Ilmo Pyyhtiä

Why is Europe lagging behind?

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Abstract

This paper builds on the literature on growth in searching for explanations for the divergent growth performance between the EU countries and the United States. We emphasise the role of R&D investment and perhaps different degrees of elasticity of substitution between capital and labour. We estimate two different production functions, namely Cobb-Douglas and CES specifications, with physical capital, a measure of labour, and residual 'technical trend' as inputs.

Our first finding is that in many ICT-producing and using countries such as Denmark, Finland, Ireland, Sweden and the United States technical progress has been accelerating during the past decade. Secondly, this speeding up of technical progress has been associated with R&D investment and perhaps with increasing elasticity of substitution between capital and labour. Hence, our results suggest that there is no growth paradox in Europe: the R&D factor and the elasticity of substitution between capital and labour which have been known to be important factors of economies' growth potential, actually explain a significant part of the divergent growth performance of the European economies as well.

Keywords: endogenous growth, panel data estimation, production function, R&D, technical progress, elasticity of substitution

JEL classification numbers: E22, E23, O51, O52

Miksi Eurooppa laahaa jäljessä?

Suomen Pankin tutkimus
Keskustelualoitteita 3/2007

Ilmo Pyyhtiä
Rahapolitiikka- ja tutkimusosasto

Tiivistelmä

Tämä tutkimus nojaa kasvua käsittelevään kirjallisuuteen etsiessään selityksiä Yhdysvaltain ja EU-maiden väliseen kokonaistuotannon kasvueroon. Työssä korostuu T&K-menojen sekä pääoman ja työn välisen substituutiojouston merkitys tuotannon kasvuerossa. Tutkimuksessa estimoidaan kaksi erilaista tuotantofunktiota, nimittäin Cobb-Douglas- ja CES-funktio tuotannon, pääoman, työn ja teknisen kehityksen väliselle riippuvuussuhteelle.

Ensimmäinen tutkimustulos on, että monissa runsaasti tieto- ja informaatiotekniikkaa tuottavissa ja käyttävissä maissa, kuten Tanskassa, Suomessa, Irlannissa, Ruotsissa ja Yhdysvalloissa, tekninen kehitys on kiihtynyt viimeisen vuosikymmenen aikana. Toiseksi tähän teknisen kehityksen kiihtymiseen ovat liittyneet tutkimus- ja tuotekehitysmenojen lisääntyminen sekä pääoman ja työn välisen substituutiojouston kasvu. Tästä syystä tulokset osoittavat, että Euroopassa ei ole mitään ”kasvuparadoksia”: T&K-menot ja pääoman ja työn välinen substituutiojousto, joiden on tiedetty olevan merkittävä talouden kasvupotentiaalia lisäävä tekijä, selittävät merkittävän osan Yhdysvaltain ja Euroopan välisestä tuotannon kasvuerosta.

Avainsanat: endogeeninen kasvu, paneeliestimointi, tuotantofunktio, T&K, tekninen kehitys, substituutiojousto

JEL-luokittelu: E22, E23, O51, O52

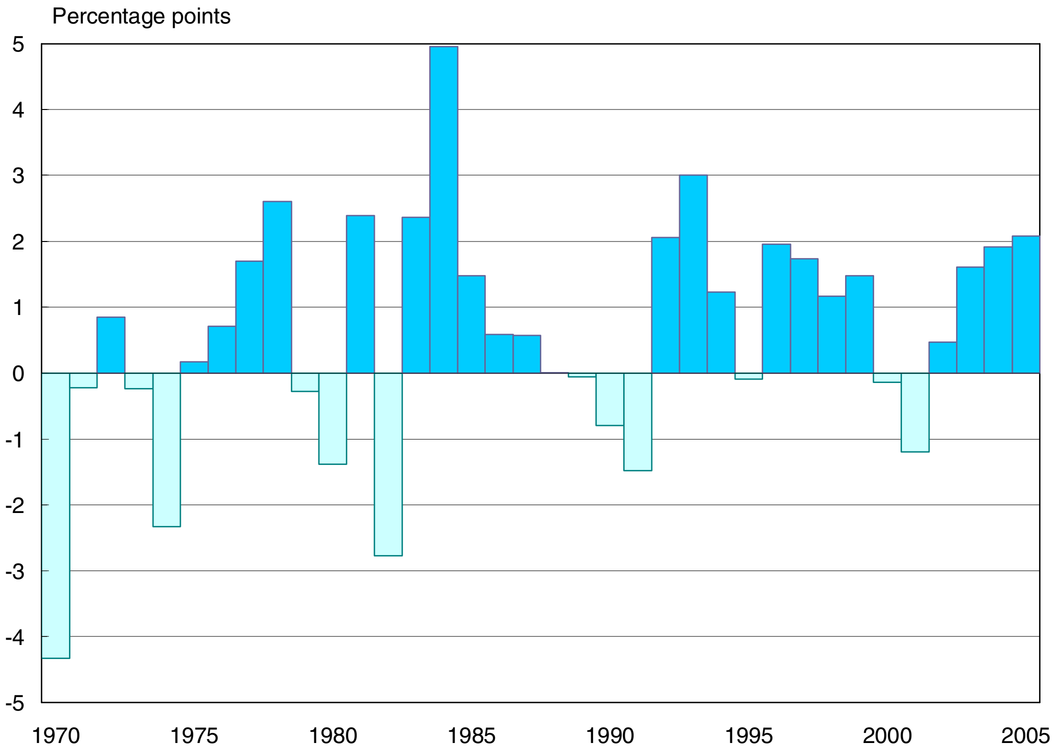
Contents

1 Introduction

EU-countries agreed on Lisbon agenda (2000) to improve a structure of the EU-countries' economy and make the EU-region more competitive in the global economy. A crucial part of this strategy was to improve the productivity by promoting investments into research and development (R&D). Most of the large EU-countries have failed to reach the Lisbon targets until now, while many small open economies have succeeded to realize these goals for many years before the target year 2010. At the same time, European economies growth performance is very heterogeneous. While part of the divergent growth performance can be explained by business cycle factors, the recent 15 years of stagnant growth performance of the EU private sector relative to the US require explanations that go beyond business cycle frequencies. As an example, Figure 1 contrasts the growth performance between EU15 and the US during the last 35 years. It is evident from the Figure that on average, the growth performance in EU15 over the 35 years time has been poorer than in the US.

While the US growth performance has been analyzed widely with different methods, understanding on the causes of European stagnant growth performance is at best incomplete. Stagnant growth performance is particularly disturbing, given that European economies have already undergone series of structural reforms and integration of the markets. Van Ark (2005) argues that the European slowdown in growth is a reflection of an adjustment process towards a new industrial structure, which has developed more slowly in the EU than in the US: The European economic environment creates too little room for good firms to excel and for failing firms to exit the market so as to free up resources for the much-needed transition. However, basic institutions that have been found important for growth in Easterly (2001) for example are already pretty much in place in the EU. Institutional impediments should thus not be a major cause for European bad performance during the last decade.

Figure 1. **GDP Growth difference between USA and EU15 1970–2004**



Source: Groningen GDC, Conference Board.

This paper builds on the growth literature in searching for explanations for divergent growth performance among the EU countries and the US. In particular, we emphasise the role of R&D investments in explaining different technical trends and thus economic growth between the countries. Similarly to most of the aggregative models of long-run growth we start from the assumption that output is generated by Cobb-Douglas specification with physical capital, a measure of labour, and residual 'technical trend' as inputs. The use of Cobb-Douglas (C-D) specification is typically motivated by the fact that the share of income accruing to capital and labour are relatively constant over time (Mankiw, Romer, and Weil, 1992; and Prescott, 1998; Gollien, 2002) and the fact that C-D is linearly homogenous with a constant elasticity of substitution between the inputs. This makes the C-D production function an attractive description of the production process as it is well in accordance with neo-classical growth model with steady state growth.[1] Cobb-Douglas type of production function is also consistent with Schumpeterian tradition of economic growth models, as discussed in section 3. However, given the heterogeneity of the factor shares across countries and time in Europe, we also estimate the CES production function.

Possible weak identification of the production function parameters notwithstanding, the estimation results from the panel framework are rather promising. First, the estimated capital share parameter is in well accordance with those obtained in other literature by various methods. Second, the estimated technical trends show very large differences between the countries. Most interestingly, the technical progress has been in many ICT-producing and using countries non-linear, exponential. These are small countries like Denmark, Finland, Ireland, Sweden and from large countries USA. The results are especially encouraging in the countries where technical progress has been accelerating. At the same time, in many large European countries that have failed to agree with Lisbon agenda, R&D investments do not appear significant. Turning into results from the estimation of CES production function, we find that elasticity of substitution between capital and labour has increased over time. The results thus seems to suggest there is no growth paradox in Europe: R&D factor that have been known for decades to be important for economies' growth potential does explain an important part of the acceleration of technological development in the countries that have heavily invested in it.

While providing further evidence on importance of R&D investment on speeding up of technological development, the paper contributes also to the existing literature by extending the time frame and the selection of countries, as well as focusing on private sector data. In the National Accounts calculations it is normally assumed that the productivity increase of the public sector is zero. In practise it is however shown (Aschauer, 1988) that movements in the public investments bring forth movements in private sector output which are as much as four to seven times as large as the public sector outlays. This means that the core infrastructure investments like streets, highways, airports, mass transit, water systems etc. has also a clear explanatory power to the private sector productivity. In the recent literature the influence of the public sector tangible and intangible investment on private sector are however estimated smaller than Aschauer's results showed (Hämäläinen, 2006).

