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389

TECHNICAL EFFICIENCY IN AN R&D INTENSIVE INDUSTRY: FINNISH ICT MANUFACTURING

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Helsinki 2006

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Acknowledgements: This paper has benefited from extremely helpful comments and guidance from professors Almas Heshmati (Seoul National University), Pekka Ilmakunnas (Helsinki School of Economics) and Timo Kuosmanen (University of Wageningen and MTT Agrifood Research).

ISBN 951–561–617–4 (nid.)
ISBN 951–561–618–2 (PDF)

ISSN 0788–5016 (nid.)
ISSN 1795–3359 (PDF)

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Oy Nord Print Ab

Helsinki, April 2006

BERGHÄLL, ELINA: TECHNICAL EFFICIENCY IN AN R&D INTENSIVE INDUSTRY: FINNISH ICT MANUFACTURING. Helsinki, VATT, Valtion taloudellinen tutkimuskeskus, Government Institute for Economic Research, 2006, (C, ISSN 0788–5016 (nid.), ISSN 1795–3359 (PDF), No 389). ISBN 951–561–617–4 (nid.), 951–561–618–2 (PDF).

Abstract: Technical efficiency levels in Finnish ICT manufacturing are established by applying a stochastic frontier model and retrieving Method of Moments and Battese-Coelli efficiency measures to identify both permanent and time-varying efficiency levels, as well as determinants of inefficiency such as R&D investments. The sample is representative of almost half of corporate R&D in Finland in 1990-2003. Results show wide and surprisingly persistent disparities in technical efficiency, with the average firm enjoying only about half of the frontier firm's technical efficiency level. The rhetoric of Finland featuring on the global technology frontier is based on few firms. Most Finnish firms are constrained to catch-up with the frontier rather than advance it by means of innovation, implying inappropriateness of an innovation focus in policy. The persistence of efficiencies suggests that high risks involved in innovative activity account for only a share of productivity differences. There appear to be considerable permanent gaps between firms related e.g. to managerial and organisational efficiency.

JEL code: O3, O39, L63

Key words: Finnish ICT industry, technical efficiency, technology frontier, technology policy and R&D

Tiivistelmä: Suomalaisten ICT-yritysten teknisen tehokkuuden selvittämiseksi tutkimuksessa sovelletaan stokastista frontier -mallia Method of Moments ja Battese-Coelli -tehokkuusmittareita käyttäen. Näin erotetaan pysyväisluontoiset jäykkyydet ajassa muuttuvista tehokkuuseroista, sekä arvioidaan niihin mahdollisesti vaikuttavia tekijöitä. Otos edustaa lähes puolta suomalaisten yritysten T&K-panostuksista. ICT-teollisuuden menestyksen johdosta Suomi liitetään usein teknologian eturintamamaihin. Tulokset osoittavat kuitenkin laajaa ja yllättävän pysyväisluonteista hajontaa yritysten teknisessä tehokkuudessa. Parhaimmillaankin Suomen sijoittuminen globaalille teknologian eturintamalle riippuu muutamasta yrityksestä, muiden yritysten jäädessä kiinnikurojan asemaan. Keskimääräinen yritys nauttii vain noin puolta eturintaman yrityksen teknisestä tehokkuudesta. Innovointiin keskittyvä teknologiapolitiikka ei siten vaikuta parhaiten soveltuvalta edes tälle sektorille. Tehokkuuden pysyväisyysluonteisuus osoittaa, että innovaatiotoimintaan liittyvät riskit selittävät vain osan yritysten välisistä tehokkuuseroista, jotka voivat sen sijaan johtua esim. organisatorisista tai johtamiseroista.

Asiasanat: ICT-teollisuus, tekninen tehokkuus, teknologian eturintama, teknologiapolitiikka ja T&K

Contents

1. Introduction

As the comparative advantage of OECD countries is increasingly perceived to be based on new knowledge, used as a broader definition for new technology, public policy has responded vigilantly in many countries, the EU Lisbon strategy being a prime example. Waves of deregulation and privatization have been accompanied by policies enabling the creation and commercialization of knowledge focusing on e.g. R&D promotion, venture capital and/ or new-firm start-ups. In its successful pursuit of this path, Finland has been praised on the European scale as a model for small countries to take action to catch-up with the global technological frontier. This is largely thanks to the information and communications technology (ICT) manufacturing sector, which raised Finland from the depths of a severe recession in the early 1990's to enjoy rapid productivity growth for the rest of the decade. The ICT sector being the only large high-tech sector, it has been the main technology frontier engine for the Finnish economy. The sector is considered highly innovative, skill-intensive, and an important contributor to employment shifts from low to high productivity firms, which employ efficiently both labour and capital.

Yet, despite the rhetoric and extensive funds invested and discussion on maintaining Finland on the technological frontier by means of innovation, no study has applied a stochastic frontier model to actually determine firms' positioning relative to the technology frontier in this most crucial sector. This is rather surprising considering the policy emphasis and the importance of the sector for the economy. Past research on technical efficiency in Finland has been limited to studies on universities, energy, farming and forestry, financial sector, social insurance offices, health care centres, etc. Productivity analyses have for the most part relied on growth accounting offering little information on its determinants, while being hampered by strong assumptions on competitive conditions, production efficiency and returns to scale.

The purpose of this paper is to remove this deficiency and explore the reality behind the common perceptions. For the sake of brevity, only technical efficiency results are reported in this paper[1]. The second section below discusses and presents the stochastic methodology employed. Section 3 describes the dataset and its transformations, with further details found in the Appendix. Results are presented in section 4 and their implications briefly discussed in the concluding section 5. In addition, the Appendix includes a brief overview of the Finnish ICT sector.

[1] For associated productivity and technical change developments, see Berghäll (2006).

2. The Stochastic Frontier Model

2.1 Issues in Measuring Efficiency

The efficiency in which factor inputs are used influences productivity growth as one factor among technical change, scale elasticities, demand effects and random/ unknown factors. Total economic efficiency is composed of technical and allocative efficiency. Technical efficiency refers to a firm's ability to obtain maximum output from a given set of inputs (given their optimal ratios), while allocative efficiency refers to a firm's ability to combine inputs in optimal proportions given their respective prices. Allocative efficiency has also been defined as the mix of outputs that maximise revenue, i.e., a concept related to scope. Meanwhile, scope efficiency has been used in the context of geographical reach and coverage of operations. Scale efficiency occurs when firms operate in the range of constant returns to scale. The firms with best practice technology form the technology frontier, which is stochastic. To these North (1990, pp. 80–81) adds the concept of adaptive efficiency of the economy, defined as the ability of economies and institutions to be responsive to new situations. Managerial, entrepreneurial and work efforts in non-profit or revenue maximising monopolies were the focus of the debate on X-Efficiency, first proposed by Liebenstein (1966) which, in addition to its focus, differs from technical efficiency in its objective function, i.e., technical efficiency assumes profit maximising or cost minimising behaviour.[2] This paper is restricted to the analysis of technical efficiency as formalised in economic theory.

Shifts in the production possibilities frontier may reflect realised dynamic efficiency gains resulting from innovation, and returns to scale. In Antonelli's (2000) categorisation, technical change represents switching costs from one technology to another, while technological change represents shifts in the frontier, i.e., technological progress or regress. In principle, only technical change within firms that are located on the technological frontier actually represents technological progress. In this paper, shifts in technical efficiency refer to changes relative to other firms in the sample, and therefore are not automatically associated with technical change. Since technological regress is unlikely, as it would not appear rational for firms to shift to less productive technology, a rise in average efficiency should represent technical change and catch-up in lagging firms. A decline in average efficiency suggests that frontier firms have increased their lead. Yet, it is possible that a firm experiences e.g.,

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[2] E.g. Stigler (1976) critized it as a rather useless concept, perceiving X-inefficiency to merely reflect differences in utility functions for leisure or other benefits, and "in neoclassical economics, the producer is always at a production frontier, but his frontier may be above or below that of other producers." In consequence, only allocative efficiencies should exist as deduced e.g. by Frantz (1992).

learning costs showing up as decline in efficiency, but this impact should be short-lived.

2.2 The Production Function

Technical efficiency is measured as improvements made in the productivity of the production process for a given level of input expenditure. That is, an output oriented measure of technical inefficiency suitable for free markets with no restrictions on output, as is the case in the Finnish ICT equipment manufacturing industry, is applied. The specification of the stochastic frontier production function is common to the literature, (see e.g., Heshmati, Kumbhakar and Hjalmarsson, 1995):

(1) $$Y_{it} = f(K_{it}, L_{it}, R_{it}; \theta)\exp(\varepsilon_{it}),$$

where Y_{it} is the output of the i-th firm observed in period t, $f(.)$ represents the production technology, K is physical capital, L is non-R&D labour, R is R&D capital input and θ is a vector of parameters to be estimated.

