamma$) from CRS value 1.

The basic figure for the variable to be explained in the model (Y) is value added, which has been obtained from Statistics Finland's industrial statistics. The independent variables are as follows: labour input (L) is a firm's personnel (industrial statistics and R&D statistics); the variable describing physical capital (C) is based on cumulated value of machinery and equipment acquisitions (industrial statistics); and the variable describing R&D capital (K) is based on cumulated intramural R&D expenditure (R&D statistics).

high-tech companies the decrease in R&D elasticity was between 0.01 and 0.03; in other industries the change in elasticity was between +0.01 and -0.03. The effect of the depreciation rate on the magnitude of the estimate of R&D elasticity was lesser than the effect of the correction for R&D double-counting. As expected, the results suggest that the choice of depreciation rate makes no difference in terms of the statistical significance of the estimates of R&D elasticity.

When the correction for R&D double-counting was not made, the estimate of R&D elasticity fell by 0.01–0.04, and the estimate of labour elasticity rose by 0.02–0.05 (see Table 6). This confirms the result based on the annual cross-sections: when the corrections were made, the estimate of R&D elasticity is higher and labour elasticity lower than otherwise. In this context, the depreciation rates had no effect on the magnitude of the changes in the elasticity estimates (compare Tables 5 and 6).

5.2. Time-series Estimates of R&D Elasticity

The within-firm estimates based on company time-series are shown in Tables 7 and 8. When the depreciation rate of 0.30 for R&D capital was used and the correction for double-counting was made, the within-estimate for R&D elasticity was 0.09 (left side in Table 7). The difference between the estimates for different branches were significant: the figure for high-tech branches was 0.13 and for other branches only 0.04. The links of R&D activities with company productivity in high-tech industries was thus clearly stronger. The estimates for the entire set of firms and for high-tech companies were statistically highly significant in contrast to the situation in other branches.

As in the case of the between-estimates, two separate calculations were made of the within-estimates; the first covered the period between 1987 and 1990, the second the period between 1990 and 1993. The within-estimates helped to throw light on how the links between R&D and productivity changed within firms during these two periods. The estimate of R&D elasticity for all the branches rose from 0.10 in the 1987–1990 period to 0.13 in 1990–1993, i.e., R&D elasticity went up by 0.03. In high-tech industries, the estimated elasticity of R&D rose from 0.16 to 0.19. In other branches the estimated elasticity was at a very low level during both periods and increased only from 0.03 to 0.04. According to the results, the estimates of R&D elasticity during the 1990–1993 period were higher than in the period 1987–1990. In other words, the relationship between R&D and productivity grew closer during the recession, whereas the estimate of physical capital elasticity declined during the 1990s, pointing at a weakening of the link between physical capital and productivity.

The results on the right side in Table 7 differ from those discussed above in that the effect of the correction for R&D double-counting is not removed. The estimate for R&D elasticity covering the whole panel period was 0.07 for all firms; the figure for firms in high-tech sector was 0.10 and for firms in other sectors only 0.03. During the 1987–1990 period R&D elasticity for the whole group of firms was 0.08 and during the 1990–1993 period slightly higher at 0.11. In high-tech industries, R&D elasticity estimate increased between the two periods from 0.13 to 0.16. The estimate of R&D elasticity for the firms in other branches remained at the same level, i.e., 0.02. This estimate can be considered exceptionally low.

The effect of the correction for R&D double-counting was that when the correction was not made, the estimate of R&D elasticity decreased by 0.01–0.03. The decrease in R&D elasticity estimates was sharpest in high-tech firms. This result was consistent with the between-estimates of R&D elasticity. However, contrary to the results based on cross-sectional regressions, the time-series results indicate that the correction for R&D double-counting had no effect on the statistical significance of the estimates of R&D elasticity. The R&D elasticity estimates were all statistically highly significant with the exception of the estimates for the firms in the other branches.