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[1] Stability of factor income shares largely applies to the US data, while in a number of countries in continental Europe this has not been the case. Willman (2002) points out that after increasing strongly in the 1970s, the share of labour income in GDP in the euro area decreased continuously in the two subsequent decades. Nevertheless, allowing for non-constant mark-ups, Willman (2002) estimates the elasticity of substitution parameter for the Euro area close to unity, suggesting that the Cobb-Douglas function is a good approximation for the euro area production function. For further discussion on estimation of CES production function for groups of countries, see for instance Duffy and Papageorgiou (2000) and for the euro area see Willman (2002).

2 Related literature

Solow (1957) showed in his seminal article the importance of the technical change to the growth process.[2] He calculated technical change as a residual from estimated Cobb-Douglas-production function, using the data directly from national account statistics of the United States in the years 1909–1949. At this period, gross output per hour of work in the US economy had roughly doubled. A path-breaking finding was that a major part of that increase could be attributed to technical change, while only a minor part to increase in capital intensity. Another interesting finding that did not receive a widespread attention however was that the trend of the technical change appeared exponential in the thirties. This made Solow to discuss also the possible non-linear form of the production function.

The Solow's model have since then been used actively in the growth accounting exercises both at time series and cross-section setup. One of the key implications from early cross-section estimations, just like Solow find for the US alone, is that a large fraction of the cross-country income variance remains unexplained after controlling for physical capital accumulation.[3] The unexplained part of the income differences in the cross-section dimension is typically labelled as different degrees of efficiency of factor usage, or technological level. Solow (1957) used technical change 'as short hand expression for *any kind of shift* in the production function (Solow, 1957, pp. 312)'. More recent literature has provided various qualifications to the earlier literature.[4] Basic findings, initiated mainly by Mankiw, Romer and Weil (1992), is that *augmented* Solow model with a measure of human capital can indeed explain a major part of the variation in output per capital across countries.

Since then, a voluminous new economic growth literature and the idea that R&D plays a central role in the production of new knowledge and technological development was initiated by a need for a better theory to explain large differences of levels and growth rates of per capita output across countries (Romer, 1990; Grossman and Helpman, 1991). This literature suggests that knowledge can be increased without bounds and it can be an input in the production function that has increasing marginal productivity. In contrast to models based on diminishing returns, growth rates can increase over time by the endogenous factors, and countries with large R&D investments can grow faster than countries with small R&D inputs.

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[2] Before Solow Denison had analysed economic development using so called 'growth accounting' method.

[3] Denison (1967), Christensen, Cummings, and Jorgenson (1981).

[4] Mankiw, Romer, and Weil (1992), Knight, Loyaza and Villanueva (1993), Islam (1995), Caselli, Esquivel and Lefort (1996), Klenow and Rodriquez-Clare (1997).

New Growth theory generated a large empirical research of the link between innovation and economic growth[5] (Cameron, 1998). It has considered a number of different measures of innovation, such as R&D spending, patenting, and innovation counts, as well as the effect of technological spill over between firms, industries, and countries. This literature's key finding is that international technological spill over account only a minor part of the productivity growth in a mature economy. It is the innovative effects of the domestic firms and organizations that are most important, and whose research spill over most easily to other domestic firms. In addition, substantial domestic research effort is necessary to exploit the results of the foreign research. Another typical finding is that the rate of return of R&D investments is surprisingly high, so that socially optimal level of R&D is likely to be higher than what private markets can deliver. (Nadir 1993). Underinvestment in R&D is related to uncertain nature of the innovation projects and the fact that firms behind the technological frontier can use the spill over from the firms on the frontier. This reduces ex ante private return from innovations and thus discourages innovation activity of the firms.

Aghion and Howitt (1992) presented a second variant of endogenous growth theory so called Schumpeterian approach. Main source of technological progress are innovations, which lead to the introduction of new production processes, new products, new management methods, and new organization of production activities. They combine the Schumpeterian (1934) thoughts of creative destruction, elements from the patent race literature (see for instance Tirole, 1989, Ch. 10) and vertical product differentiation model of Grossman and Helpman (1991b) and formulate a nonlinear growth model, where growth is based on technological progress. Economic growth in this and many subsequent models of Aghion and his colleagues is achieved through quality improvements, or innovations, of the existing technology resulting from a stochastic innovation process. Innovations are created by self-interest firms, entrepreneurs, and researches who expect to be rewarded with rents in the event that their innovation is successfully implemented. The monopoly rents continue so long as there will become new innovations and new technologies which drive old production methods out of the markets.[6]

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[5] Cameron (1998).

[6] This is not without problems however. Even with costly adjustment of inputs of production that generates cross-section variation in the relative levels of different inputs does not seem to be enough to identify well the production elasticity parameter (for discussion, see for instance Bond and Söderbom, 2005).

3 Theoretical framework

Before proceeding into estimation of the production function, it is useful to discuss different specifications of the productions processes as suggested by the literature more formally. A natural starting point is the aggregate production function suggested by Solow (1957).

$$Y = A(t)F(K,L) = AK^{\alpha}L^{1-\alpha} \tag{3.1}$$

where Y is production, K is capital stock, A is labour augmenting technology, L is labour input and α is a capital share parameter between 0 and 1. The production function in (3.1) can be written neatly in per-worker terms, or in intensive form, such that

$$y_t = A_t F(k_t, 1) = A_t k_t^{\alpha} \tag{3.2}$$

where k is capital labour ratio (k = K/L). Equation (3.2) illustrates how changes in output per worker can be decomposed between an accumulation of physical capital per worker and technical development captured by the time varying term A. With data on K, L and Y, the term A can be recovered as a ‘residual’ once production elasticity parameter α has been estimated. Gundlach (2005) notice that failing to directly observe and thus allow for differences in technology across countries leads into an identification problem. The data from output per person and capital per person alone does not reveal which part of the observed difference in income is due to a difference in technology and which part is due to a difference in factor accumulation. However, in the time-series-cross-section context, we can use cross-section variation to estimate α[7] and thus isolate the shifts in aggregate production function from the accumulation of production inputs. Technical trends can then be recovered individually and studied in separation after estimating of α.

Lucas (1988), Romer (1986 and 1990), and subsequently many others following this tradition began to consider that technological progress can be endogenous, in the sense that marginal product of capital does not tend to zero as capital accumulates. Instead the marginal product of capital will be asymptotically positive, so that assumption about some exogenous driving forces of long-run growth becomes unnecessary. One way of generating endogenous growth like this, is to augment production function so that the production process exhibits

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[7] This is not without problems however. Even with costly adjustment of inputs of production that generates cross-section variation in the relative levels of different inputs does not seem to be enough to identify well the production elasticity parameter (for discussion, see for instance Bond and Söderbom, 2005).

increasing returns to scale, like Lucas (1988) and Romer (1990) did. For instance, the Romer type (Romer 1990) endogenous production function is written in the form

$$Y = A^{\gamma}K^{\alpha}L^{1-\alpha} \tag{3.3}$$

where γ describes the elasticity of the technological progress in the production. Increasing returns to scale in the economy now depend on the effectiveness of the investments into the research and development. Alternatively, endogenous growth can be generated in the neoclassical setup by assuming CES production technology with the elasticity of substitution between capital and labour greater than one (Pitchford, 1960; Jones and Manuelli, 1990; and Rebelo, 1991). However, the elasticity of substitution greater than one, does not seem to get a wide support from empirical literature.

Aghion and Howitt (1992, 1998) and their subsequent work with many other authors follow Schumpeterian tradition. In their theory economic growth is primarily driven by the rate of technological innovations. Technical innovations are endogenous in the sense that they result from entrepreneurial activities and investments in R&D and human capital. These innovative activities of the entrepreneurs then drive the evolution of production shift parameter A.

Following Aghion and Howitt (2005), the Schumpeterian production function is specified at the industry level

$$Y_{it} = A_{it}^{1-\alpha}K_{it}^{\alpha} \tag{3.4}$$

where $0 < \alpha < 1$, Y is production per worker, A is productivity parameter attached to the most recent technology used in industry i at time t, K represents the flow of intermediate product used in this sector, each unit of which is produce by one-for-one by capital. The aggregate output of the economy is the sum of the industry level outputs. The aggregate per worker production function is the sum over all the industries i. Intermediate products are produced and sold exclusively by the most recent innovator, and each successful innovation driving the technology A. Industry level production function can be aggregated, bringing us back to Cobb-Douglas aggregate per worker production function

$$y_t = A_t^{1-\alpha}k_t^{\alpha} \tag{3.5}$$

where labour augmenting productivity factor A is the unweighted sum of the sector specific shift factors. There are various ways of describing how production shift parameter A evolves over time and depend on innovative activities of the firms and public policies adapted. The speed of innovation growth may depend upon the institutional characteristics of the economy such as property rights, protection, financial system, the government policy and distance to frontier. At this stage, it suffices us to conclude[8] that this Schumpeterian growth paradigm puts us back to a neo-classical, Solow type of production process, where the economy's long-run growth rate is driven by the growth rate of A.