Another disadvantage of the stochastic frontier approach is the need to specify a functional form for the production function.[3] A flexible translog functional form is assumed to approximate the production technology of Finnish firms, allowing for variable returns to scale. The robustness of the results is tested against a Cobb-Douglas formulation. The frontier production model can be rewritten as

(2) $$\begin{aligned}\ln Y_{it} &= \beta_0 + \sum_j \beta_j \ln X_{jit} + \tfrac{1}{2}\sum_j \beta_{jj}(\ln X_{jit})^2 + \sum_{j\neq h}\sum_h \beta_{jh} \ln X_{jit} \ln X_{hit} \\ &+ \beta_t t_i + \tfrac{1}{2}\beta_{tt} t^2 + \sum_j \beta_{jt} \ln X_{jit} t + \sum_i \mu_i D_i + \tau_{it} + v_{it},\end{aligned}$$

where the β's denote parameter estimates of the production function, i the company, j and h denote inputs (i.e., logarithms of physical capital *(k)*, non-R&D labour *(l)* and R&D capital *(r)*, and t the year.

The frontier production function is estimated with COLS and maximum likelihood. Technical inefficiency is estimated using method of moments and Battese-Coelli efficiency. In the COLS case, the parameter estimated residuals are calculated and decomposed into inefficiency and random error components. Meanwhile in the maximum likelihood method case, both estimation of the parameters and variance decomposition are carried out in a single step.

[3] Coelli, Rao and Battese (1999).

2.3 Assumptions regarding the error terms and advantages of different methods

The period of observation is firm-specific due to the unbalanced panel data set. The error term, ε_{it} , does not include any pure time-specific component since time is introduced as one of the explanatory variables in the production function. It is composed of three components

(3) $$\varepsilon_{it} = \mu_i + \tau_{it} + \nu_{it},$$

with the following assumptions:

a) μ_i are fixed or the unobservable firm-specific effects. These are absent in the Battese-Coelli model;

b) τ_{it} is i.i.d. and $N(0,\sigma^2_\tau)$ when truncated from above ($\tau_{it} \leq 0$,). It represents technical inefficiency, ($-u_{it}$ in the Battese-Coelli model). τ_{it} indicates the firm's shortfall from the most efficient firm(s) in the sample and over which the firm has some measure of control;

c) ν_{it} is i.i.d. and $N(0,\sigma^2_\nu)$ measuring uncontrollable statistical noise, which arise from measurement errors in the dependent variable, exogenous shocks, etc.; and

d) τ_{it} and ν_{it} are independent among themselves.

Of these (b)-(d) are standard stochastic frontier assumptions for cross section and panel data, while (a) and (c) are standard in regular panel data models. The assumption of independent and identically distributed (i.i.d.) technical efficiency in assumption (b) is strong and critical, as there are no foundations for assuming firms to be independent of technical efficiency over time. This is the main problem associated with this type of stochastic frontier model, i.e., their sensitivity to distributional assumptions made on the technical inefficiency error term. Consequently, symmetrically distributed inefficiency components may show up as random error components, while asymmetrically distributed random errors may be measured as inefficiency. These problems are present in the other approach used, i.e., the Method of Moments to calculate technical efficiency.

Heterogeneity in productivity among firms with comparable products and equipment undermines the appropriateness of an aggregate production function based on a representative firm relative to frontier models. By introducing individual firm-specific fixed effects, μ_i, as parameters to be estimated, correlation between individual effects μ_i and the explanatory variables X is allowed for. Firm dummies control for heterogeneity allowing the capturing of time-invariant technical efficiency leaving only time-variant to the error term, τ_{it}. That is, μ_i may arise from unobserved systematic effects which vary across firms, but are constant over time for the firm in question. For example, part of long-term capital may be fixed or technical inefficiency may be persistent due to some firm-specific characteristics such as management or location. Thus firm dummies mitigate also the risk of categorising symmetrically distributed inefficiency components as random error components and *vice versa*.

The other approach, the Battese-Coelli Maximum Likelihood (ML) model finds an appropriate cut off/ truncation point for the normal distribution, allowing the distribution of the inefficiency term to differ from a half normal, which at least partly overcomes the main limitation of the stochastic frontier model. As shown by Ritter and Simar (1997), some of the sensitivity of the shape of the error term distribution remains, translating into a wide variety of frontier and individual inefficiencies. This shortcoming can be mitigated by increasing sample size, and by focusing more on average results as indications of directions.

Growth accounting by index methods, such as Divisia, Malmqvist, Solow and Kendrick indexes, typically require price data and assume constant returns to scale confusing technical efficiency with scale efficiencies. While mathematical programming by data envelopment analysis (DEA) can quantify the degree of returns to scale, technical change and efficiency, stochastic frontiers offer the benefit of accounting for noise and applicability to conventional testing of hypotheses. The stochastic component of the frontier production function reflects measurement error and other random factors such as weather, strikes, luck, etc. on the value of the output variable.[4] That is, in situations where there is considerable random variation from e.g. exogenous shocks, the deterministic approach gives a biased picture of actual productivity growth and technical change.

Consequently, in light of the available data and questions to be explored, the Battese-Coelli model appears most appropriate for defining technical efficiency levels, while the translog production function provides the best fit, and the method of moments can be applied to disaggregate technical efficiency into permanent and time-varying components. Furthermore, according to Coelli, Rao and Battese (1999), the ML method should be preferred over OLS since the former is asymptotically more efficient, particularly when the contribution of technical efficiency effects to the total variance term is large. Altogether four models are estimated with

1) Simple OLS with no dummies and technical efficiency estimated with the method of moments (D0 henceforth);

[4] Coelli, Prasada Rao & Battese (1999).

2) OLS with firm characteristic dummies, i.e., foreign/domestic ownership (type), size (number of employees in six groups), export status (exports or not), age (4 categories), and leverage and technical efficiency estimated with the method of moments (D1 henceforth);

3) OLS with firm dummies and technical efficiency estimated with the method of moments (D2 henceforth);

4) Maximum Likelihood with firm characteristic dummies and technical efficiency estimated with the Battese-Coelli method (ML henceforth)[5] with similar determinants of efficiency as in the D1 model.

2.4 The Method of Moments

Despite the strong assumptions regarding the error terms, the Method of Moments is useful for obtaining estimates of differences in time-varying and time-invariant inefficiency, since it does not suffer from the data capacity constraints of the program used to estimate Maximum Likelihood and their results tend to be sufficiently similar.

Following Heshmati, Kumbhakar and Hjalmarsson (1995), estimates of the variance components σ^2_τ and σ^2_ν are obtained first, by applying Corrected Ordinary Least Squares (COLS) in two steps. First, the production frontier parameters are estimated using OLS, and second, the second and third moments of the residuals are used to estimate the random error and inefficiency variance components, using assumptions (a) – (c). That is,

(4) $$m_2 = E(e_{it})^2 = \sigma_\nu^2 + \frac{\pi - 2}{\pi}\sigma_\tau^2,$$

and

(5) $$m_3 = E(e_{it})^3 = -\sqrt{\frac{2}{\pi}}\left(\frac{4-\pi}{\pi}\right)\sigma_\tau^3,$$

where the e_{it}'s are the OLS residuals including the intercept β_0 . These equations can be solved for σ^2_τ and σ^2_ν. Assuming that inputs are uncorrelated with ν and τ, the OLS estimators will be consistent, with the exception of the intercept, β_0. These estimators do not depend on any distributional assumptions with regard to the error components (other than zero mean and constant variance). In contrast to

[5] The Frontier4.1 program was used to estimate the ML model. It is readily available at the Centre for Efficiency and Productivity Analysis (CEPA) web-site:
http://www.uq.edu.au/economics/cepa/software.htm.

the BC model, in the Method of Moments the bias in the intercept needs to be adjusted to gain the appropriate reference point. The unbiased and consistent estimator of $\tilde{\beta}_0$ can be obtained from the following corrections:

(6) $$\tilde{\beta}_0 = \hat{\beta}_0 - E(\tau), \text{ by substituting } E(\tau) = \sqrt{\frac{2}{\pi}}\hat{\sigma}_\tau$$

Once consistent estimators of all parameters have been obtained, the adjusted OLS-residuals can be calculated as

(7) $$\tilde{e}_{it} = \hat{e}_{it} + \sqrt{\frac{2}{\pi}}\hat{\sigma}_\tau,$$

where $\hat{e}_{it}$ are the OLS residuals. The adjusted OLS residuals and the estimated variances are used to calculate technical inefficiency specific to each firm over time. The distribution of τ_{it} is conditional on $(\tau_{it} + \nu_{it})$ being a truncated normal. Thus, one can use the modal value of τ_i, as a point estimator of technical efficiency. The estimator is given by

(8) $$\hat{\tau}_{it} = \frac{\hat{\sigma}_\tau^2}{\hat{\sigma}_\nu^2 + \hat{\sigma}_\tau^2}\tilde{e}_{it},$$

The estimator of technical efficiency for each firm is then derived from

(9) $$Teff_{it} = \exp(\hat{\tau}_{it}),$$

which lies in the interval of 0 and 1, with the most efficient firm(s) found at the technical efficiency frontier with *Teff* value equal to 1.

2.5 The Maximum Likelihood Efficiency Effects Model

The assumptions regarding the error terms allow the estimation of the Battese and Coelli (1995) Maximum Likelihood model (BC hereafter) in a single step. The frequently used model is suitable for output oriented measures with unbalanced panel data. It compares firms to the fully efficient reference point.