When the depreciation rate of 0.10 was used and the corrections for double-counting made, the estimate of R&D elasticity for the whole group of panel firms was 0.10 (left side in Table 8). The estimate for high-tech companies was 0.13, for other branches 0.05. In all the panel firms, the R&D elasticity estimate for the 1980s period was 0.11 and for the 1990s period 0.13. The difference in

Table 7. Within-firm estimates of production function for the 1987–1993 panel firms. Separate estimates are also given for the panel periods 1987–1990 and 1990–1993. On the left side, corrections for R&D double-counting are made, i.e., the number of researchers is subtracted from the total number of employees and physical capital devoted to R&D activities is deducted from total physical capital. On the right side, corrections for R&D double-counting are made only in part, i.e., the number of researchers is not subtracted from the total number of employees. The rate of depreciation of R&D capital is 0.30.

Dependent variable: Value added/Employee

Time	1987–1993	1987–1990	1990–1993	1987–1993	1987–1990	1990–1993
	Corrections for double-counting are made			Corrections for double-counting are made only in part		
Labour log(L)	**0.791 (0.041)****	**0.737 (0.044)****	**0.733 (0.055)****	**0.822 (0.041)****	**0.775 (0.044)****	**0.773 (0.056)****
hi-tech branches	0.748 (0.048)**	0.690 (0.052)**	0.669 (0.072)**	0.772 (0.050)**	0.733 (0.054)**	0.703 (0.074)**
other branches	0.869 (0.075)**	0.822 (0.086)**	0.774 (0.098)**	0.909 (0.075)**	0.854 (0.086)**	0.820 (0.099)**

Physical capital log(C/L)	**0.150 (0.029)****	**0.182 (0.031)****	**0.154 (0.039)****	**0.147 (0.029)****	**0.177 (0.030)****	**0.146 (0.038)****
hi-tech branches	0.163 (0.037)**	0.166 (0.038)**	0.157 (0.050)**	0.164 (0.036)**	0.165 (0.037)**	0.155 (0.048)**
other branches	0.143 (0.055)**	0.189 (0.061)**	0.203 (0.074)**	0.130 (0.054)*	0.179 (0.060)**	0.185 (0.073)*

R&D capital log(K/L)	**0.092 (0.019)****	**0.102 (0.020)****	**0.129 (0.026)****	**0.072 (0.019)****	**0.079 (0.020)****	**0.106 (0.026)****
hi-tech branches	0.126 (0.031)**	0.163 (0.032)**	0.193 (0.047)**	0.100 (0.031)**	0.127 (0.032)**	0.162 (0.047)**
other branches	0.039 (0.028)	0.028 (0.031)	0.035 (0.043)	0.029 (0.028)	0.018 (0.031)	0.023 (0.042)

Deviation from CRS#	**0.033**	**0.021**	**0.016**	**0.041**	**0.031**	**0.025**
hi-tech branches	0.037	0.019	0.019	0.036	0.025	0.020
other branches	0.051	0.039	0.012	0.068	0.051	0.028
---						
root MSE ja VCF	**0.246 (0.084)**	**0.174 (0.097)**	**0.252 (0.096)**	**0.245 (0.076)**	**0.175 (0.087)**	**0.252 (0.088)**
hi-tech branches	0.250 (0.093)	0.166 (0.105)	0.259 (0.100)	0.252 (0.083)	0.170 (0.092)	0.262 (0.092)
other branches	0.234 (0.080)	0.172 (0.096)	0.241 (0.091)	0.231 (0.077)	0.171 (0.091)	0.237 (0.088)

Elasticity estimates and standard errors for all panel firms and for hi-tech firms and other branches separately.

** p-value < 0,01 * 0,05 ≥ p-value ≥ 0,01 in other cases the estimate is not statistically significant at below 5 % risk level.

root MSE = root mean standard error; VCF = variance component for firms

= Deviation from constant returns to scale (CRS) refers to the difference of the sum of factor elasticities ($\alpha+\beta+\gamma$) from CRS value 1.