4 Data

The data consists of annual private sector labour input, capital stock, output and R&D of the 12 EU countries and USA economies following OECD sector definitions. The data for labour input, capital stock and output is collected from the OECD-data bank STAN, transformed into euros and converted into the year 2000 price level. Consequently, the estimated labour productivity figures can be compared across countries (Figure A1). The data for labour input is based on the working days not the working hours. This weakens somewhat the comparability of the labour productivity figures due to the differences in the amount of working days and working hours in different countries. In particular, effective working days between USA and Europe differ substantially, as there are clearly more annual working days in the USA than Europe due to shorter holidays and fewer religious holidays in USA. This biases the labour productivity figures upwards in USA when compared with in Europe.

There are also large differences in the working hours between European countries. Furthermore, OECD Stan data bank statistics concerning employment differs from the information which is published in the Eurostat SBS statistics. The OECD STAN data is based on the labour force survey while the SBS data is collected from the firms. The number of employed of EU15 is 4 per cent smaller in SBS statistics than in STAN statistics and the differences between countries can be very large in some cases. There are also large differences in the working hours between OECD Stan and SBS statistics.

The capital stock for each country is calculated by the investment accumulation method using the equation

$$K_{t+1}^{net} = K_t^{net} + I_{t+1} - \delta K_t \tag{4.1}$$

where K^{net} = net Capital stock, I = gross fixed investment, and δ = depreciation coefficient of the capital stock. The depreciation parameter is approximated to 3,8% in all countries, being an average depreciation rate during the last 25 years in the private sector. The initial levels of the capital stock are based on the

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[8] See fors intance Aghion and Howitt (2005).

calculations of the World Bank and presented in the article of King and Levine (1994).

The R&D data is taken from the OECD ANBERD data bank and Eurostat data bank, being the only available and consistent data sets to all the countries included in the study. The R&D data concerns the private business sector, total economy, public sector and high education industries. The R&D data is used in the estimations in the form of the share of GDP so that the estimation results are comparable between large and small countries. The labour income data used in CES-production function calculations is taken from the OECD Stan data bank. The data concerns the total compensation per employee.

5 Estimation of the Cobb-Douglas production function

We start our empirical analysis by specifying the Cobb-Douglas technology but allowing for time and cross-section variation in the production function shift factor A

$$Y_{it} = A_{it} K_{it}^{\alpha} L_{it}^{\beta} \tag{5.1}$$

where Y is production, K is capital stock, L is labour input and the production elasticity parameters α and β are treated initially unrestricted. A is level of technology, or efficiency of factor usage capturing shifts in the production function. I denotes country and t denotes time at which production occurs. We specify a stochastic process for technology as follows

$$A_{it} = A(0) e^{\gamma t + \varepsilon_{it}} \tag{5.2}$$

where A(0) denotes the initial value of the scale factor A, common to all countries and parameter γ captures a common linear trend in the technological development. Finally, ε_{it} is the error term. Taking logarithms of both sides of (3.1) and substituting from above, delivers

$$\log Y_{it} = \log A(0) + \alpha \log K_{it} + \beta \log L_{it} + \gamma t + \varepsilon_{it} \tag{5.3}$$

We estimate the production function parameters directly in the form (5.3). Furthermore, we estimate the same production function also in an intensive form, thus implicitly restricting $\alpha + \beta = 1$. Intensive form reads as

$$\log y_{it} = \log A(0) + \alpha \log k_{it} + \gamma t + \varepsilon_{it} \tag{5.4}$$

The production elasticity parameters might not be consistent due to the simultaneity and their identification may be weak. Nevertheless, preliminary results from panel data estimation looks very typical compared to the mainstream production function estimations (Table 1, column 1, 3). The estimate for the production elasticity parameter α hovers around 0.3 which is a quite typical value compared to the other estimation results from the literature. The sum of the unrestricted parameter estimates for K and L is slightly over 1, but does not deviate statistically significantly from unity. The estimate for the parameter of the trend term implies that on average technological progress advances by 1.4–1.5 per cent per annum depending whether the production function is estimated in an unrestricted form (equation 5.3) or in an intensive form (equation 5.4). Including common quadratic trend in the panel estimations does not change the results quantitatively (Table 1, Columns 2, 4). Quadratic trend is also insignificant.[9]

Table 1. **Panel data estimation results of 5.4**

	Unrestricted		Intensive form	
Estimated parameter	1	2	3	4
α	.342	.343	.305	.305
	(2.53)	(2.46)	(2.95)	(2.86)
β	.704	.704	–	–
	(5.40)	(5.23)	–	–
γ_1	.014	.013	.015	.015
	(3.01)	(1.74)	(4.46)	(2.48)
γ_2	–	.0007	–	.0003
		(.110)	–	(.04)
R^2	0.988	0.987	0.665	0.665
SSR	10.71	10.71	12.28	12.28

Note: t-values in parenthesis. Columns 1 and 2 refer to estimation results based on equation (5.3) and columns 3 and 4 refer to estimation of equation (5.4) γ_1 (γ_2) indicates the coefficient of a linear (quadratic) trend.

Turning into individual country estimation it is clear that the hypothesis of the equal parameter values among the countries of our sample has to be rejected (Table A2, appendix). Table 2 shows the parameter estimates from intensive form by relaxing the assumption that production elasticity is common across countries.

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[9] All the variables by the individual country level are integrated of degree I(1) and the same result comes from the unit root test in the panel data form (Table A1, appendix). Co-integration tests suggest one co-integration vector for each country.

We also relax the assumption that the speed of technical change is common to all countries[10] In addition, we allow for quadratic trend for the technical change.

The production parameter α becomes statistically significant besides one country the US. The estimates differ significantly from country to country but the estimates look however quite plausible disregarding the outlier of the US. The estimation results suggest that the production elasticity parameter varies between 0.17 in Denmark and 0.36 for Spain. The parameter estimate for the USA data is not significant and can be included to the individual country estimation problems.

Table 2 also reveals that the speed of technical progress varies considerably between the countries. The results suggest that technological progress has been speeding up in the small open economies like Ireland, Sweden, Finland, Denmark and also in the United States. These countries are also known to share a fast growth of the ICT-sector during the last ten years time. They are also the countries that have invested heavily in the research and development either directly or indirectly through multinational's subsidiaries.[11] On the contrary, in the large European economies such as in Germany, Italy and Spain technological progress has been slowing down, as suggested by the statistically significant, but negative coefficient for quadratic trend variable.

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[10] The individual country estimation problems of the production function parameters are well-known in the literature. It is well known that if all inputs are chosen optimally and they are perfectly flexible in the sense that they can be varied immediately without incurring any costs, all the inputs are perfectly collinear with the productivity shocks observed by firms. Same situation arises if only some inputs are predetermined so that they cannot be adjusted in response to the current productivity shock. This breaks down the standard estimation procedures. With costly adjustment of inputs, variation across cross-sections generates variation in the relative levels of inputs and thus improves the identification of the production function parameters in cross-section setup. However, as discussed by Bond and Söderblom (2004) identification is still rather weak. The results from individual country estimation should then be interpreted with caution.

[11] Repeating the estimation for equation (5.3) by restricting the production elasticity parameter equal across countries, but letting technological development differ across countries, yields quantitatively similar result.

Table 2. **Individual country estimates of 5.4**

Country	α	γ_1	γ_2
Austria	.317	.015	-.0003
	(10.63)	(7.95)	(-.135)
Belgium	.289	.031	-.0003
	(7.94)	(23.67)	(-16.26)
Denmark	.166	.010	.0001
	(3.59)	(2.70)	(2.90)
Finland	.358	.012	.0001
	(9.71)	(5.32)	(4.59)
France	.268	.023	-.0001
	(9.16)	(10.84)	(-6.65)
Germany	.273	.020	-.0001
	(8.00)	(2.22)	(-5.22)
Ireland	.321	.012	.0003
	(11.91)	(3.93)	(5.09)
Italy	.372	.027	-.0002
	(12.45)	(11.90)	(-6.05)
Netherlands	.221	.020	-.0001
	(5.59)	(8.39)	(-4.91)
Sweden	.182	-.0	.0003
	(4.94)	(-.02)	(9.33)
Spain	.364	.024	-.0003
	(11.38)	(11.14)	(-9.74)
United Kingdom	.244	.019	-.0005
	(7.23)	(10.16)	(-1.69)
USA	.011	.002	.0002
	(.30)	(1.22)	(4.72)

t-values in inside parenthesis; R^2 = .995, SSR = .190, LL = 1115. γ_1 (γ_2) indicates the coefficient of a linear (quadratic) trend.

Given a sharp contrast between the large and the small European economies, we next explore whether the variation in R&D intensity across countries explains variation in the speeding up of technological development across the countries.

Comparison of the estimation results with the data of the research intensity by countries shows that there is a clear relationship between the estimated parameter values for quadratic trend term and the R&D intensity with a very significant Spearman's correlation coefficient value of 0.63. Figure 2 presents the graphs of the parameter values of the quadratic trend from pooled estimation and the R&D intensity of the 12 EU-countries and USA on average during 1987–2003. The time paths of the R&D intensity are presented in the Figure A2, Appendix.