(10) $$\ln Y_{it} = \beta_0 + \sum_j \beta_j \ln X_{jit} + ½\sum_j \beta_{jj}(\ln X_{jit})^2 + \sum_{j\neq h}\sum_h \beta_{jh} \ln X_{jit} \ln X_{hit} + \varepsilon_{it_i}$$

(11) $$\varepsilon_{it} = v_{it} - u_{it}$$

where the random error term, v_{it} is i.i.d. $N(0,\sigma^2_v)$. Unlike in the method of moments, the inefficiency term, u_{it} is i.i.d. $N(Z_{it}\delta, \sigma^2_u)$, i.e., obtained from a truncation of the normal distribution at zero, but with mean $Z_{it}\delta$ and variance σ^2_u. This specification allows for a much wider range of distributions of the inefficiency term defined by the data. Z_{it} is a vector of firm-specific variables which may influence firms' efficiency. In the BC model, efficiency is specified as

$$(12) \qquad u_{it} = Z_{it}\delta + w_{it},$$

where w_{it} is defined by truncation of the normal distribution $w_{it} \sim N(0,\sigma^2_w)$ with left truncation at $-Z_{it}\delta$ for each i and t. These determinants of efficiency introduced into the Battese-Coelli (BC) model, include a firm-specific Lerner index to measure the intensity of competition, the firm leverage ratio, and four dummy variables, i.e., ownership status in terms of domestic or foreign, exporter status, size and age. Maximum likelihood (ML) is proposed to estimate β and δ simultaneously. Technical efficiency is given by

$$(13) \qquad Bceff_{it} = \exp(-\hat{u}_{it}) = \exp(-Z_{it}\delta - w_{it}).$$

According to Battese and Coelli (1988), the best predictor of $exp(-u_i)$ is obtained from

$$(14) \qquad E[\exp(-u_i) \mid e_i] = \frac{1-\Phi(\sigma_A + \gamma e_i/\sigma_A)}{1-\Phi(\gamma e_i/\sigma_A)}\exp(\gamma e_i + \sigma_A^2/2),$$

where $\sigma_A = \sqrt{\gamma(1-\gamma)(\sigma_u^2+\sigma_v^2)}$, and $\gamma = \frac{\sigma_u^2}{\sigma_u^2+\sigma_v^2}$, and $\Phi(.)$ is the density function of the standard normal random variable, and $e_i = \ln(y_i) - x_i\beta$.[6] The time-dependence of technical efficiency and the assumption of truncated normality of u_i can be tested. If, for instance, $\delta = 0$, there are no efficiency effects. Other tests of time-invariance and truncated normality can also be carried out.

[6] The Frontier 4.1 program provides these estimates by replacing the unknown parameters with their ML estimates (Coelli, Rao & Battese, 1999, p.190).

3. The Data and Variables

The unbalanced panel was constructed of private manufacturing firms engaged in ICT equipment manufacturing during 1990–2003 from the Longitudinal Database on Plants in Finnish Manufacturing (LDPM/ Teollisuustilasto) 1974–2002, Financial Statements Statistics (Tilinpäätöspaneeli) 1986–2003, and the R&D Surveys 1985–2003 from Statistics Finland. Only firms with at least 20 employees were included due to data shortages on smaller firms.

Real value-added measures output (*Y*), the dependent variable, while input factors are non-R&D labour, the physical capital stock and the R&D stock. Labour input is proxied by total firm personnel due to data shortages on hours worked. As R&D was included as an input, R&D employees were deducted from the total number of labour input to avoid double-counting. To the extent that R&D expenditure represents wages of educated R&D employees, the R&D capital measure, also incorporates human capital into the model. The LDPM database provided proxies for physical capital, built from machine and equipment assets using the perpetual inventory method with a ten percent depreciation rate, i.e., $K_t = (1-\delta)K_{t-1} + I_t$, where δ is the depreciation rate. Similarly, R&D capital stocks were built from total internal R&D investments[7], available in the R&D panel. The initial R&D stock was based on data from 1985–1989 when available. Otherwise only reported R&D data could be used to construct the R&D stock. Several annual depreciation rates were experimented on and the 30 % depreciation rate was found most appropriate, and hence was also used to construct initial R&D stocks. R&D, capital, labour and value-added data was available for altogether 164 firms.

Table 1. Summary Statistics for Variables in the Stochastic Production Function.

	N	Mean	Std. Deviation	Minimum	Maximum
Value added (€)	988	39029555	284298161	91 531	6 474 956 360
Turnover (€)	944	147864331	1051549520	768 851	25 578 904 364
Capital (€)	988	12386491	39379952	218	541 878 095
No of personnel minus R&D personnel	988	305	931	1	13 516
Total personnel	988	353	1060	20	13 516
R&D Capital Stock (€)	988	8962878	42069068	826	695 930 103
Lerner index	929	0.06	0.19	-3.66	0.57
Debt ratio (%)	929	113	453	-2 863	8 854

The panel firms can be assumed to be subject to similar (minimal) regulation, demonstrate similar behaviour, i.e., profit or revenue maximising, allowing us to apply an output distance function, i.e., output oriented efficiency measure (as opposed to cost minimisers in regulated industries), and third, fit into the same

[7] External R&D was varyingly available and does not build up the R&D capital of the company.

functional form of the production function, i.e. technology, for their relative efficiencies to be comparable. As an unbalanced panel was applied, entry and exit do not introduce a considerable bias on the results. Further details are presented in the Data Issues Appendix.

The additional determinants of efficiency introduced into the Battese-Coelli (BC) model include the firm-specific Lerner index, the firm leverage ratio, and four dummy variables, i.e., ownership status in terms of domestic or foreign, exporter status, size and age. Profitability or the firm-specific Lerner index was specified as operating profit divided by the value of gross output (turnover). This provides a better measure of the intensity of competition than market share as international trade is high in the sector. Operating profit was derived from firm value added minus factor input costs, i.e., personnel expenses including payroll taxes and social security payments incurred by the firm, as well as capital costs as indicated by financing expenses[8] in firm profit and loss statements. Shortages in the LDPM database rendered data on exports unreliable and therefore only exporter status was extracted for 1995–2002. Similarly it proved impossible to establish an exact age for each firm, and therefore firms were merely grouped into 4 age categories.

Foreign owned firms have been found to show higher productivity, but domestic multinationals are even more productive, proving firm- and/or ownership-specific advantages of importance. Deregulation of an industry to open competition has also been found to reduce slack. In sum, reduced profit margins, higher indebtedness, foreign ownership and exports are expected to affect the efficiency of firms positively. The Schumpeterian hypothesis (1950) assumes larger firms to be more able to be innovative and improve their productivity, confirmed by Link (1981) and Cohen and Klepper (1996). Thus firm size is expected to affect efficiency positively[9].

Table 2a. Frequency Distribution of Firms by Debt Ratio, Age and Number of Personnel.

Debt ratio	**Freq. (%)**	**Age in years**	**Freq. (%)**	**Size by number of personnel**	**Freq. (%)**
< 50 %	594 (60%)	years<=2	244 (25%)	20<=labour<50	347 (35%)
50-100%	151 (15%)	2<years<=4	144 (15%)	50<=labour<100	167 (17%)
>100%	243 (25%)	4<years<=7	135 (14%)	100<=labour<250	195 (20%)
		7<years	465 (47%)	250<=labour<500	119 (12%)
				labour=>500	160 (16%)
	988		988		988

[8] These financing expenses are the sum of interest and other financial expenses, (such as those from foreign currency exchange), multiplied by one hundred and divided by long-term debt.

[9] Several contrasting findings of small firm innovativeness exist.

Table 2b. Frequency Distribution of Firms by Urbanisation, Localisation, Export and Ownership.

Urbanisation	**Freq. (%)**	**Localisation**	**Freq. (%)**	**Exports**	**Freq. (%)**	**Ownership**	**Freq. (%)**
1, smallest	73 (7%)	1, smallest	84 (8%)	No	130 (13%)	Domestic	857 (87%)
2, medium	203 (21%)	2, medium	105 (11%)	Yes	858 (87%)	Foreign	131 (13%)
3, largest	712 (72%)	3, largest	799 (81%)				
Total	988		988		988		988

4. Results

The appropriateness of the approach and the functional form of the production function was tested for scale effects. The Cobb-Douglas model is clearly rejected by test results. Several R&D depreciation rates (δ) were applied to determine the robustness of the results, and found to make little difference to the explanatory power of various models. Individual effects models enjoy a 92 % R-square, while the pooled model explains about 85 % of the variation and firm characteristic dummy model 86 %. Since a 30 % depreciation rate is in line with rapid technological development (confirmed by the results) and a prior finding for electrical products (Bernstein & Mamuneas, 2006)[10], results are reported primarily for this R&D depreciation rate.

Maximum likelihood estimation supported the stochastic frontier formulation (γ in Table 4 and 7), as a large share of the variation in the error term is caused by variation in efficiency. For a smaller R&D depreciation rate (δ =10 %) the share of average inefficiency is even higher. Thus the traditional average response function underestimates the actual frontier of the Finnish ICT manufacturing industry because of technical inefficiency effects. The other half of the variation is noise, and hence a deterministic frontier model would give significantly different results.