The basic figure for the variable to be explained in the model (Y) is value added, which has been obtained from Statistics Finland's industrial statistics. The independent variables are as follows: labour input (L) is a firm's personnel (industrial statistics and R&D statistics); the variable describing physical capital (C) is based on cumulated value of machinery and equipment acquisitions (industrial statistics); and the variable describing R&D capital (K) is based on cumulated intramural R&D expenditure (R&D statistics).

Table 8. Within-firm estimates of production function for the 1987–1993 panel firms. Separate estimates are also given for the panel periods 1987–1990 and 1990–1993. On the left side, corrections for R&D double-counting are made, i.e., the number of researchers is subtracted from the total number of employees and physical capital devoted to R&D activities is deducted from total physical capital. On the right side, corrections for R&D double-counting are made only in part, i.e., the number of researchers is not subtracted from the total number of employees. The rate of depreciation of R&D capital is 0.10.

Dependent variable: Value added/Employee

Time	1987–1993	1987–1990	1990–1993	1987–1993	1987–1990	1990–1993
	Corrections for double-counting are made			Corrections for double-counting are made only in part		
Labour log(L)	**0.793 (0.041)****	**0.731 (0.044)****	**0.736 (0.056)****	**0.822 (0.041)****	**0.769 (0.045)****	**0.775 (0.056)****
hi-tech branches	0.757 (0.048)**	0.671 (0.052)**	0.692 (0.072)**	0.779 (0.049)**	0.719 (0.055)**	0.725 (0.074)**
other branches	0.872 (0.075)**	0.822 (0.086)**	0.776 (0.099)**	0.910 (0.075)**	0.854 (0.086)**	0.821 (0.099)**
...						
Physical capital log(C/L)	**0.146 (0.030)****	**0.181 (0.031)****	**0.152 (0.040)****	**0.143 (0.029)****	**0.177 (0.030)****	**0.144 (0.039)****
hi-tech branches	0.159 (0.038)**	0.173 (0.038)**	0.158 (0.051)**	0.161 (0.036)**	0.171 (0.037)**	0.155 (0.050)**
other branches	0.134 (0.056)*	0.181 (0.061)**	0.194 (0.076)*	0.122 (0.055)*	0.172 (0.060)**	0.176 (0.074)*
...						
R&D capital log(K/L)	**0.103 (0.021)****	**0.112 (0.022)****	**0.134 (0.028)****	**0.081 (0.020)****	**0.088 (0.021)****	**0.110 (0.027)****
hi-tech branches	0.127 (0.033)**	0.175 (0.035)**	0.173 (0.048)**	0.103 (0.032)**	0.136 (0.035)**	0.144 (0.047)**
other branches	0.053 (0.033)	0.041 (0.035)	0.048 (0.048)	0.041 (0.032)	0.030 (0.034)	0.036 (0.047)
...						
Deviation from CRS#	**0.042**	**0.024**	**0.022**	**0.046**	**0.034**	**0.029**
hi-tech branches	0.043	0.019	0.023	0.042	0.026	0.024
other branches	0.059	0.044	0.018	0.073	0.056	0.033
...						
root MSE ja VCF	**0.244 (0.087)**	**0.174 (0.097)**	**0.250 (0.103)**	**0.245 (0.078)**	**0.174 (0.087)**	**0.250 (0.094)**
hi-tech branches	0.250 (0.098)	0.167 (0.107)	0.258 (0.111)	0.252 (0.086)	0.170 (0.093)	0.260 (0.100)
other branches	0.234 (0.081)	0.172 (0.094)	0.239 (0.095)	0.230 (0.077)	0.171 (0.090)	0.236 (0.091)

Elasticity estimates and standard errors for all panel firms and for hi-tech firms and other branches separately.