Figure 2. **Parameter estimates for quadratic trend and R&D intensities by countries**

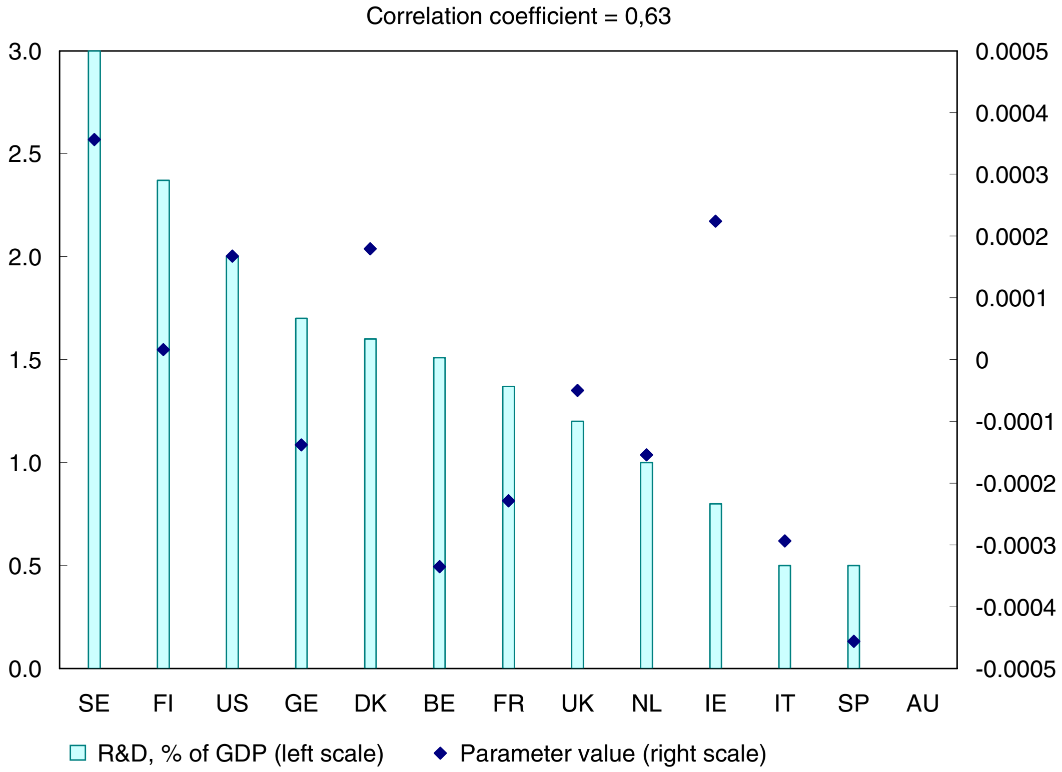


Figure 2 shows that the highest R&D intensities are found in Sweden and Finland, where at the same time the quadratic trend received statistically significant positive values in the estimation. On the contrary, the lowest R&D intensities are found in Italy and Spain with large negative and statistically significant coefficient estimates for the quadratic trend. Clear outliers in the relationship between the level of R&D intensity and speeding up of technological progress are Belgium and Ireland. Below we suggest some tentative explanations for their different behaviour.

In case of Ireland, high productivity of its industry is largely a result of extremely well performing foreign owned ICT and Pharmaceuticals sector firms. Productivity growth in these companies is likely to benefit from the R&D effort of the parent company and thus spill over effects from oversees R&D effort is large in case of Ireland. These spill over effects are naturally not taken into account in the simple measure or R&D activity used here. Consequently, in case of Ireland, the official R&D figure may underestimate the effective R&D effort.

In case of Belgium, the situation is opposite to Ireland: relatively high R&D effort does not seem to translate into speeding up of technological progresses. Like Ireland, also Belgium is characterized by a large presence of subsidiaries of multinational companies and openness. It benefits from openness through access to international technology market, but a virtuous circle of technology and innovation spill over between foreign subsidiaries and domestic firms has not occurred. For instance Dumont and Meeusen (2000) argue that the position of Belgian firms as partners in international strategic alliances is comparatively weak. Furthermore, a lack of absorptive capacity of domestic firms may undermine the relationship between R&D and productivity performance in Belgium.

In order to shed more light on the estimation results, we calculate the time path of the technical progress for each country, using the equation (3.2) and transforming it into the form (5.5)

$$A = \frac{Y}{L} \Big/ \left(\frac{K}{L}\right)^{\alpha} \qquad (5.5)$$

This is equivalent to the Solow's (1957) equation for the technical change. We call here the term A for technical change or progress but it includes naturally all the things outside K and L which influence the production capacity of the country.

The calculated time paths of the technical change are presented in Figures 3.1 and 3.2. The value for the production elasticity parameter α has been taken from the panel data estimation results from Table 1, Column I, since this parameter value corresponds well the estimation results of the earlier studies. Consistently with out estimation results, the Figure 3.1 presents the time paths of the technical trends of the countries where the parameter value of the quadratic trend received a positive value. The figure suggests that technological progress has accelerated in Sweden, Finland and Denmark in the 1990s, while in the US and Ireland speeding up of technological progress has started already in the 1980s. In all the other countries, technical progress seems to depend linearly on time, or in some cases like Spain and Italy, it has even slowed down since mid-1980s (Figure 3.2).

Figure 3.1 **Technical progress**

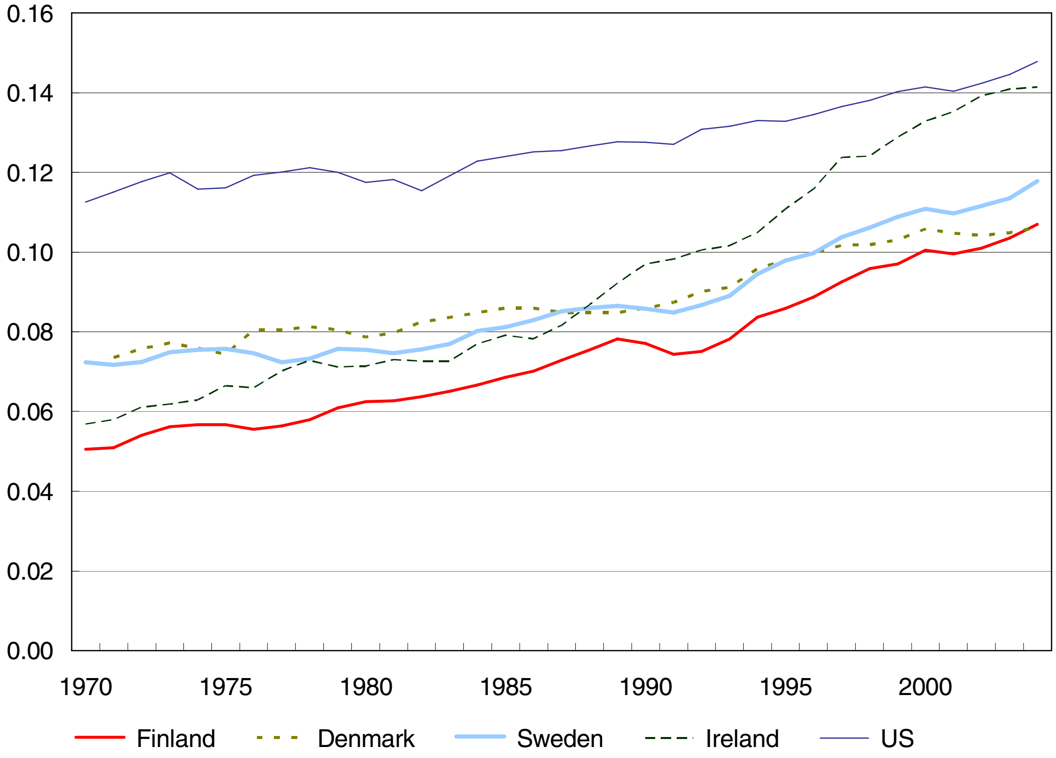
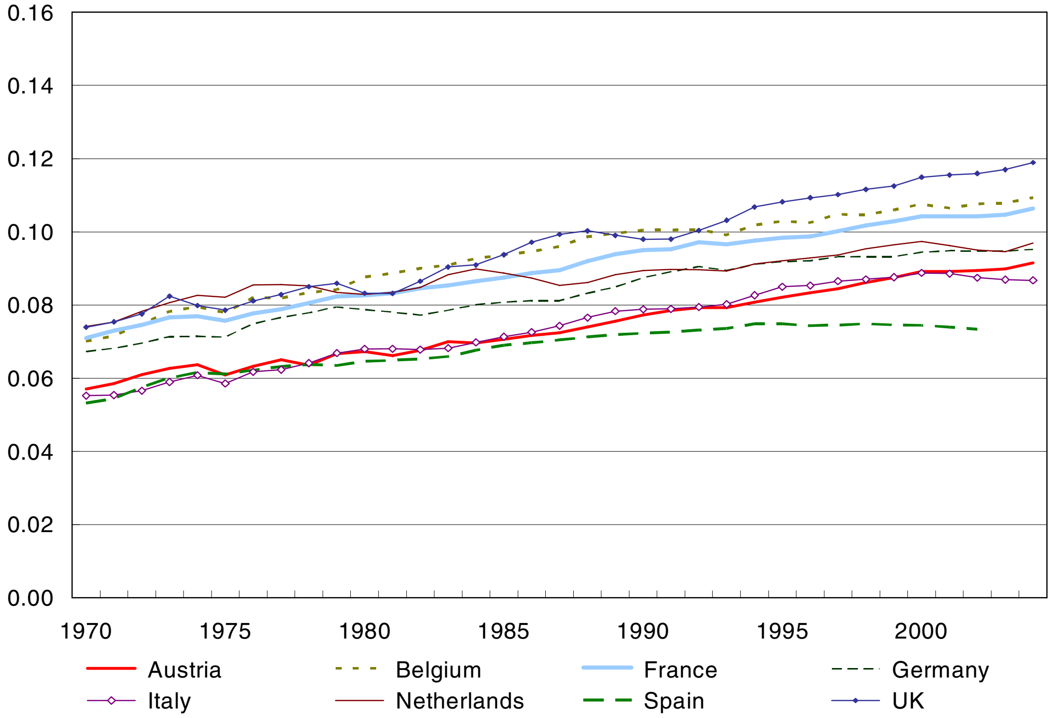


Figure 3.2 **Technical progress**



Given an indicative relationship between R&D and the non-linear part of the technical progress, we then perform a formal analysis by regressing the technical progress on investments into the R&D. The country specific R&D investments are shown in the Appendix, in Figure A2. In order to avoid the possibility of a spurious relationship between R&D investments and technical trend, we express the R&D variable as a share of GDP and use its one year lagged logarithmic change as an explanatory variable for the logarithmic change in technical progress. Furthermore, we separate between, private sector R&D and public sector R&D investments in our regressions. The estimation results are presented in Table 3.

