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Public and Private Inputs in Aggregate Production and Growth: A Cross-country Efficiency Approach

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Public and Private Inputs in Aggregate Production and Growth: A Cross-country Efficiency Approach*

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Abstract

In a cross section of OECD countries we replace the macroeconomic production function by a production possibility frontier, TFP being the composite effect of efficiency scores and possibility frontier changes. We consider, for the periods 1970, 1980, 1990, 2000, one output: GDP per worker; three inputs: human capital, public physical capital per worker and private physical capital per worker. We use a semi-parametric analysis, computing Malmquist productivity indexes, and we also resort to stochastic frontier analysis. Results show that private capital is important for growth, although public and human capital also contribute positively. A governance indicator, a non-discretionary input, explains inefficiency. Better governance helps countries to achieve a better performance. Non-parametric and parametric results coincide rather closely on the countries movements vis-à-vis the possibility frontier, and on their relative distances to the frontier.

JEL: C14, D24, H50, O47
Keywords: economic growth, public spending, efficiency, Malmquist index.

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Contents

Non-technical summary

In a cross section of OECD countries we replace the macroeconomic production function by a production possibility frontier, Total Factor Productivity being the composite effect of efficiency scores and possibility frontier changes. We consider, for the periods 1970, 1980, 1990, 2000, one output, GDP per worker, and three inputs, human capital, public physical capital per worker and private physical capital per worker. We use a semi-parametric analysis, computing Malmquist productivity indexes, and we also resort to stochastic frontier analysis.

Results show that: i) private capital is important for growth, and contributes in a significant manner to input accumulation; ii) public and human capital contribution is usually estimated as positive, but, depending on the specification, it was not always significant from a statistical point a view; iii) a governance indicator (government effectiveness), a non-discretionary input, explains inefficiency. Our results also support the idea that better governance helps countries to achieve a better performance and to operate closer to the production possibility frontier.

Deterministic and stochastic estimation methods provide similar results and conclusions. Notably, non-parametric and parametric results coincide rather closely on the countries movements vis-à-vis the possibility frontier and on their relative distances to the frontier. The number of countries that can be nominated as efficient was stable throughout the period, with six or seven countries usually on the frontier (Belgium, Canada, Spain, Italy, Japan, Portugal, and the USA). In addition, it is worthwhile noticing the steady improvement in (technical) efficiency throughout the time sample for such countries as Ireland, Norway, and Finland, with the first two countries reaching the efficiency frontier in 2000, and depicting the biggest TFP change in that period. An opposite development can be seen for the case of Japan that shifts away from the efficiency frontier between 1970 and 2000.

Our estimations imply that policy may matter for growth by at least three different channels. One is public investment. The public capital elasticity is imprecisely estimated. These estimates and their variability are consistent with other results available in the literature concerning the effects of public investment across countries. The policy content of these results has to be seen with caution – macroeconomic analysis can be no substitute for the careful evaluation of each public project on its own merits.

The second channel by which policy operates is governance. Our governance indicator (government effectiveness), depends on policy in the broad sense of the word, i.e., results not only from policy measures, but also from the way institutions are at the same time shaped by history and designed by contemporaneous men and women.

Finally, our results are also consistent with the importance of human capital formation for growth. There is some evidence of a positive macroeconomic return for human capital investment. Some countries in our sample, even if they are close to or at the efficiency frontier (Portugal, Spain), are probably limited in their growth prospects by their relative human capital scarcity.

1. Introduction

The empirics of growth are generally based on an aggregate production function approach. In a typical framework, production depends on labour, physical capital, human capital and total factor productivity (TFP). Total factor productivity is an unobserved variable, and is generally estimated following a procedure that involves: i) specifying a production function (e.g. of a Cobb-Douglas variety); ii) estimating or calibrating the production function parameters; iii) and obtaining TFP as a Solow residual, the change in production that is not explained by changes in production factors.

The researcher is very often interested in TFP estimates. For example, one may be interested in how TFP differs across countries in response to different environments likely to affect growth (policies, governance, institutions...), and also in how TFP changes throughout time. However, TFP estimates obtained in the manner described above heavily depend on the assumptions about the production function.

In this paper we replace the macroeconomic production function by a production possibility frontier. TFP is computed as the composite effect of efficiency scores and possibility frontier changes. The efficiency score provides information on how far away a country is from the frontier, given the inputs it is using in production. We will consider, in a cross section of countries, one output: GDP per worker; three inputs: human capital, public physical capital per worker and private physical per worker; and an environmental variable (a non-discretionary input), related to public policy, under the form of a governance indicator. These variables are usually useful to explain changes in country efficiency scores and therefore in the distance to the frontier.