** p-value < 0,01 * 0,05 ≥ p-value ≥ 0,01 in other cases the estimate is not statistically significant at below 5 % risk level.

root MSE = root mean standard error; VCF = variance component for firms

= Deviation from constant returns to scale (CRS) refers to the difference of the sum of factor elasticities ($\alpha+\beta+\gamma$) from CRS value 1.

The basic figure for the variable to be explained in the model (Y) is value added, which has been obtained from Statistics Finland's industrial statistics. The independent variables are as follows: labour input (L) is a firm's personnel (industrial statistics and R&D statistics); the variable describing physical capital (C) is based on cumulated value of machinery and equipment acquisitions (industrial statistics); and the variable describing R&D capital (K) is based on cumulated intramural R&D expenditure (R&D statistics).

comparison with the cross-sectional estimates was that estimates of R&D elasticity in different groups of firms showed no noticeable increase during the periods. The estimate of R&D elasticity of high-tech firms remained virtually unchanged, and there were no signs of significant change in the case of firms in other branches either.

The estimates of R&D elasticity were at most 0.02 higher than those obtained by using the depreciation rate of 0.30. Thus, the effect of the depreciation rate on the magnitude of the estimate of R&D elasticity may be considered relatively weak. Also, as expected, the choice of depreciation rate made no difference to the statistical significance of the estimates of R&D elasticity. According to Hall and Mairesse (1995: 287), the choice of depreciation rate in constructing R&D capital does not make much difference to the estimates of R&D elasticity, particularly on the within-firm dimension, although it does change the average level of measured R&D capital. The results of this study confirm this statement as far as the within-firm estimates of R&D elasticity are concerned. The situation was slightly different when we examined the results of cross-sectional regressions.

The estimate of labour elasticity for the entire set of firms varied in the range of 0.73–0.82. In high-tech sector, the estimate was in the range of 0.67–0.78, whereas in other sectors it was in the range of 0.77–0.91 – thus, the difference between these two groups of industrial branches was quite remarkable. In general, the labour elasticity estimate was lower when the correction for R&D double-counting was not made. A somewhat suprising result was that the estimates of labour elasticity for the period 1990–1993 were not always lower than the estimates for the period 1987–1990. In fact, in the cases where the rate of depreciation of R&D capital was 0.10, the labour elasticity estimates for the entire group of firms and for high-tech branches were higher for the period 1990–1993. For firms in other branches, the estimate of labour elasticty was higher for the period 1987–1990. This result was an exeption compared to all other within-firm or between-firm estimates of labour elasticity of this study.

In all calculations the estimate of physical capital elasticity was mostly within the range of 0.15 and 0.20. The within-regression estimates of physical capital elasticity varied from case to case quite significantly in comparison with the between-regressions. It is particularly noteworthy that especially the within-estimates of physical capital elasticity for the period 1990–1993 were clearly higher and perhaps more credible than the corresponding results based on cross-section type estimates of physical capital elasticity. The within-regression estimates of physical capital elasticity may be regarded as better than others also in the sense that they were all statistically significant, with p-values clearly below 0.05. Of course, it needs to be stressed here that p-values are always approximations and that they are quite sensitive to the size of a sample.

In contrast to the situation with between-regressions, the within-regression estimates of physical capital elasticity were far more often at a clearly higher level than the estimates of R&D elasticity. The differences between the magnitudes of R&D elasticity and physical capital elasticity were particularly evident in the within-estimates for firms in other branches. In these estimates the elasticity of physical capital ranged between 0.13 and 0.20 and those for R&D elasticity between 0.02 and 0.05.

The differences between different industry groups were not equally clear in estimates of physical capital elasticity as in the case of R&D capital. It is noteworthy that in the calculations covering the whole panel, the estimates of physical capital elasticity for high-tech industries were in fact higher than in other branches. However, in the results for the periods 1987–1990 and 1990–1993, the opposite is true: the elasticities of physical capital in other branches were 0.02–0.04 higher than in the high-tech branches.