Table 3. Test Results, Pr>F.*

δ =30 %	**CD-Model test 1****	**CD-Model test 2*****	**δ =10 %**	**CD-Model test 1****	**CD-Model test 2*****
No dummies	<0.0001	<0.0001		<0.0001	<0.0001
Firm characteristic dummies	<0.0001	<0.0001		<0.0001	<0.0001
Firm-dummies	<0.0001	<0.0001		<0.0001	<0.0001
Verdict*	H_0 rejected at 1 % level	H_0 rejected at 1 % level		H_0 rejected at 1 % level	H_0 rejected at 1 % level

*If probability smaller than 0.05, H_0 is rejected at the 5 % level, if smaller than 0.01, H_0 is rejected at the 1 % level.
** Cobb-Douglas Test 1: The coefficients of the logarithms of the inputs (i.e., k= ln K etc.) l^2, k^2, r^2, t^2, kl, kr, lr all equal zero.
*** Cobb-Douglas Test 2: The coefficients of the logarithms of the inputs l^2, k^2, t^2, kl, all equal zero.

[10] The depreciation of the R&D stock (δ) is often fixed arbitrarily at 10 % or 15 %. These orders of magnitude are consistent with the estimates obtained by Bosworth (1978) on the basis of patent renewal data. Pakes and Schankerman (1984) estimate an average rate of 25 % also from patent renewal data, and recently Bernstein and Mamuneas (2006) estimate industry-specific rates that range from 18 % for chemicals to 29 % for electrical products.

Table 4. Model Fit and Test Results, and Mean Battese-Coelli (BC)Efficiency.

R-squares	**δ =30 %**	***δ =10 %***
No dummies	0.8505	*0.8495*
Firm characteristic dummies	0.8566	*0.8558*
Firm-dummies	0.9237	*0.9240*
Likelihood Ratio Test Results with one-sided error from Maximum Likelihood Estimation**	308.2*	*318.2**
Gamma (γ) from Maximum Likelihood Estimation**	0.364*	*0.46**
Mean Battese-Coelli (BC) Efficiency	0.561	*0.597*

δ= R&D Depreciation Rate.
*significant at the 1 % level.
**The gamma result of γ=0.46 shows that a large share of the observed variation in the error term is caused by variation in efficiency. The LR test results exceed the 5 % critical value of 2.71. Hence the traditional average response function nor a deterministic efficiency model would provide an adequate representation of the data. The null hypothesis is that there are no technical efficiency effects, i.e., H_0 : $\gamma=0=\delta_0=\delta_1=\delta_2=\ldots=\delta_n$ and H_1 : $\gamma>0$.

The Battese-Coelli formulation of technical efficiency (Bceff) gave 56 % average efficiency of the frontier firm's 100 % efficiency for δ=30 %, and about 60 % for δ=10 %. The method of moments average (Teff) varied from 43 % (D2) to 81 % (D0). This about 40 % lower average from the fixed effects model (D2) relative to the pooled model (D0) suggests persistent differences in firm-specific technical inefficiencies, confirmed by large and significant coefficients for many firm dummies. Thus technical efficiency has varied greatly by firm, but time-varying efficiency averages at little over 40 % of the most efficient firm's reference rate, while total average efficiency reached 56 %. There are large firm-specific efficiencies rather than inefficiencies. Many firms enjoy constant advantages relative to their competitors. All firms suffer from large time-varying inefficiencies.

Table 5. Average Battese-Coelli Technical Efficiency and its Average Growth.

δ=30 %	D0, mean	D1, mean	D2, mean	ML mean	***δ=10 %***	*D0, mean*	*D1, mean*	*D2, mean*	*ML mean*
Growth of Technical Efficiency	0.00	0.00	0.00	0.00		*0.00*	*0.00*	*0.00*	*0.00*
Technical Efficiency	0.81	0.54	0.43	0.56		*0.58*	*0.48*	*0.42*	*0.60*

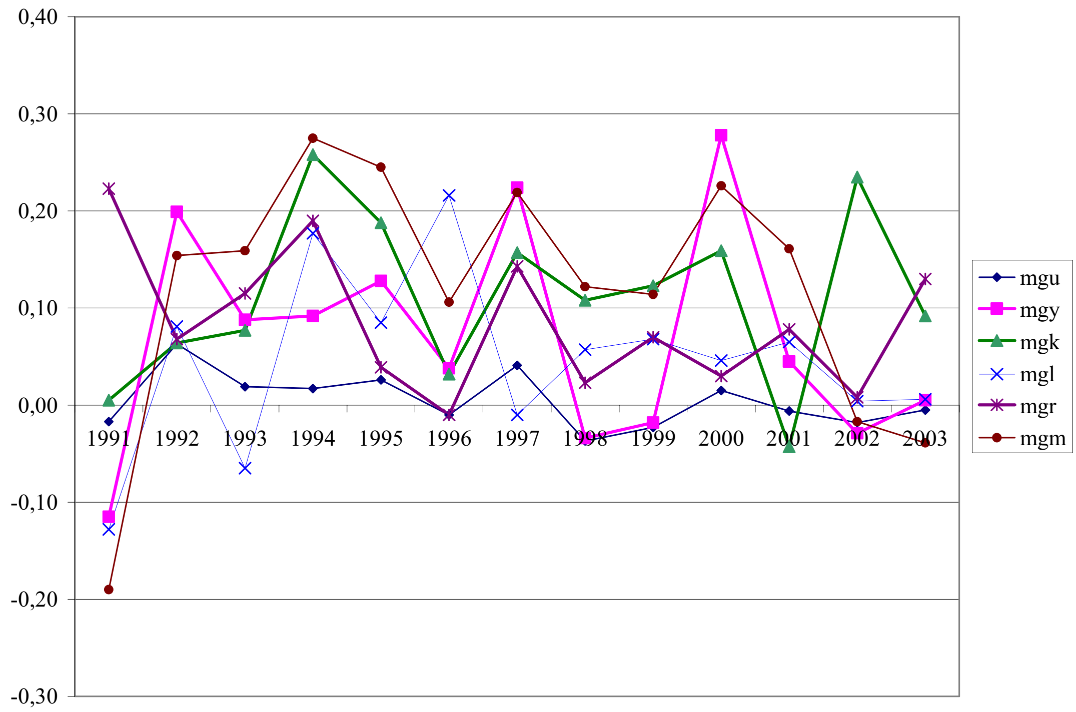

Figure 1. *Annual Average Growth Rates of Factor Inputs, with Output and Efficiency obtained from the Maximum Likelihood (ML) Model.*

Abbreviation	Explanation	Average growth rate in percent
mgu	Mean technical efficiency change	0 %
mgy	Mean value-added change	7 %
mgk	Mean physical capital change	11 %
mgl	Mean non-R&D labour change	5 %
mgr	Mean R&D stock change with 30 % R&D deprecation rate	8 %

The volatility of the industry is clearly apparent from Figure 1 above. The high time-varying inefficiency is likely related to the characteristic volatility of the industry and the risks involved in R&D investments. But the large differences in permanent efficiencies suggest that this is only part of the story, and that e.g., managerial practices may need to be revised and organisational changes executed in lagging firms. The slight decline detected in the time trend of technical efficiency is negligible enough for one to conclude only that average technical efficiency does not appear to have improved over the period.

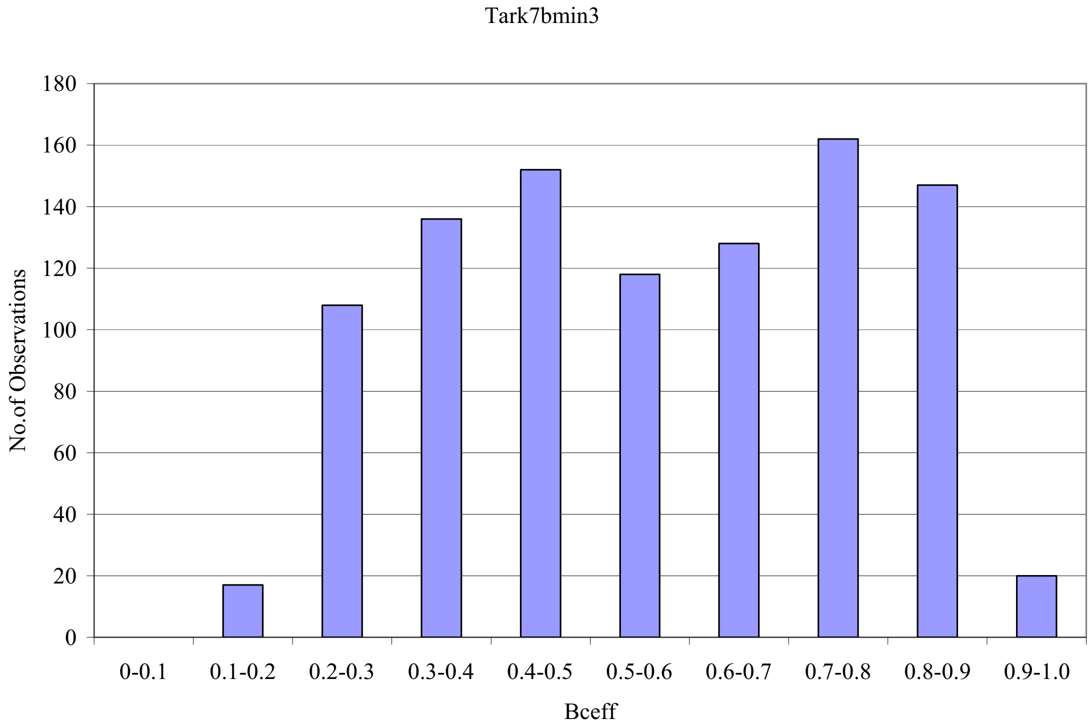

Figure 2. Distribution of Observations by Battese-Coelli Efficiency.