In the panel estimation the private sector R&D variable is highly significant with t-value of 4.58. Also the total economy R&D variable is significant with t-value of 2.25. R&D outlays are thus very important single explanatory variable for technical progress. Looking at the individual country regressions we find that R&D investment is significant only in the case of Finland, Ireland and Netherlands.[12] In all the other countries R&D investments does not become significant. Hence, the country level estimation results support only weakly the indicative relationship between R&D spending and speeding up of technological progress found in Figure 2. Partly this may be explained by the fact that the data used in this estimation spans only from 1987 to 2003.

Concerning the discussion on the influence of the public R&D investment we repeat the estimations using a share of public R&D investment as explanatory factor. It turns out that public R&D investment is not significant in the regression. We get the same result using the R&D investment on high education as an explanatory variable.[13]

We are thus left with mixed evidence as to whether R&D investments have contributed to the speeding up of technological progress or not. There is some evidence that small countries investing heavily on R&D have been able to benefit from their R&D investments while in the large EU countries, R&D investments have had at most limited impact on growth during the last 20 years.

In the literature (Jones, 1997) it has been suggested that R&D investments are much under their optimal level in most of the EU-countries (and this has been one of the motivation of Lisbon agenda too). One may thus speculate with the possibility that there exists some threshold level of R&D that is needed to attain higher growth. There can be also many other factors that explain the divergent relationship between technical progress and R&D investment across countries on the one hand, and divergent growth performance on the other. In the next section, we allow for more flexible form of production function and Harrod neutral technological development.

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[12] Lagging R&D with different time interval does not change the results significantly.

[13] This result is in contradiction with Aschauer (1989). However, he accounts also for the public sector infrastructure investment, that is missing from our data of public sector R&D.

Table 3. **Technical progress and investment in the R&D**

Panel data estimation results (restricted)				
Panel estimates	1 Private	2 All	3 Public	4 High education
Coefficient of RD investment	.078 (4.52)	.068 (2.25)	.008 (0.76)	.015 (1.14)
R^2	0.058	0.068	0.002	0.003
SSR	0.040	0.052	0.053	0.053

Coefficient estimates for individual countries

Country	R&D
Belgium	-.005 (-.081)
Denmark	.094 (1.68)
Finland	.178 (3.03)
France	-.043 (-.556)
Germany	-.004 (-.050)
Ireland	.128 (2.32)
Italy	-.167 (-.323)
Netherlands	.092 (3.24)
Sweden	.128 (1.20)
Spain	-.045 (-1.55)
United Kingdom	-.014 (-.157)
United States	.030 (.546)

t-ratios are inside parentheses.

6 Estimation of the CES-production function

6.1 Nonlinear form

In above analysis we imposed the elasticity of substitution between capital and labour equal to one and assumed Hicks neutral technical change. These choices are typically motivated by the fact that factor income shares have been relatively constant since the WWII, particularly in the US. However, in continental Europe the situation is more heterogeneous. For instance, Willman (2002) points out that after increasing strongly in the 1970s, the share of labour income in GDP in the euro area decreased continuously in the two subsequent decades. There are also relatively large differences in factor shares across the countries, as reported for instance Duffy and Papageorgiou (2000). Hence, Cobb-Douglas specification of production technology may not be the most appropriate choice for the cross-section growth analysis conducted previously.

Furthermore, there has been recently plenty of discussion on the relationship between the elasticity of substitution and the growth rate of the economy. Klump and De La Grandville (2000) have shown that when two countries start from common initial conditions, a country with a higher elasticity of substitution will always reach a higher income per head.[14] Higher degree of substitutability may thus provide an explanation why some countries have higher technical progress than others irrespectively on how much they invest on technological development.[15]

Finally, CES production technology admits a possibility of long-run endogenous growth if the elasticity of substitution between capital and labour is significantly greater than unity. Under certain parameter constellations, there is no need to assume exogenous technological development to explain long-run growth.[16] It is also possible that the elasticity of substitution evolves over time along the development path of the country as a function of endogenously determined input shocks (Romer, 1990). It has also been argued that R&D investments may affect on substitution elasticity of the economy and thus contribute to higher growth indirectly.

In this section, we thus estimate the CES production function allowing for both Hicks neutral and Harrod neutral technical change. The Harrod neutral

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[14] Ky-Huyang (1991) find some support for Klump and De La Grandville (2000) hypothesis using the data from South Korea and from the US.

[15] Alternatively, higher elasticity of substitution increases possibilities to produce at given level of output with different factor combinations. Hence, entrepreneurs can choose more flexibly the optimal combination of technology, for instance, in response to disturbances hitting the economy, and this may contribute positively to growth.

[16] The reason for this is that the marginal productivity of capital remains positive even when the capital stock approaches infinity (see for instance Barro and Sala-i-Martin, 1995).

specification of technological progress permits technological change to affect a ratio of marginal productivities between input factors. This makes CES production function consistent also with constant factor shares found for instance in the US.

The constant elasticity of substitution production function with Hicks neutral technical change can be written into a form

$$Y_{it} = A_0 e^{\gamma t+\varepsilon_{it}}\left[\delta K_{it}^{-\rho} + (1-\delta)L_{it}^{-\rho}\right]^{-\frac{\upsilon}{\rho}} \tag{6.1}$$

In equation (6.1) A_0 denotes an initial value of the scale factor A and $e^{\gamma t+\varepsilon_{it}}$ denotes Hicks neutral exogenous technological growth process. $\rho,\delta \geq 1$ and υ are substitution, distribution and returns-to-scale parameters. Notice that, under the CES-production technology, the capital's share of output is given by

$$S_K = \frac{\delta K^{-\rho}}{\delta K^{-\rho} + (1-\delta)L^{-\rho}} \tag{6.2}$$

where δ depends on the values of K, L and ρ. The restriction that $S_K \in [0,1]$ implies that $\delta \in [0,1]$. In addition to $\partial_{S_K}/\partial\sigma \succ 0$, so that for a given ρ, K and L, a higher value for δ is associated with a higher S_K. The substitution parameter ρ is related to the marginal rate of substitution of K for L by the equation (6.4)

$$\sigma = \frac{1}{1+\rho} \tag{6.3}$$

In the Harrod neutral case we express production function such that to allow for non neutral technological change

$$Y_{it} = \left[\delta(A_0 e^{\gamma_K t}K_t)^{-\rho} + (1-\delta)(A_0 e^{\gamma_L t}L_t)^{-\rho}\right]^{-\frac{\upsilon}{\rho}} \tag{6.4}$$

where the capital and labour efficiency are allowed to grow at rates of γ_K and γ_L.

We estimate equations (6.1) and (6.4) by nonlinear least squares (NLLS) for entire panel with 455 observations and also by individual countries between years 1970–2004. The coefficient estimates using the unrestricted model equation (6.1) are provided in the Table 4.a ρ and γ parameters were estimated by fixing δ and υ because we cannot solve all the parameters at the same time in the single equation. We allow for both linear and non-linear time trend of technical progress.

We see in the Table 4.a that the coefficient estimates of ρ and γ are significantly different from zero and economically plausible when δ has been fixed at 0.30 and υ has been set equal to one. The latter implies constant returns-to-scale, found in other estimations with larger cross-country data sets (see Duffy and Papageorgiou, 2000). Estimated coefficients imply that the marginal rate of substitution between capital and labour is 0.70, which is significantly below one. The value of the rate of substitution depends on the value of the distribution parameter δ. So we have estimated the production function with different values of δ and selected the model with the best fit into the data. There is large interval where the explanation of the model is almost as good.

Table 4a. **Estimation results of equations 6.1 and 6.4**

Estimated parameter	**1**		**2**	
ρ	0.43	0.44	1.23	1.21
	(2.28)	(2.38)	(15.59)	(28.57)
σ	0.7	0.7	0.45	0.45
γ_1	0.0056		-0.012	
	(2.31)		(2.73)	
γ_2		0.0009		-0.0002
		(2.43)		(2.24)
R2	0.976	0.976	0.986	0.976

t-values in parenthesis. Estimation sample is 1970–2004. Column 1 refers to estimation results of equation 6.1 and column 2 to 6.4. In the case of Harrod neutral technical change (column 2), we report the estimated coefficient for labour augmenting technical change only. γ_1 (γ_2) indicates the coefficient of a linear (quadratic) trend.