In addition, the estimate of physical capital generally remained fairly low. The productivity effects of machinery and equipment were excepted to be greater. We also expected that especially in other than high-tech branches the links between productivity and physical capital would have been more clearly visible through the estimates. After all, the stock of physical capital, for instance, was considerably higher in other branches than in the high-tech sector. In this regard, too, the results were somewhat surprising.

6. Conclusions

This study examined the relationship between R&D activities and productivity from an econometric perspective. The focus was mainly on the estimation of factor elasticities and, specifically, on the productivity of R&D. Although different firm-level factors (such as firm size, amount of capital, staff know-how) and general economic climate (such as market structures, availability of venture capital, supply of labour) have a major influence on companies' R&D activities and productivity, these aspects were not treated in this analysis.

The results clearly indicate that in Finnish manufacturing firms R&D activities have had a positive and statistically significant impact on productivity. The impact of R&D on productivity was clearly greater in high-tech branches – for companies in high-tech branches, the estimates of R&D elasticities were relatively high and, in most of the cases, statistically very significant. In other branches, estimates of R&D elasticity were often at a much lower level. Also, the estimates of R&D elasticity in other branches were not always statistically significant. Regardless of the alternative models used for the calculations and the different values of the variables, the results were largely consistent and parallel: the annual cross-sectional estimates of R&D elasticity for all the firms ranged between 0.07 and 0.20, and the between-estimates for the whole period ranged from 0.12 to 0.16. The time-series estimates, i.e., the within-estimates, were between 0.07 and 0.10.

The between-estimates and within-estimates of R&D elasticity for the periods 1987–1990 and 1990–1993 provided further information on the changes that have occurred in R&D activities and productivity. According to the results, the links between R&D and productivity strengthened considerably during the 1990s. The results were opposite when we examined the relationship between labour and productivity – the contribution of labour input on productivity decreased during the 1990s. This was the case especially in high-tech sector. The results supported the estimated factor elasticities obtained in the annual cross-sections. In this regard, the estimates of R&D elasticity calculated using different methods were all very similar. The results obtained with different production function specifications and alternative ways of constructing variables also pointed at remarkable differences in the links between R&D and productivity between high-tech and other firms.

The depreciation rate of R&D capital was found to have only rather limited effect on the estimate of R&D elasticity. The within-estimates of R&D elasticity tended to be slightly higher when a depreciation rate of 0.10 was used. In the case of cross-sectional estimates, R&D elasticity tended to be higher when a depreciation rate of 0.30 was used. The effect of the depreciation rate on the magnitude of the R&D elasticity estimate was weakest in the within-estimates. The results also indicate that, when we use the perpetual inventory method, the differences between the R&D elasticity based on different depreciation rates of R&D capital tend to grow as the time span gets longer from the point at which the calculation of R&D capital is started.

The effect of the double-counting on the R&D elasticity estimates was far clearer than the effect of the depreciation rate of R&D capital. When the correction for double-counting was not made, the estimate of R&D elasticity was lower (at most 0.05 lower) and the statistical significance of the estimate was often weaker. The effect of double-counting on the estimates of labour elasticity was also quite unambiguous. The correction for double-counting (of R&D expentitures) produced the most important difference between the labour elasticity estimates. As we have already noticed, the corrections tend to increase the R&D elasticity estimate. This increase comes primarily at the expense of the labour elasticity estimate, which usually falls nearly the same order of magnitude (see also Hall & Mairesse 1995: 271, 274).

It needs to be stressed that the generalizability of our results is undermined by problems with representativeness and the small size of the panel. The panel included relatively small proportion of all manufacturing firms in Finland with R&D activities. In this sense, the results of the panel in particular must be read and interpreted with caution. In any event, the magnitude of estimated estimates of R&D was certainly affected by the fact that the companies included in the data showed a clearly higher than average R&D intensity. Measured in terms of labour productivity, the companies also had a better than average productivity. If calculations could have been made of all companies with R&D activities, these calculations would have included companies with very low level of R&D intensity. In this situation, the estimates of the R&D elasticity would probably have been somewhat lower.