If the most efficient 10 % of firms in the sample are taken to form the frontier[11], frontier firms show 3 % technical efficiency change, relative to the 0 % average of the total sample. Thus average technological catch-up has been zero and the efficiency distribution of firms is as scattered as it was at the beginning of the period. On the other hand, catch-up among frontier firms has averaged 3 %, meaning that the frontier firms are more closely clustered around the frontier and the less efficient frontier firms have improved on their technologies relatively more than the fully efficient firms. Annual variation is broad also for frontier firms. Technical efficiency improved, i.e., differences among firms narrowed until 1994 and widened again thereafter. These shifts may have to do with the recession and recovery, which imposed considerable changes in factor costs, availability, demand, etc. Employment declined and structural change made physical capital obsolete, while R&D had only begun to grow. The extent of the variation in technical efficiency between firms shows that the exclusion of outliers would do little to improve average results, but would instead introduce a bias.

If the global technological frontier is benchmarked as by Sabirianova, Svejnar and Terrell (2004) as the average efficiency of the top third of foreign firms in a

[11] A wide margin of 0.84–1.00 was used to define the frontier to capture movements within the frontier and ensure that results are at least indicative of trends.

given two-digit industry, many Finnish firms form their respective global frontier. However, according to Bartelsman and Doms (2000), empirical results show foreign owned firms to typically enjoy higher productivity, but domestic multinationals to be even more productive. The global frontier cannot be determined by Finnish data. In the total sample, foreign firms showed on average slightly higher efficiency (0.565 vs. 0.561), but among the 10 % frontier, foreign firms were slightly less efficient (0.86) than domestic frontier firms (0.87).[12] Thus foreign firms' efficiency distribution is narrower than that of indigenous firms, but at least average differences are negligible.

[12] These results will be discussed in more detail in another paper by the author.

5. Discussion

Over the past decade and more, innovation has advanced the global technological frontier in ICT manufacturing rather rapidly. Its Finnish counterpart is no exception. Yet, the results of this study show wide disparities in how firms have caught up with even the domestic technology frontier. It would appear a gross oversimplification to assume that all high productivity growth firms are necessarily efficient, employ factor inputs efficiently, or are even close to the technology frontier.

Inefficiencies may arise from organisational factors (e.g. strong trade-unions), structural heterogeneity (e.g. product differentiation), dynamic disturbances (e.g. some units absorb innovation created technology shocks incompletely) and regulation. In Finland liberalisation, deregulation, taxation, wage policy, technological diffusion, the abolishment of investment incentives, etc. should have contributed to competitive conditions and efficiency. In addition, Finnish policy-makers are generally credited for a combination of sound macroconomic policies[13] and well-functioning institutions. The market structure with a dominant firm, Nokia, is likely to have had an impact. In particular, Nokia appears to apply its market power on supplier firms "sucking them dry". This factor should, however, raise competition among suppliers and pressure them to improve technical efficiency.

The large disparities in technical efficiency are in line with previous reports of great heterogeneity in technology usage in manufacturing establishments even after controlling e.g., for industry, size, region, and age[14]. It is possible for firms to overinvest or use inputs excessively, i.e., negative externalities from congestion may overcome the inputs' productive effects. Excessive labour may bring about negative congestion externalities. High levels of R&D may complicate information flows reducing managerial efficiency. High levels of capital may introduce sunk costs and debt levels, which restrain managers from updating production processes to latest technologies. Inefficiencies appear, indeed, to be very much related to firm-specific factors, such as R&D subsidies, location, managerial ability, technology and human capital. The causes of inefficiency are left for further research.

For the international competitiveness of the remaining firms, policy-wise lagging average technical efficiency implies the need to focus on improving the use of known technologies, e.g., by learning-by-doing processes or managerial practices. Technology policy should not focus solely on innovation and ignore the need to upgrade outdated technologies. Prejudices against the concept of

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[13] That is, after the outbreak of the depression in 1991.

[14] Dunne (1994).

technical efficiency may arise from its association with cost reducing and process optimisation activities, which in turn are the main competitive means for industries dominated by large companies, mature technologies and low R&D intensities, being more related to static gains. In contrast, innovation and technological diffusion are related to dynamic efficiency from ongoing productivity gains by means of technical change. As the technological opportunity narrows and radical innovations cease, however, incremental innovation gains ground and competition intensifies in terms of technical efficiency. Thus, one should expect disparities in technical efficiency levels to narrow over time as technologies mature and the nature of competition shifts from product innovation to process efficiency. There appears to be significant untapped productivity growth potential even if this happens and the world-wide technological progress in the sector slows down.

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Appendix

Table 6. Translog Production Function OLS Estimates for 30 % R&D Depreciation Rate (δ=30 %) for models D0 (no dummies), D1 (firm characteristic dummies), D2 (firm dummies).

	D0 Param. Est.	Std Error	**D1 Param. Est.**	Std Error	**D2 Param. Est.**	Std Error
β0	10.991***	1.457	10.708***	1.492	15.358***	2.181
βκ	-0.107	0.170	-0.007	0.173	-0.342	0.236
βl	0.511	0.236	0.149	0.287	0.162	0.348
βr	0.079	0.121	0.138	0.121	-0.148	0.204
βt	-0.002	0.062	0.051	0.063	-0.040	0.074
βkk	0.044***	0.014	0.034**	0.014	0.038**	0.018
βll	0.253***	0.035	0.237***	0.036	0.148***	0.039
βtt	0.002	0.003	0.001	0.003	0.000	0.003
βrr	0.039***	0.008	0.035***	0.008	0.053***	0.012
βkl	-0.050***	0.019	-0.034*	0.020	0.012	0.024
βkt	0.002	0.005	0.000	0.005	0.007	0.006
βtl	0.025***	0.008	0.027***	0.008	0.015*	0.008
βkr	-0.017*	0.009	-0.019**	0.009	-0.017	0.017
βlr	-0.031**	0.012	-0.022*	0.013	-0.047**	0.019
βtr	-0.011***	0.003	-0.012***	0.003	-0.007*	0.004
Foreign ownership			-0.114*	0.064		
Size 2			0.112	0.082		
Size 3			0.280**	0.120		
Size 4			0.290*	0.157		
Size 5			0.334*	0.197		
Age 2			0.061*	0.067		
Age 3			0.012*	0.069		
Age 4			0.071*	0.052		
Debt 2			-0.079*	0.058		
Debt 3			-0.207**	0.049		
Exporter			-0.104*	0.062		
Localisation 2			0.193*	0.097		
Localisation 3			-0.012*	0.100		
Urbanisation 2			-0.061*	0.103		
Urbanisation 3			0.097	0.115		

*** t-value significant at the 1 % level; ** at the 5 % level; * at the 10 % level.

Table 7. Maximum Likelihood Estimates for δ=30 % R&D Depreciation Rates.

	Model (Tark7)	Parameter Estimate	Standard Error
β0		13.22***	1.32
βκ		- 0.09	0.14
βl		- 0.07	0.24
βr		0.13	0.10
βt		- 0.08	0.05
βkk		0.04***	0.01
βll		0.21***	0.03
βtt		0.01***	0.00
βrr		0.04***	0.01
βkl		- 0.02	0.02
βkt		- 0.00	0.00
βtl		0.04***	0.01
βkr		- 0.02***	0.01
βlr		- 0.02	0.01
βtr		- 0.01***	0.00
δ0	Intercept for efficiency	1.34***	0.21
δ1	Log Lerner index (profits/turnover)	- 0.29***	0.03
δ2	Log debt ratio	0.02	0.01
δ3	Log material intensity	0.15	0.14
δ4	Type 2 (Foreign owned)	0.10	0.10
δ5	Exp2 (Exporter)	0.14	0.09
δ6	Size 2	- 0.17	0.10
δ7	Size 3	- 0.54***	0.12
δ8	Size 4	- 0.55***	0.17
δ9	Size 5	- 0.98***	0.21
δ10	Age 2	- 0.07	0.10
δ11	Age 3	- 0.06	0.11
δ12	Age 4	- 0.12	0.09
δ13	Localisation 2	- 0.26	0.13
δ14	Localisation 3	0.07	0.13
δ15	Urbanisation 2	0.15	0.16
δ16	Urbanisation 3	- 0.14	0.18
σ^2	**Sigma-squared**	0.32***	0.02
γ	**Gamma**	0.36***	0.07
	Mean BC-Efficiency	0.561	

*** t-value significant at the 1 % level; ** at the 5 % level; * at the 10 % level.

Note: The positive delta e.g., for debt ratio indicates that the more indebted firms in the sample tend to be less efficient. A negative delta for a dummy variable like size and age imply an opposite relationship with inefficiency. A negative delta for the Lerner Index indicates that the higher the firm's profitability, the lower its inefficiency.