In addition we estimate the CES-function for individual countries using the same estimation method and parameter assumptions (see Appendix A3). The largest parameter estimates of the substitution elasticity are found for Finland, Netherlands and France. For some countries we are not able to solve the individual country equations by non-linear-least-squares. When interpreting these results, it is useful to bear in mind that the identification of substitution parameters can be rather weak due to the problems mentioned on page 10 of this study.

Taking account the estimation results with the CD-production function we estimate the CES-function by assuming nonlinear time trend of technical progress. The estimation results are presented in the Table 4.a. The estimated parameters ρ and γ are statistically significant and economically plausible. The estimated elasticity of substitution is around 0.70 both under linear and non-linear technological development. Interestingly, the non-linear trend term is significant, while this was not the case when C-D-production function was used. Turning into individual country estimates substitution between capital and labour are highest in the US, Finland, Netherlands and Austria (see Appendixes A3 and A4). Another interesting finding is that the parameter ρ is more often significant when compared to the model with linear time trend. When both linear and non-linear trends are included in the regression, neither of them remains significant. In general, it seems that the nonlinear trend term fits the data slightly better than the linear trend. Repeating the estimation under the assumption that technical progress is Harrod neutral change the results in expected direction (see Column 2 in Table 4a). In those countries where factor income share is relatively constant, the estimated elasticity of substitution will be biased upward under Hicks neutral technical change. This has been discussed extensively for instance in Antràs (2004). The estimated substitution parameter (Column 2) implies clearly a lower degree of substitution between capital and labour. The point estimate for σ in the whole sample is 0.45, being in line with the results presented by Antràs (2004). However, the parameter estimates for labour augmenting technical trend, both for quadratic and linear trend is negative, being in contrast to typical balanced growth path assumption. Capital augmenting technical trend is not significant in either of the regressions.

Finally, we test for the constancy of the elasticity of substitution and estimate the CES-function by allowing for substitution parameter to be a linear function of time. Formally, we estimate the following equation

$$\log Y_{it} = \alpha - \frac{1}{\rho + \theta * t} \times \log\left[\delta (K_t)^{-\rho} + (1-\delta)(e^{\gamma_L t} L_t)^{-\rho-\theta * t}\right] \qquad (6.5)$$

Parameter θ captures the possibility that elasticity of substitution parameter has increased or decreased over time depending on whether the estimated coefficient is negative or positive. The estimation results are presented in Table 4b. As suggested by a negative coefficient for parameter θ there is indeed a clear increase in the elasticity of substitution between capital and labour. The results are not sensitive to assumption about non-linearity of the technological change.

Table 4b. **Estimation results of equation 6.5**

Estimated parameter	
δ	0.35
α	-2.64
	(-38.23)
ρ	0.26
	(2.67)
θ	-0.014
	(-3.20)
γ	0.007
	(2.64)
R^2	0.99

t-values are inside parenthesis. Estimation period is 1970–2004. Estimation is carried out using a two-step produce where ρ is first fixed at 0.20 and the other parameters were estimated freely. At the second stage, δ was fixed at the first-stage estimated value and the other parameters were estimated freely.

6.2 Estimation of CES production function based on the first order conditions

We have noticed from the previous estimations of the nonlinear CES-production function that the elasticity of substitution between capital and labour is not stable over time. In order to gain more understanding about the development of the substitute elasticity between capital and labour we estimate the substitution elasticity from the first-order conditions for profit maximizations of the CES-production function. Once more, we estimate the production function in the Hicks-neutral and Harrod-neutral case. We use data from real compensation per employee in order to measure the real value of marginal labour product.

Under Hicks' neutral technological development, technological efficiency does not have an effect on the ratio of marginal products at given capital-labour ratio. The first-order condition of the marginal labour product is of the form

$$\log(Q_t / L_t) = \alpha_1 + \sigma_1 \log(W_t / P_t) + \varepsilon_{1,t} \tag{6.6}$$

where W_t is the total labour cost per employee and P_t is the price index of the production. σ_1 is the estimate of the substitution elasticity between capital and labour. However, it is shown in the literature (Pol Antràs, 2004) that allowing for biased technological change leads to estimates of the elasticity of substitution that are in general significantly lower than one. Under biased technological change the above equation is of the form

$$\log(Q_t / L_t) = \alpha_2 + \sigma_2 \log(W_t / P_t) + (1 - \sigma_2)\lambda_L \cdot t + \varepsilon_{2,t} \qquad (6.7)$$

The estimation results of the equations (6.7) and (6.8) are presented in the Table 5a and 5b. In the Hicks' neutral case (equation 6.6) the estimated elasticity of substitution (Table 5b) is comparable to the earlier results by Antràs (2004) and Berndt (1976). Antràs (2004) shows that there is problem of omitted variables in the estimated equation, making the estimated elasticity of substitution biased towards unity.

When the econometric specification is changed to take into account biased technical change, the estimated substitution elasticity becomes clearly lower (Table 5a). The substitution parameter is estimated to be 0.78 in the whole sample. Both linear and non-linear technological trends are significant, the non-linear term being somewhat more precisely estimated.

Table 5a. **GLS estimation results for the first order condition (6.7)**

	1970–2004	
σ	.71 (33.87)	.78 (36.86)
γ_1	.01 (24.22)	
γ_2		.0002 (22.04)
R^2	0.740	0.932

t-values are inside parentheses. Estimates are derived from the panel data. γ_1 (γ_2) indicates the coefficient of a linear (quadratic) trend.

Table 5b. **Alternative estimates for equations (6.6) and (6.7)**

Estimated parameter	1	2	3	4	5	6
σ	1.13 (30.22)	.79 (17.18)	1.15 (53.61)	.78 (36.86)	1.12 (212.5)	.78 (176.3)
γ_2		.0002 (11.13)		.0002 (22.04)		.0002 (88.72)
Estimator	OLS	OLS	GLS	GLS	SUR	SUR
Nature of technical change	Hicks	Harrod	Hicks	Harrod	Hicks	Harrod
R^2	0.669	0.741	0.864	0.932	0.991	0.995

t-values are inside parentheses. γ_2 indicates the coefficient of a quadratic trend. Estimation period is 1970–2004.

In addition, the significance level of the quadratic trend increases clearly when we control for fixed country effects. The substitution elasticity is also higher when we control the model with fixed effects. Allowing for random country effects does not change this conclusion. We estimate the CES-production function also with GLS and SUR estimation methods. It is evident that with SUR and GLS estimation methods the results are more precise than with OLS-method.

The estimation results of the first-order conditions of the CES-production function show that the substitution elasticity between capital and labour has been below one on average during the last 35 years. However, we are unable to say precisely what the right level is, because the estimation results between nonlinear and linear model differ. One relatively robust finding however is especially with nonlinear model that the substitution elasticity has increased during the estimation period, and this increase seems to be associated with speeding up of non-neutral technical change. This can be seen from the following Figure 4. in which we drawn the time varying estimate of the elasticity of substitution from equation (6.8).[17] We have controlled the labour augmented technical progress by countries. In the Figure, the elasticity of substitution between capital and labour increases from 0.53 to 0.83 during the sample period.

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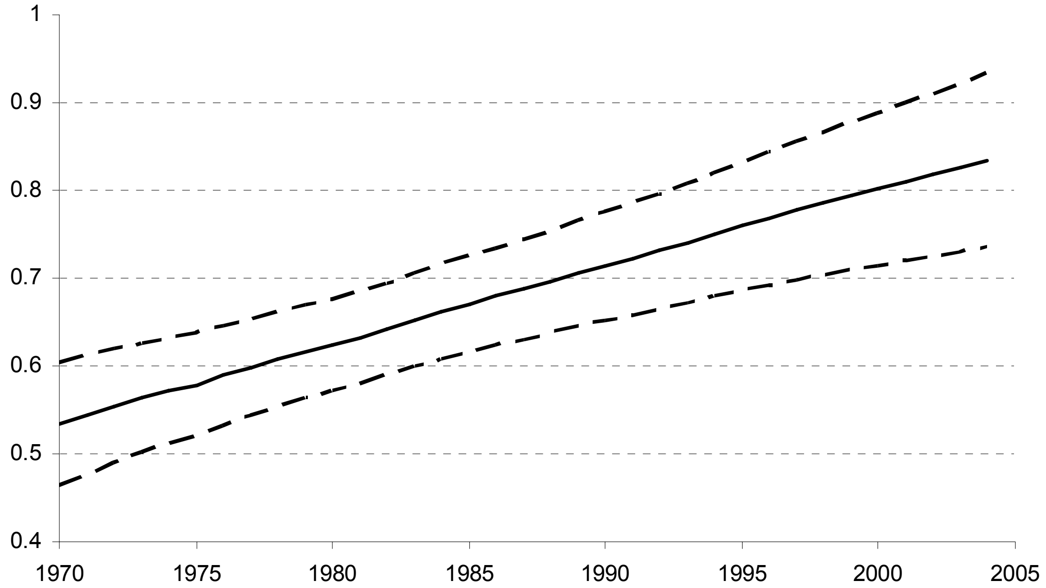
[17] Castro and Coen–Pirani (2005) and Depuy and Marey (2004) find that the US production function shifted in a non neutral way over the last decades due to technical and organizational changes. They suggest that the elasticity of substitution depends in non neutral way of the technical change.