The crude classification we used in this analysis serves to iron out some of the differences between industrial branches and firms in terms of their volume of R&D activities. It needs to be stressed that there may be firms in the high-tech sector that are not very R&D intensive or that have no high-tech R&D activities. Accordingly, in the category of other industries we may find firms that do meet these criteria of high-tech industry. However, a more detailed classification might have led to a straightforward, clear-cut result as regards the elasticity coefficients for different variables: the estimates for technology-intensive firms would have been extremely high, whereas in companies of a low technology intensity the estimates of R&D elasticity would probably have been at lower level (see Husso, Leppälahti & Niininen 1996: 46–47).

As firm-level data become more accurate and research data improve, the above problems can to some extent be relieved, allowing for more reliable and more accurate measurement of the productivity of R&D activities. However, it needs to be borne in mind that the approach which is based on the production function is highly abstract. Its primary purpose is to quantify the phenomenon studied in very crude terms. Since econometric methods have their obvious limitations, we also need to have more detailed case studies using complementary methods to obtain a more comprehensive picture of such a complex phenomenon as R&D and productivity.

The purpose of this study was not to focus primarily on estimates of physical capital elasticity. However, it can be briefly observed that the estimated elasticities of physical capital varied greatly depending on the specification of the model and on the construction of the variables. The estimates of physical capital elasticity were mostly within the range of 0.11–0.20. Overall, the estimates were somewhat lower than was expected; in some calculations the estimates of physical capital elasticity come very close to or were even below the magnitude of the estimate of R&D elasticity. This is explained at least in part by the specific characteristics of the companies included in the data. The analysis included firms that showed a stronger than average commitment to R&D activities. This is not to say that machinery and equipment capital are of no major consequence to productivity. Simultaneously, it must be noted that the operation of R&D intensive firms is not nearly as often so heavily dependent on machinery and equipment capital as is the case in traditional manufacturing industry. In sum, the relationship between physical capital and productivity was relatively weak. This gives reason to assume, for example, that the method we employed or the rate of depreciation we used in constructing physical capital variable was not the best possible. To address this issue, we will need in the future to devote closer attention to the construction of the physical capital variable.

7. Discussion

A widely accepted view on the economic impact of science and technology is that investments in science and industrial R&D have been crucial factors of economic growth in the past. There are no signs that the role of R&D in industrial development will get any less important in the future (see e.g. Griliches 1995). However, the measurement of the impact of R&D on productivity or on economic growth in general involves numerous difficulties. Quite obviously, it is hard to give unambiguous answers. The factor that makes these questions so difficult to answer is that links between R&D and productivity are so highly complex.

In this study, we have presented one of the first attempts to estimate the contribution of R&D to productivity with firm-level data for Finnish manufacturing, using a production function approach. Cross-sectional estimates (or between-estimates) of R&D elasticity have typically varied in different studies between 0.07 and 0.26; and time-series estimates of R&D elasticity between 0.07–0.16 (see e.g. Griliches 1980; Cuneo & Mairesse 1984; Griliches & Mairesse 1984; Mairesse & Sassenou 1991; Hall & Mairesse 1995; Husso, Leppälahti & Niininen 1996). The results show that the productivity effects of R&D activities have mostly been statistically significant and positive. In spite of the different specifications of models and different ways of constructing variables in different studies, the results have been quite consistent. However, as far as comparability is concerned, it must be noted that the data sets and the representativeness of these data sets may vary quite considerably from one case to the next. Estimates of factor elasticities are very much influenced by how well different types of firms (in terms of R&D activities) are represented in the sample: obviously, we may get somewhat higher estimates of R&D elasticity if the sample includes large numbers of technology-intensive firms. For these and other reasons, we must be very cautious in comparing the results of different studies. In very general terms, however, it may be noted that the results obtained by different researchers for R&D elasticity estimates come quite close to each other.