Table 8a. Average Technical Efficiencies with δ =30 %.

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
Teff D2	0.47	0.42	0.45	0.45	0.41	0.43	0.41	0.44	0.43	0.41	0.45	0.44	0.43	0.44
Teff D0	0.81	0.80	0.82	0.83	0.81	0.81	0.80	0.82	0.81	0.80	0.82	0.81	0.81	0.81
Difference D0-D2	0.34	0.38	0.37	0.38	0.40	0.38	0.39	0.38	0.38	0.39	0.38	0.38	0.39	0.38
Bceff	0.51	0.48	0.57	0.60	0.59	0.61	0.58	0.63	0.58	0.55	0.57	0.54	0.52	0.52
No. of obs.	39	46	50	53	63	68	67	77	84	86	93	91	87	84

Table 8b. Average Technical Efficiencies with δ =10 %.

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
Teff D2	0.45	0.41	0.44	0.44	0.40	0.42	0.40	0.42	0.42	0.40	0.43	0.42	0.42	0.43
Teff D0	0.58	0.56	0.59	0.60	0.58	0.58	0.56	0.59	0.57	0.56	0.59	0.58	0.58	0.58
Difference	-0.13	-0.15	-0.15	-0.17	-0.18	-0.16	-0.16	-0.16	-0.16	-0.17	-0.17	-0.16	-0.17	-0.14
Bceff	0.54	0.50	0.61	0.63	0.62	0.64	0.62	0.66	0.62	0.59	0.61	0.58	0.57	0.55
No. of obs.	39	46	50	53	63	68	67	77	84	86	93	91	87	84

D2 – refers to firm dummy COLS model.
D0- refers to no dummy COLS model.

The above results for the 10 % R&D depreciation rate are reported to show the little impact the R&D depreciation rate has on technical efficiency results.

Data Issues Appendix

Nominal variables were deflated with sectoral producer price indices at the 2 and 3 digit levels (1995=100), with the exception of R&D prior to 1995. Due to the unavailability of better options, the general earnings level index was used to deflate R&D prior to 1995. Double-deflation of output would also have been an option, as it has been considered superior particularly when input and output prices move differently over time, by e.g., Stoneman and Francis (1994), but due to the strong decline in some ICT output prices, it would more likely have introduced a distortion.

Maximum Likelihood estimation results gave a significantly positive effect on efficiency from firm size and declining competition (as indicated by increasing profit margins). There appears to be some non-monotonicity in size and debt, since the adverse effects of high debt levels are apparent only for the most indebted firms. Otherwise, non-monotonic relationships are unlikely to distort results since the factors explaining efficiency were almost all grouped into dummy categories allowing for differing signs to coefficients of sub-groups. Although it is difficult to tell when the impact of a dummy variable turns from negative to positive or *vice versa*, i.e., identify the non-monotonic point, the dummy indicates it for those with a sufficient number of sub-groups. The frequency distributions of dummies are presented in the Tables 2a and 2b. Although exports and ownership type had only two categories, it is not intuitive to assume that high levels of exports or total foreign ownership would be detrimental to efficiency. (On the contrary, more productive firms have been found to become exporters, and thus more efficient firms are more likely to be exporters.) Since the objective of this paper is not to provide exact measurements, but rather indications on the direction of developments, the use of dummies can be considered sufficient.

Potential Selectivity Biases

As sector information fluctuated somewhat causing disruptions in the time series for a number of firms, the categorisation was broadened to include all firms which had for several years belonged to the ICT equipment producing sector.[15] The LDPM (Teollisuustilasto) and Financial Statements statistics (Tilinpäätöspaneeli) were used as primary sources, complemented by the R&D Survey.

The ICT sector has experienced considerable turbulence at the micro level over the period resulting in entries, exits, mergers and fluctuations. The exclusion of entry and exit from consideration may bias results downward or upward, but since an unbalanced panel was employed, this only means that the ups and highs are smoothed out over the period and results should be considered as indicative of trends rather than as absolute realised outcomes. Exiting firms are not necessarily bankrupt basket cases, but may actually be productive or innovative acquisitions of a larger firm.

The labour input variable may be biased downwards due to the unavailability of hours worked. Reported overtime averages at most at 5 % of regular working time for the

[15] E.g., some firms have shifted focus back and forth between ICT services and manufacturing.

electronics, machinery and metal industries as a whole, but unreported overtime may be much higher.

Capital stock estimates were calculated into the Statfin Longitudinal database by Maliranta (2003, p. 296) based on the continuity, non-negativity and availability of machine and equipment investment data. He used the perpetual inventory method with a 10 % annual rate of depreciation. Secrecy requirements prevented the identification of firms and data checks on publicly available information. The disaggregation of data in the LDPM database caused some disparities relative to the firm level Financial Statements Panel. Nevertheless, according to Maliranta (2003), capital inputs are available for 66–79 % of all plants in the 1990–1998 period. After the exclusion of firms with less than 20 employees, the data covers 35–70 % of all firms in the period. Despite the exclusion of firms with less than 20 employees, he considers the dataset reasonably representative from the standpoint of total manufacturing employment and production[16]. In addition, capital stocks were complemented from financial reports on investments to the extent knowledge on initial capital stocks and investments were available for a reasonable estimate.

For 1998–2000, the R&D panel suffers from serious errors, selection bias or discontinuity, as reported R&D investment drops drastically and inexplicably. This problem was overcome by replacing missing observations with averages of the former and the subsequent year prior to the estimation of the R&D stock, which in itself smoothed the R&D impact. While the true economic depreciation or obsolescence of R&D assets is determined by technical change (which was rapid) in the industry, imputations and a high depreciation rate can be justified by the predominance of wages and salaries in R&D spending. In recent years, approximately half of R&D expenditure in the ICT manufacturing sector has consisted of labour costs. In 2004, external R&D and investments accounted for only about 5 % of total R&D expenditure. The remaining part has been predominantly material expenditure. Since the firms' knowledge base is human capital embodied to a large degree, firms smooth their R&D spending over time to avoid lay-offs, i.e., high serial correlation of R&D relative to other investment is a well known fact.[17]

Statistics Finland uses only a sample to collect R&D data for firms with less than 100 employees. The R&D survey ignores current R&D investments in starting firms at the quantitative aggregate level, but their significance was small as only 2 percent of total industrial R&D originated from firms with less than 10 employees or 7 % respectively for firms with less than 50 employees in 2003. Meanwhile, firms with 500 or more employees accounted for 70 % of all R&D, and firms with at least 100 employees for 87 % of total corporate R&D.[18] Similarly in the sample, firms with over 500 employees account for 76 % of total R&D capital. In 2004, the Statistics Finland R&D survey included 233 firms in the sector, of which 165 had 10 or more employees and 91 at least 50 employees.

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[16] Maliranta, M. (2003): Micro Level Dynamics of Productivity Growth. An Empirical Analysis of the Great Leap in Finnish Manufacturing Productivity in 1975–2000, ETLA A 38, p.295.

[17] Hall, 2002.

[18] Statistics Finland, Science, Technology and Information Society Statistics, 2005.

Table 9. R&D and Size of Firm in 2003.

Number of Personnel	Share of industrial R&D in Finland	Number of Personnel	Share of R&D Capital in Sample	Number of Personnel	No. of Firms in ICT Manufacturing in R&D Panel, 2004*	Share in Total
0-9	0.02		0 %	0-9	68	29 %
10-49	0.07	20-50	3 %	10-49	75	32 %
50-99	0.04	50-99	3 %	50-249	60	26 %
100-249	0.08	100-249	6 %			
250-499	0.09	250-499	12 %	250+	31	13 %
500+	0.70	500+	76 %			
Total	1.00	Total	100 %	Total	233	100 %

*Annual R&D panel survey of the Statistics Finland not including all firms, Science, Technology and Information Society Statistics, 2005.

Kleinknecht (1987) found large firms to account for 77 % of Dutch R&D contrary to the official 91 %. Also Stoneman and Toivanen (2001) found large firms more likely to report their R&D expenditures relative to more informal and mixed R&D efforts in small firms. The official data is biased in favour of large firms in terms of data collection, but official collectors of R&D survey data claim it to be representative of the entire population and to cover most Finnish firms engaged in R&D activity. Furthermore, the ICT hype of the end of the 20th century is likely to have encouraged many small firms to exaggerate R&D investment to appeal to investors rather than underestimate it.

In addition, the R&D Survey data description admits that measurement errors may arise from varying firm responses to the survey, but that sample error and under-coverage are small.[19] These hindrances may bias the results somewhat, but are tolerable provided that the omissions do not change the shape of the production function significantly. Though there may be firms excluded due to their lack of R&D, this is unlikely to cause a problem, since non-R&D-performing firms compete in a different category and are unlikely to be comparable with the R&D-performing firms in any case. It is, however, necessary to underscore the fact that the analysis concerns only innovative firms, and the exclusion of smallest firms is unlikely to bias results excessively in terms of the bulk of R&D.