Figure 4. **Time varying elasticity of substitution between capital and labour**



Dotted lines are 95% confidence intervals.

7 Conclusions

This paper's estimation results suggest that technical progress differ widely across countries, both in levels and in growth rates. In particular, in the ICT – using and producing countries, technical progress has been rapid and even accelerating, while in a number of European large countries technical progress has been rather slow. The results provide some evidence that the country differences in technical progress and R&D investments are related. Those countries that have fulfilled the Lisbon agenda and invested heavily on R&D, have also enjoyed rapid growth, generated primarily by the speeding up of technical progress.

The estimation results based on the CES-production function show that the substitution elasticity between capital and labour may have been on average below one during the last 35 years. However, we are unable to say precisely what the right level is because the estimation results in various specifications differ widely. Nevertheless, one robust finding is that the substitution elasticity has increased over time.

Hence, our results suggest that there is no growth paradox in Europe: R&D factor and the elasticity of substitution between capital and labour that have been known to be important factors of economies' growth potential, do explain a significant part of the divergent growth performance of the European economies as well.

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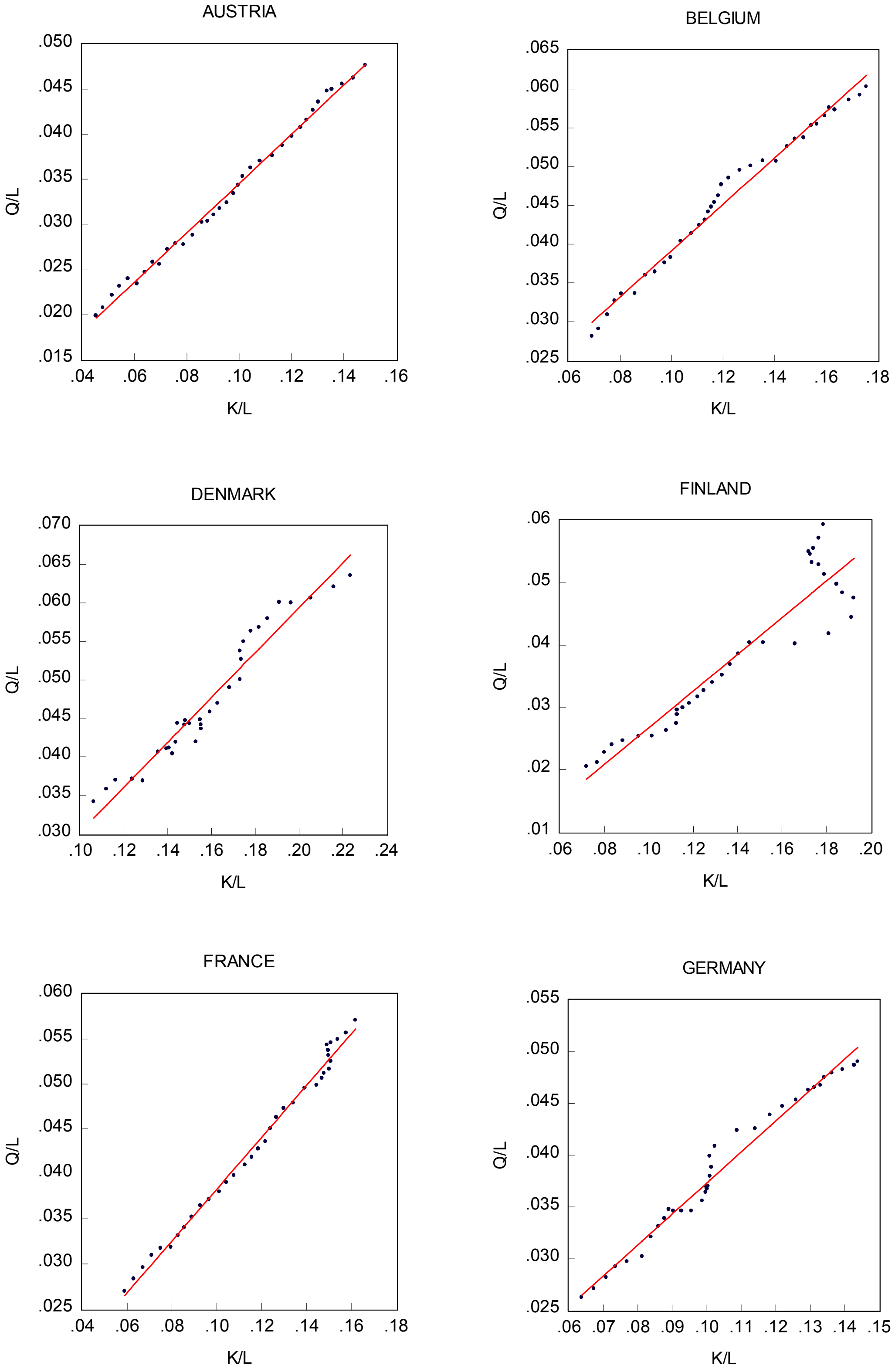
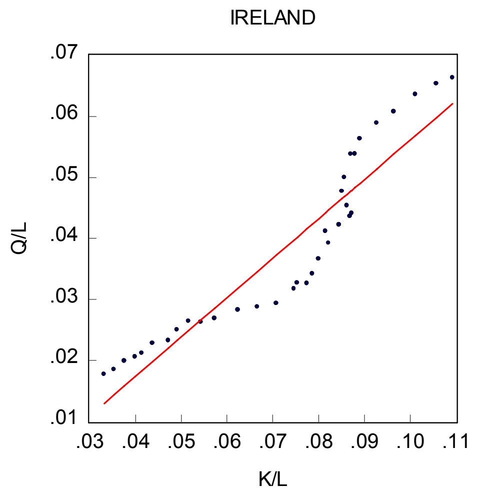
Appendix

Figure A1. **Productivity and capital intensity**

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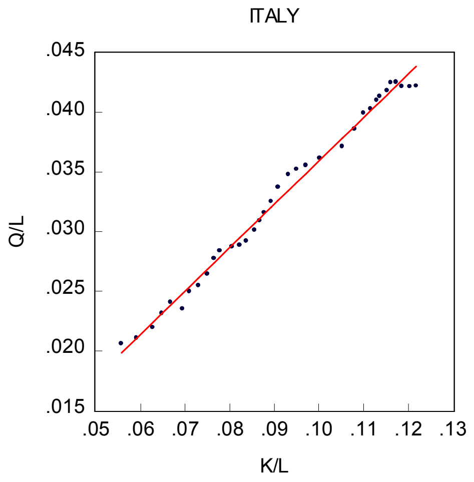
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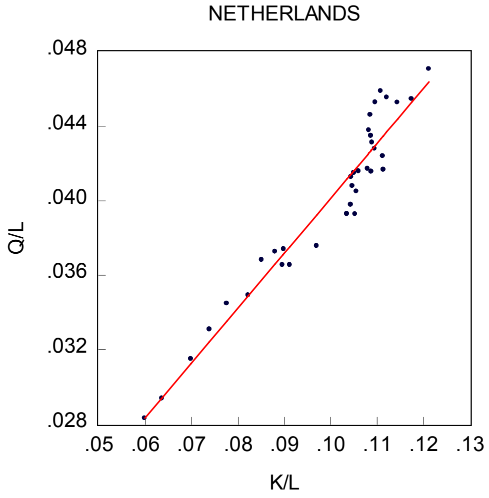
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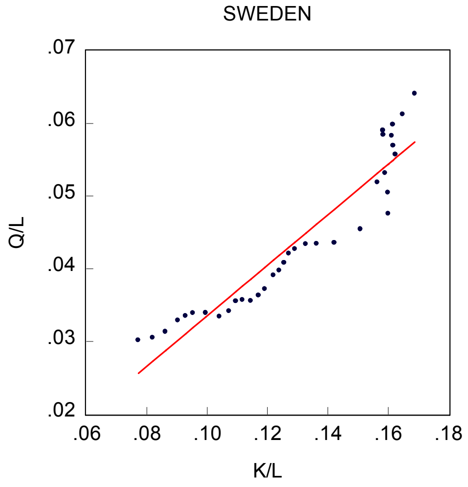
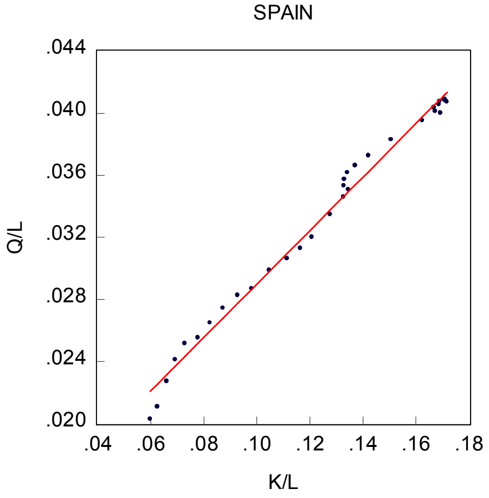
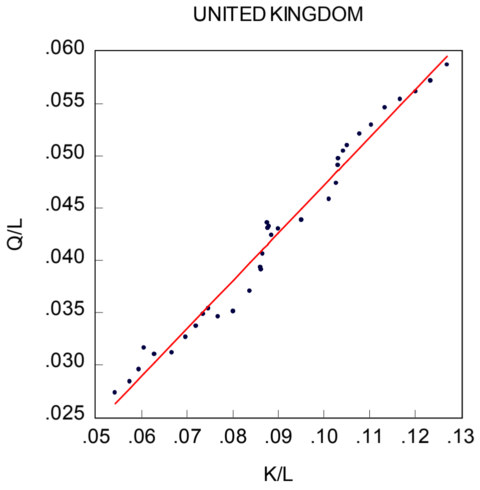
.13
K/L