An important issue in the interpretation of estimates calculated in different ways has to do with the estimates that best describe the effects of R&D activities on productivity. The fact that there are significant disparities between estimates arising from the cross-sectional and time-series dimensions is a common feature of panel data econometrics. In spite of the fact that time-series estimates may themselves be biased and less robust, the common view is to give preference to the time-series (i.e., within-firm) estimates. The reason for this is that these are not affected by the biases caused by the omission of firm effects (see Mairesse & Sassenou 1991: 23).

On the other hand, Hall and Mairesse (1995: 277) argue that both within-firm estimates and between-firm estimates are informative indicators of the relationship between R&D and productivity, even though they describe the phenomenon studied from different angles. Within-estimates provide a more accurate description of what goes on in a firm as it allocates resources to R&D; between-estimates, on the other hand, provide a better picture at the national economy level of the effect of R&D activities or public R&D subsidies on productivity. However, in comparing estimates calculated in different ways, it needs to be stressed that there exists no single correct or superior method for measuring the productivity effects of R&D. Different ways of constructing R&D variables and model specifications all serve to generate additional information that is necessary in studying the complex phenomenon of productivity.

One of the difficulties with the production function is that it constrains reality. Another major problem is that the models often assume that a firm's productivity depends only on its own R&D expenditure, not on technological spillovers or on the amount spent on R&D by others (see Mansfield 1990: 344). Given the shortcomings of the models, the results must always be approached with caution. The difficulties in the measurement of productivity or growth in productivity are closely associated with difficulties in constructing the R&D variable. R&D capital usually consists of a weighted sum of past R&D expenditure, in which the weights reflect both the delayed effects of R&D expenditure on output and the wear off of investments over time. Consequently, one of the major questions has to do with the time lag of R&D to commercialisation. R&D expenditure is not normally reflected very rapidly in value added or sales. Assessments of the time lag between R&D and commercialisation usually range from 1–2 to 5–6 years or even longer, depending on the nature of the research activities. In order to calculate R&D capital stock more accurately, it follows that the estimates on the time lag and service life of technology need to be based on a more careful examination in the future. Also, the misspecification biases (f.ex. selectivity problem, simultaneity of labour and output), as well as issues of the comprehensiveness and reliability of data obtained on R&D activities have proved problematic.

We need to emphasise that firms obtain and use technology from several different sources, and often the various forms of technology complement one another rather than being substitutes for each other (see Vuori 1995: 54). Thus, estimates of R&D elasticity only tell us one side of the "productivity story". We need to bear in mind the multidimensional effects of R&D on productivity in manufacturing firms. The whole story is that, in order to stay in business, firms invest in R&D so that they can generate product and process innovations, but the indirect effects of R&D must also be stressed – R&D helps firms to develop their capacity to adopt, introduce, and gain economic benefit from the knowledge produced elsewhere.

To sum this all up, we would like to lend our support to the following words by Mairesse and Sassenou (1991: 35): *The issue at stake is not so much the question of whether or not a relationship exists between R&D and productivity. Individual case studies and other factual knowledge in the* *field, as well as the fact that firms do indeed undertake research, leave little room for doubt on this score. The question is whether or not econometric studies can characterise such a relationship in a satisfactory and useful manner.* The production function model and the estimates of its parameters allows us to study some of the mechanisms between R&D and productivity. However, in order to gain a deeper understanding of the relationship and interaction between R&D and productivity, a great deal of research in this field of science still remains to be done.

References

Baltagi, B.H. (1992). Specification issues. *In* Mátyás, L. & P. Sevestre (eds.): *The econometrics of panel data: Handbook of theory and applications*, 196–209. Kluwer, Dordrecht.

Baltagi, B.H. (1995). *Econometric analysis of panel data.* 257 pp. John Wiley & Sons, Chichester.

Bartelsman, E., G. van Leeuwen, H. Nieuwenhuijsen & K. Zeelenberg (1995). R&D and productivity growth: Evidence from firm-level data for the Netherlands. Statistics Netherlands, Department of Statistical Methods. Discussion paper (unpublished).