The proportion of all firms employing less than 20 people was 89 % in 1993 and 86 % in 2004. Their share of total employees was, however, only 12 % and 7 % respectively, and their share of total turnover only 6 % and 2 %, or of total wage costs 9 % and 5 % respectively for 1993 and 2003. Though large in number, the exclusion of firms with less than 20 employees cuts out only about 10 % of total economic activity in the sector.

In 2003, the true number of firms operating in the sector rose to almost 1700, and 233 if only firms with over 20 employees are considered. Meanwhile, observations were available for only 84 firms in the sample, i.e., for about 36 % of the total number of firms in the sector. In 2004, the sector employed more personnel in subsidiaries abroad than in Finland, but the sample figures include only activities in Finland.

[19] Statistics Finland. Quality description: R&D. 2005.

Table 10. The ICT Manufacturing Sector in Finland in 1993 and 2003.

1993	No. of Firms	No. of Personnel	Turnover (€1000)	Wages	No. of Firms	No. of Personnel	Turnover (€1000)	Wages
Employees <20	1331	4239	282430	67055	88.5 %	11.7 %	6.0 %	8.8 %
20≤ Employees <50	82	2543	209725	54382	5.5 %	7.0 %	4.4 %	7.1 %
50≤ Employees <100	34	2493	283919	54748	2.3 %	6.9 %	6.0 %	7.2 %
100≤ Employees <250	26	4025	412188	83638	1.7 %	11.1 %	8.7 %	11.0 %
250≤ Employees <500	19	6580	651932	131471	1.3 %	18.1 %	13.8 %	17.3 %
Employees ≥500	12	16483	2887185	370140	0.8 %	45.3 %	61.1 %	48.6 %
Total	1504	36364	4727379	761434	100 %	100 %	100 %	100 %
2003								
Employees <20	1463	4465	515504	121801	86.3 %	6.7 %	1.7 %	4.9 %
20≤ Employees <50	112	3473	481738	105773	6.6 %	5.2 %	1.6 %	4.3 %
50≤ Employees <100	46	3127	367413	87639	2.7 %	4.7 %	1.2 %	3.6 %
100≤ Employees <250	40	6149	1044346	188385	2.4 %	9.2 %	3.4 %	7.6 %
250≤ Employees <500	19	6759	1136841	214317	1.1 %	10.2 %	3.7 %	8.7 %
Employees ≥500	16	42564	27504551	1747084	0.9 %	64.0 %	88.6 %	70.9 %
Total	1696	66537	31050393	2464999	100 %	100 %	100 %	100 %

Source: Statistics Finland, Finnish Enterprises Database.

Outliers and robustness of results

There are clearly some outliers in the data, but in frontier analysis the exclusion of outliers is even more suspect than usual. Due to data secrecy requirements there was no other basis for their exclusion other than their extremeness in value. For example, as Table 11 below shows, the subtraction of reported R&D personnel from total personnel resulted in three observations having only 1 employee. This is, however, a perfectly plausible outcome in a small firm where all employees are required to do R&D. The number is low enough to round up into 0 % of total observations. Since the Nokia Group has been split into its subgroups in the data, it does not stand out too clearly among the largest companies.

Table 11. Frequency distribution of Firms by Size of Personnel Excluding R&D Personnel.

Number of Personnel Excluding R&D Labour	Cumulative Frequency of Observations	Cumulative Percent of Observations
1	3	0 %
10	10	1 %
21	111	11 %
27	197	20 %
37	298	30 %
52	394	40 %
80	493	50 %
128	593	60 %
203	692	70 %
356	790	80 %
678	889	90 %
1029	939	95 %
13516	988	100 %

The exclusion of outliers could have resulted in the removal of frontier firms defeating the purpose of the exercise. The principle of non-exclusion was therefore adopted, with few exceptions: Altogether 3–4 % of observations were removed due to a negative or missing value-added when logarithms were taken, extreme annual variation or impossible value-added figures. Since the results should only be considered as indicative of magnitude and direction, outliers should not have a significant impact on the conclusions.

Several experimentations were made in regard to the robustness of the results. The flexibility of the functional form renders the results less robust to changes than those from more rigid functional forms. However, the rejection of constant returns to scale proved extremely robust, as well as high average technical change, productivity growth, elasticity of inputs, inefficiency, the persistency of differences between firms, high distribution of firms with respect to the frontier and high time-varying inefficiency. That is, all the main trends reported as results proved extremely robust regardless of the type of the model applied.

There was only one exception. If labour number is replaced with labour expenditure, the Maximum Likelihood equations no longer vary by efficiency, stochastic or deterministic. Deviations from the frontier are due entirely to noise and none to inefficiency. Labour expenditure also reduces average scale elasticities to constant returns to scale, but the tests still reject the hypothesis, which may be due to the variation in individual firm returns to scale. If material expenditure, obtained by subtracting value-added from turnover, is included in the function, the explanatory power of the OLS regressions rises to over 99 %. Material purchases are such an important share of operations that managing them optimally is the main determinant of output. Yet, with labour expenditure as the labour variable, maximum likelihood estimation did not give efficiency any role, but variation in output was again due to some other determinants. Labour expenditure is, however, inappropriate for output oriented efficiency measurement.

Appendix: A Brief Overview of the Finnish ICT Sector

Hampered by a severe recession in the early 1990's, which shrunk GDP by roughly 11 %, the Finnish economy rebounded in 1994–2000 to about 4–6 % annual growth (Table 12) characterised by rapid technological development, productivity growth, and further internationalisation of companies and of the economy. At the core of the economic momentum was the electronics industry and within them, ICT equipment and particularly the mobile phone industry. Firms' turnover in the electronics and telecommunications equipment sector grew 3.7-fold.[20] According to international competitiveness comparisons, Finland advanced to the global frontier of innovation and productivity, largely due to its technological progressiveness.[21] In 1995–2000 high-tech industries grew by 28 % p.a. on average, tripling the value of high-tech production, while other industries reached 7 % average annual growth. A slowdown followed only in 2001–2002.

Table 12. Growth rates 1990–2002 (percentage change from the previous period).

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
Real GDP	-0.3	-6.4	-3.8	-1.2	3.9	3.4	3.9	6.3	5.0	3.4	5.1	1.1	2.3
TFP growth	..	-3.7	-0.8	1.5	3.7	2.1	2.7	4.0	3.5	1.2	3.5	-0.1	1.2
Electronics and optical equipment manufacturing	3.8	-12.5	12.1	19.9	26.5	24.5	13.1	19.4	34.9	24.9	38.3	0.4	9.4
Labour productivity growth in ICT	10.3	-1.5	18.4	15.8	10.0	3.5	8.6	13.7	23.4	13.3	33.2	-0.5	14.3

Sources: Finnish Economy – Structural Indicators 2004. Government Institute for Economic Research; National Accounts. Statistics Finland.

Liberalisation of the telecommunications market in the early 1990's gave a major push to the sector, though at first it meant severe cuts in employment.[22] The Finnish sector has a global market leader, Nokia. Despite its dominance on the domestic market, neighbouring Swedish Ericsson and other global producers have brought about competition also for smaller equipment suppliers. Of all industries, the ICT equipment industry invests most, approximately 2 billion euros in recent years, in R&D p.a. and exports 80 % of its output, accounting for 25 % total Finnish goods exports in 2004. Innovative electronics solutions can be found all around us ranging from mobile phones and various products to production processes.[23]

High productivity growth during this period is a well established fact. TFP growth accelerated from 0.3 % p.a. in 1990–1995 to 2.2 % p.a. in 1995–2002, reaching about

[20] Statistics Finland, Science, Technology and Information Society Statistics.

[21] E.g., in 2001, the International Institute of Management Development (IMD) rated Finnish technological infrastructure as the third best in the world after the USA and Sweden. The United Nations Development Programme (UNDP) has considered Finland as the technologically most advanced country in the world, and in 2001, the World Economic Forum rated Finland first in its growth and its current competitiveness rankings. In 2002, the IMD placed Finland second in its competitiveness ranking, while the WEF ranked Finland third in its technology index and first for public institutions.

[22] Paija (2001).

[23] Source: Technology Industries of Finland (Teknologiateollisuus).

3 % p.a. in the late 1990's. While estimated growth rates vary somewhat by source, productivity growth placed Finland in the same category with Ireland and Korea in ICT equipment manufacturing.[24] In 1992–1999 ICT manufacturing grew 32 % p.a. on average. ICT equipment and electronic components manufacturing dominate the ICT sector, but some overlap exists between services and manufacturing in the data. [25]The ICT services sector (telecommunications and computer services) also made rapid progress, but as an emerging smaller scale industry. Consequently, the ICT equipment manufacturing sector appears as the technologically most progressive source of productivity growth with some critical mass in Finland.