SWEDEN
Q/L
.07
.06
.05
.04
.03
.02
.06
.08
.10
.12
.14
.16
.18
K/L


SPAIN
Q/L
.044
.040
.036
.032
.028
.024
.020
.04
.06
.08
.10
.12
.14
.16
.18
K/L


UNITED KINGDOM
Q/L
.060
.055
.050
.045
.040
.035
.030
.025
.05
.06
.07
.08
.09
.10
.11
.12
.13
K/L

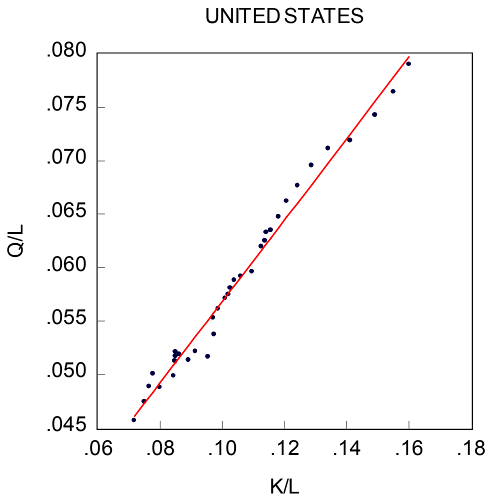
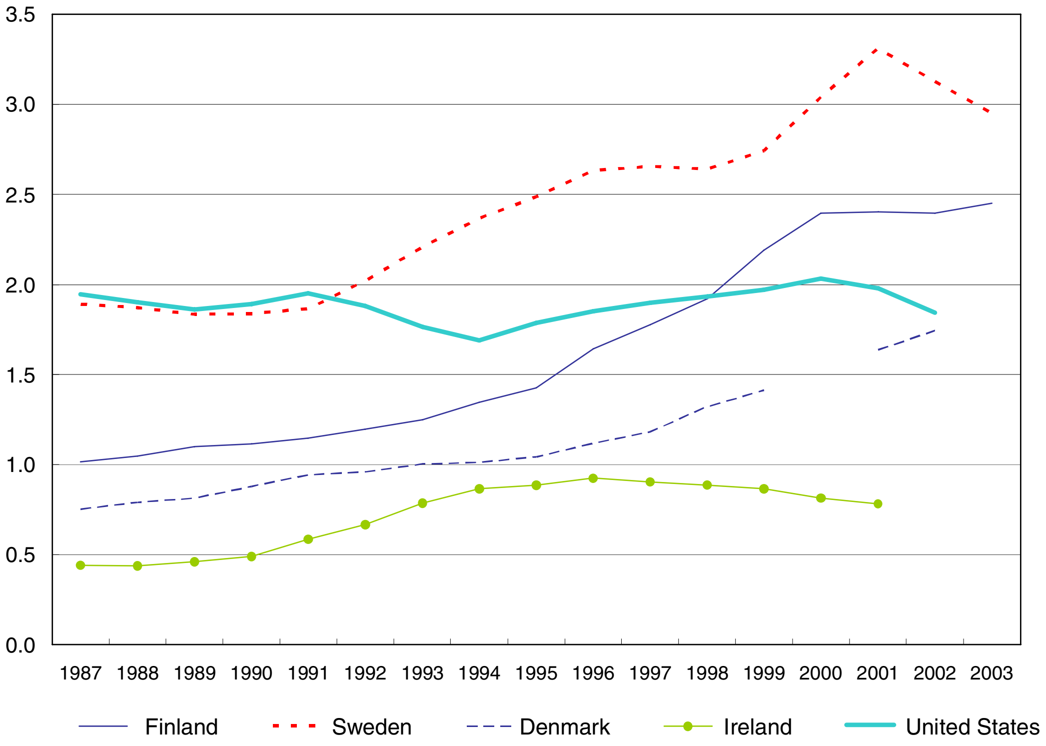
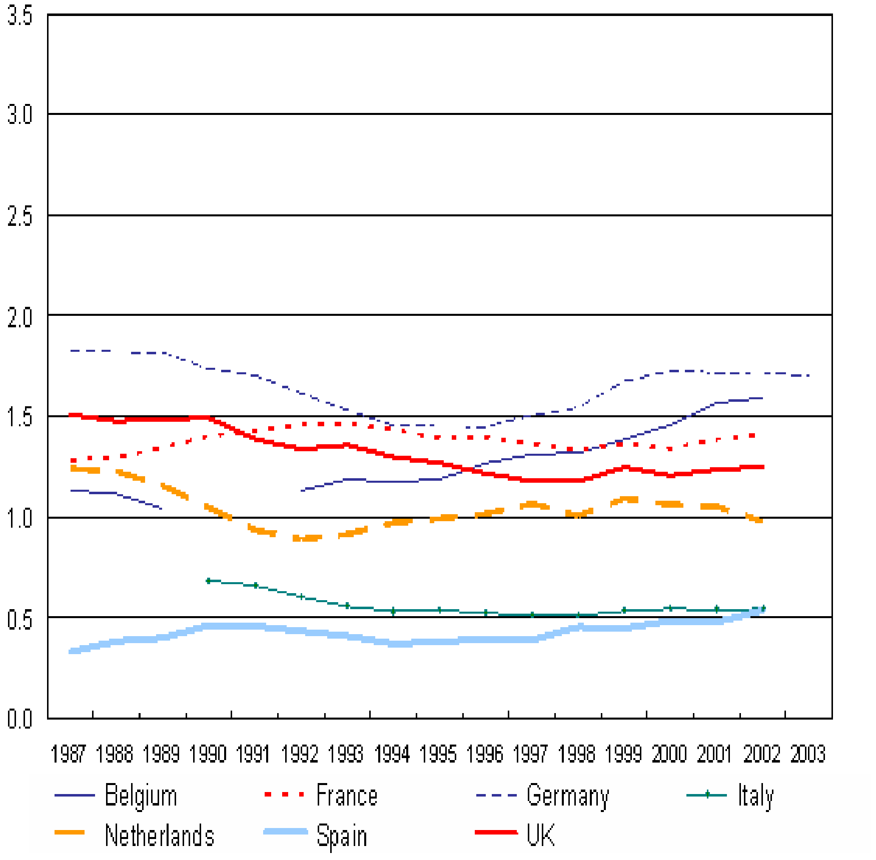


Figure A2.1 **R&D expenditure, total business enterprise, % of GDP**



Source: OECD STAN

Figure A2.2



Source: OECD STAN

Table A1. **Pool unit root test**

	Statistic	Probability	Observations	Transformations
Levin, Lin&Chu	6.65	1.00	1344	level
	-5.42	0.00	1341	first difference

Null hypothesis: unit root

Table A2. **Wald test for parameter equality by individual countries**

	F-statistics	Degrees of freedom	Probability
K	16.47	12.00	0.00
L	14.42	12.400	0.00
Linear trend	29.03	12.411	0.00
Quadratic trend	36.96	12.411	0.00

Null hypothesis: parameters equal

Table A3. **Estimation results of CES production function for individual countries**

	ρ	σ	γ_1	R^2
Austria	.04 (.63)	.96	.014 (13)	0.998
Belgium	.89 (3.55)	.52	.001 (.43)	0.993
Denmark	.003 (.01)	.99	.012 (6.30)	0.981
Finland	-.32 (2.39)	1.47	.026 (25.6)	0.992
France	.31 (8.12)	.76	.008 (15.1)	0.998
Germany	.28 (1.69)	.78	.008 (3.82)	0.993
Ireland	–	–	–	
Italy	–	–	–	
Netherlands	.25 (3.40)	.80	.005 (7.88)	0.980
Sweden	-1.99 (-.22)	-1.0	.02 (8.62)	0.980
Spain	.54 (9.63)	.65	.001 (1.18)	0.996
United Kingdom	–	–	–	
United States	.35 (2.23)	.74	.004 (2.61)	0.997

t-ratios are inside parentheses. δ is set at 0.30.

Table A4. **Estimation results of CES production function for individual countries**

	ρ	σ	γ_2	R^2
Austria	.39 (9.07)	.72	.0001 (10.41)	0.997
Belgium	1.21 (5.28)	.45	-.0004 (-1.08)	0.993
Denmark	.15 (.72)	.87	.0002 (7.36)	0.984
Finland	.34 (4.36)	.75	.0003 (19.57)	0.986
France	.51 (15.88)	.66	.0009 (12.71)	0.998
Germany	.76 (4.22)	.57	.0003 (1.14)	0.990
Ireland	.18 (1.63)	.85	.0004 (14.41)	0.994
Italy	3.36 (.04)	.23	-.000006 (-.01)	0.993
Netherlands	.37 (5.85)	.73	.0007 (7.85)	0.995
Sweden	-.17 (-1.25)	1.21	.0003 (17.93)	0.989
Spain	.58 (13.50)	.63	.0001 (.80)	0.996
United Kingdom	.59 (4.30)	.62	.0001 (4.40)	0.993
United States	-.18 (4.30)	1.22	.0001 (4.40)	0.999

t-ratios are inside parentheses. δ is set at 0.30.

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