Cohen, W.M. & D.A. Levinthal (1989). Innovation and learning: The two faces of R&D. *The Economic Journal* 99: September, 569–596.

Cuneo, P. & J. Mairesse (1984). Productivity and R&D at the firm level in French manufacturing. *In* Griliches, Z. (ed.): *R&D, patents, and productivity*, 375–392. University of Chicago Press, Chicago.

Griliches, Z. (1980). Returns to research and development expenditures in the private sector. *In* Kendrick, J. & B. Vaccara (eds.): *New developments in productivity measurement and analysis*, 419–461. University of Chicago Press, Chicago.

Griliches, Z. (1979). Issues in assessing the contribution of R&D to productivity growth. *Bell Journal of Economics* 10: 1, 92–116.

Griliches, Z. (1995). R&D and productivity: Econometric results and measurement issues. *In* Stoneman, P. (ed.): *Handbook of the economics of innovation and technological change*, 52–89. Blackwell, Oxford.

Griliches, Z. & J. Mairesse (1984). Productivity and R&D at the firm level. *In* Griliches, Z. (ed.): *R&D, patents, and productivity*, 339–374. The University of Chicago Press, Chicago.

Griliches, Z. & J. Mairesse (1990). R&D and productivity growth: Comparing Japanese and U.S. manufacturing firms. In Hulten, C. (ed.): Productivity growth in Japan and the United States, 317–340. *Studies in Income and Wealth*, volume 53. University of Chicago Press, Chicago.

Hall, B.H. & J. Mairesse (1995). Exploring the relationship between R&D and productivity in French manufacturing firms. *Journal of Econometrics* 65: 263–293.

Husso, K. (1996). Production and foreign trade of high-technology products in Finland. 26 pp. *Statistics Finland, Science and Technology* 1996: 5.

Husso, K., A. Leppälahti & P. Niininen (1996). R&D, innovation and firm performance: Studies on the panel data of Finnish manufacturing firms. 86 pp. *Statistics Finland, Science and Technology* 1996: 3.

Klette, T.J. & F. Johansen (1996). The accumulation of R&D-capital and the dynamic performance of manufacturing firms. Paper presented at The International Conference on Comparative Analysis of Enterprise Data, 17–19 June 1996, Helsinki, Finland. (unpublished).

Lehtoranta, O. (1995). Teollisuuden tuottavuuskehityksen mittaaminen toimialatasolla. 72 pp. *Statistics Finland, Research Reports* 212.

Mairesse, J. (1990). Time-series and cross-national estimates on panel data: Why are they different and why should they be equal? *In* Hartog, J., G. Ridder & J. Theeuwes (eds.): *Panel data and labor market studies*, 81–95. North-Holland, Amsterdam.

Mairesse, J. & M. Sassenou (1991). R&D and productivity: A survey of econometric studies at the firm level. *STI Review* 8, 9–43.

Mansfield, E. (1990). Comment on the article by Griliches and Mairesse (1990). In Hulten, C. (ed.): Productivity growth in Japan and the United States, 341–346. *Studies in Income and Wealth*, volume 53. University of Chicago Press, Chicago.

Rosenberg, N. (1990). Why do firms do basic research (with their own money?). *Research Policy* 19: 2, 165–174.

Science and Technology Policy Council of Finland (1994). *Towards an innovative society: A development strategy for Finland.* 59 ss. Printing Centre, Helsinki.

Statistics Finland (1993). Tutkimus- ja kehittämistoiminta 1991. *Statistics Finland, Science and Technology* 1993: 1.

Virtaharju, M. & M. Åkerlund (1993). Technology intensity of Finnish manufacturing industries. 105 pp. *Statistics Finland, Science and Technology* 1993: 3.

Vuori, S. (1995). Technology sources in Finnish manufacturing. 72 ss. *ETLA B*: 108.

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