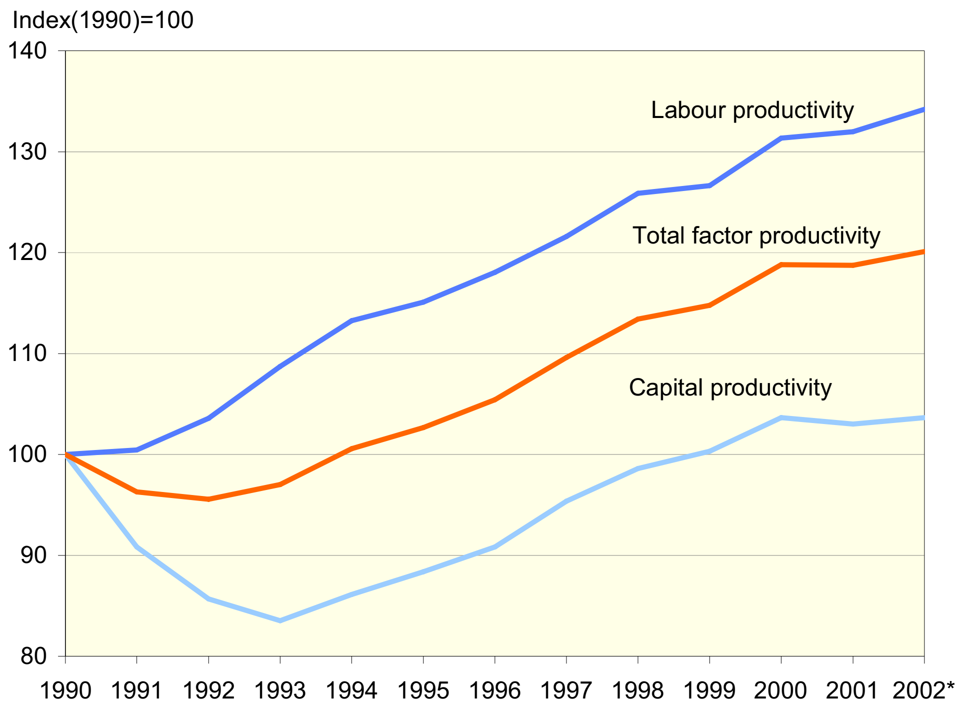

Figure 3. Productivity Growth.

Source: Finnish Economy – Structural Indicators 2004. Government Institute for Economic Research.

The confinement of growth and technological progress to the ICT equipment manufacturing sector is striking. Daveri and Silva (2004) have estimated productivity growth to have relied almost solely on the "Nokia" industry. as well as Post & Telecoms and Rental of Machines & Equipment/ IT consulting services with highly limited spillovers to the rest of the Finnish Economy. In 1992–2000, "the three sectors together accounted for more than 40 % of the aggregate TFP performance and more than one-third of aggregate labour productivity, with Nokia being in both cases the main contributor. Although this result is partially induced by the large share of value added imputed to Nokia, the bulk of it is driven by the spiky acceleration of industry productivity as documented above. The contribution of IT consultancy services … is limited by its rather small size." Moreover, Daveri and Silva (2004) suggest that "the

[24] Statistics Finland, National Accounts, Pilat and Wyckoff (2003), Maliranta (2001), Junka (2003).

[25] Paija (2001).

main mechanism underlying the observed TFP acceleration in the IT services industries in Finland has not been spillovers from Nokia, but rather the world decline in the price of semiconductors." In 1999, Nokia employed one third of all employees in the sector directly, and almost 45 % if first-tier subcontractors are included.[26]

R&D investments grew rapidly in the latter half of the 1990's mainly due to the 20–40 % R&D growth rate in the rapidly expanding electronics sector, before halting in 2000. The electronics industry has accounted for roughly half of all business sector R&D investments. Finnish industry's high R&D intensity relies on the electronics industry, which alone produces over 55 % of all corporate R&D activity, i.e., 1.4 % of GDP, of which Nokia Corporation accounts for about 90 %. Without it, Finland would not be a high-tech country or at the forefront in international R&D comparisons. Developments in the sector have repercussions on the entire economy across regions. At least in the medium term, Finnish industry's positioning on the global technology frontier is linked to developments within the ICT cluster and will likely be central in defining Finland's future role in the global distribution of work.

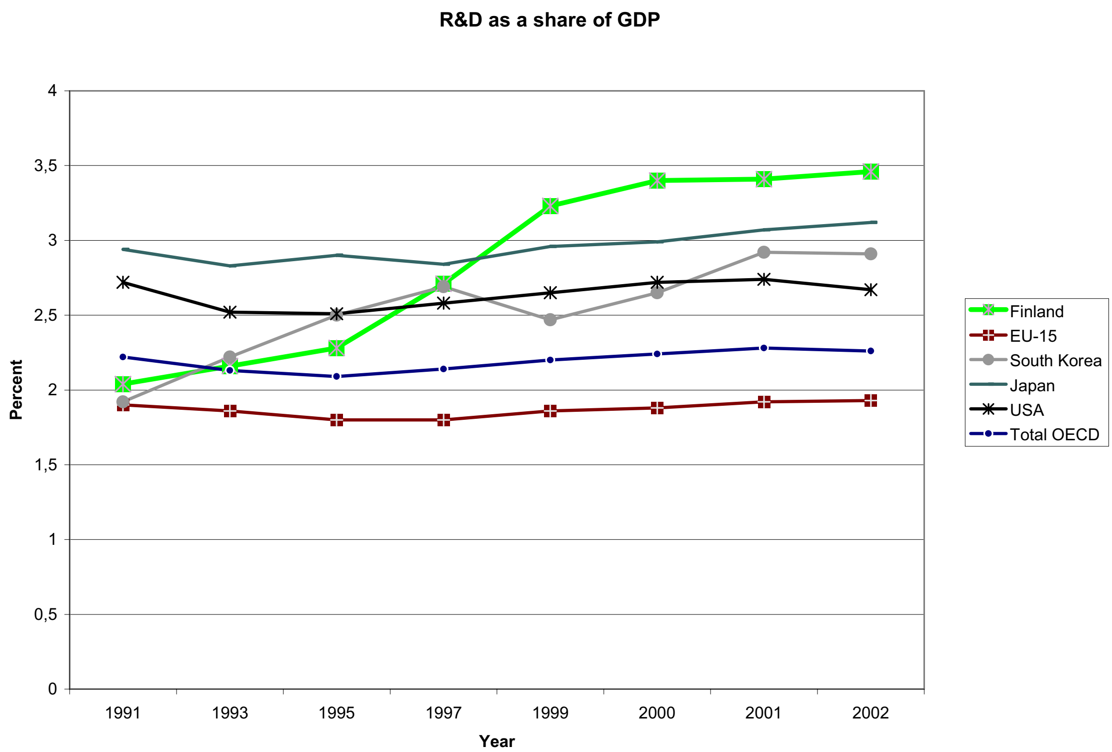

Figure 4. *R&D in percent of GDP in 1991–2002.*

[26] Paija (2001).

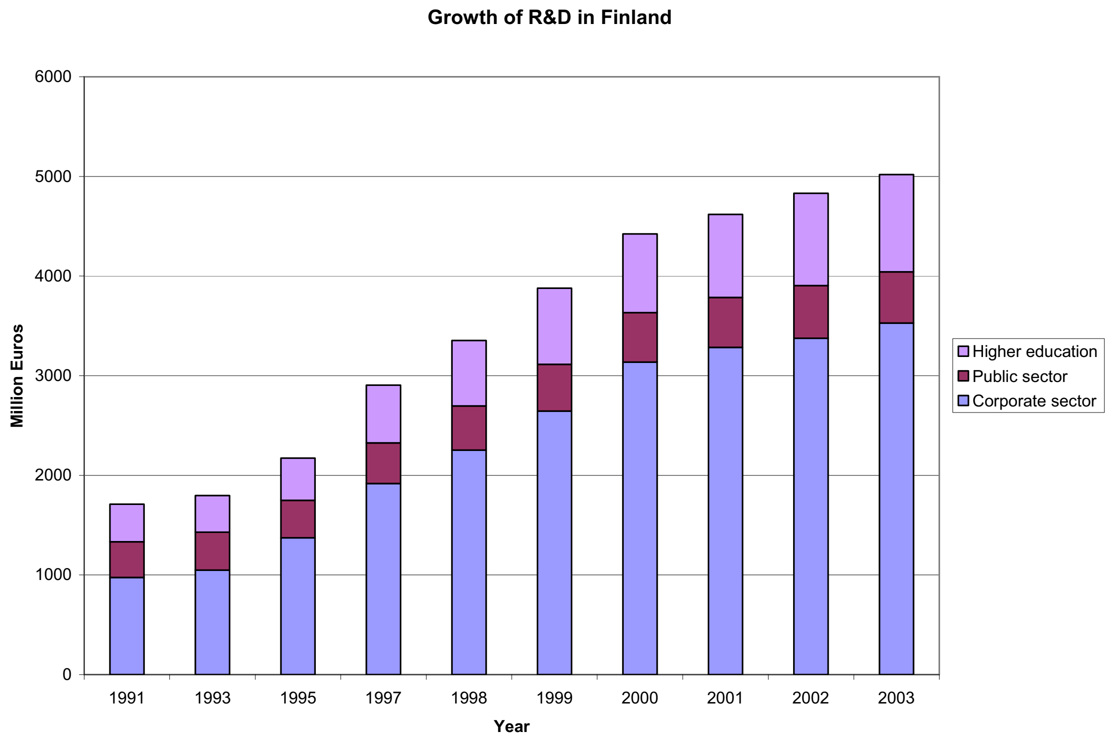

Figure 5. Growth of public and private R&D investment in 1991–2003 in Finland.

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