We use two different methods to estimate the production possibility frontier.

Firstly, we apply the semi-parametric analysis with non-discretionary inputs in a similar manner as in Afonso and St. Aubyn (2006). This approach has one important advantage – the number of a priori assumptions is much smaller, as there is no need to specify a functional form for the relationship between inputs (production factors) and output (income). Namely, no a priori hypothesis is made in what concerns returns to scale or substitution elasticities.[1] The only restrictions imposed on the production frontier are that it is convex and monotonic (increasing factor quantities does not decrease production possibilities). Moreover, we take advantage of the time series dimension to assess the developments of TFP by computing Malmquist productivity indexes.

Secondly, we resort to stochastic frontier analysis (SFA). This is a parametric method, so that a specific functional form for the production possibility frontier has to be assumed. It retains, however, the idea that countries operate either on or below a production frontier. Consequently, improvements may be attained in two different ways, either by decreasing the inefficiency score, or by sharing the increased possibilities given by an upward shift in the frontier. Both efficiency measurement methods allow for a fruitful distinction between the sources of improvement.

Discretionary inputs are those that can be changed at will by the decision making unit (DMU). Taking a national economy as a DMU, we consider it chooses each period which quantity of production factors it employs (human and physical capital, labour). Non-discretionary or environment inputs are inputs which are pre-determined at least in the short to medium run. They affect the DMU operational conditions and its distance to the frontier. We consider government effectiveness as a non-discretionary input.

By resorting to the World Bank indicators, our paper provides evidence that government effectiveness is an important non-discretionary factor explaining inefficiency, supporting the idea that better governance helps developed countries to achieve a better performance and to operate closer to the production possibility frontier.

[1] Recall that the widely used Cobb-Douglas production function imposes simultaneously a loglinear functional form, and a unit elasticity of factor substitution and constant returns to scale.

The remainder of the paper is organised as follows. Section two briefly reviews the related literature. Section three presents the methodology used in the analysis. Section four reports and discusses the empirical analysis. Section five concludes the paper.

2. Literature

The use of non-parametric analysis to macroeconomic issues has been growing recently, notably in what concerns the assessment of public sector efficiency. For instance, Data Envelopment Analysis (DEA) became widely used to calculate changes in TFP within specific sectors (for instance, hospitals, schools, where price data is difficult to find and multi-output production is relevant), because it needs fewer assumptions about the form of the production technology. DEA analysis has also been used recently to assess the efficiency of the public sector in cross-country analysis in such areas as education and health (Afonso and St. Aubyn, 2005, 2006) and also for overall public sector efficiency analysis (Afonso et al., 2005).

A different but related small strand of the literature has applied DEA methods and the associated Malmquist TFP computations to GDP and GDP growth. Kumar and Russell (2002) and Krüger (2003) were among the first to adopt this approach. They only considered output and physical capital per worker. Henderson and Russell (2005) added human capital as an input, and Delgado-Rodríguez and Álvarez-Ayuso (2008) separated private from public capital. Apart from (important) differences in the considered sample and in the way stocks are measured, namely human capital, we also relate governance conditions to macroeconomic efficiency and factor productivity growth within this framework. Additional discussions and applications of the overall Malmquist productivity index to the traditional notion of total factor productivity can be found in Färe et al. (1994), Ray and Desli (1997), and Färe, Grosskopf and Norris (1997).

Applications of stochastic frontier analysis to infer efficiency changes in aggregate production across countries are even rarer. It is worthwhile mentioning the work of Koop, Osiewalski and Steel (2000) for Western economies, Poland and Yugoslavia, and of Mastromarco and Ghosh (2008) concerning developing countries. The former estimate a Bayesian stochastic frontier for aggregate production, considering capital and labour as production factors and decompose growth between 1980 and 1990 into input growth, technical growth and efficiency growth. Mastromarco and Ghosh (2008) estimate a stochastic production frontier for 57 developing countries for the period 1960-2000. GDP depends on two production factors, labour and private capital. Efficiency or total factor productivity is driven by technology diffusion interacting with human capital.

Some recent papers have emphasised the importance of institutions and governance as a deep determinant for growth. For instance, Olson, Sarna and Swamy (2000) claim that differences in "governance" can explain why some developing countries grow rapidly, taking advantage of catching up opportunities, while others lag behind. In these authors' assessment, the quality of governance explains in a straightforward manner and in empirical terms, something that neither standard endogenous or exogenous growth models do – why a (small) number of developing countries converge towards higher income levels and therefore display high growth rates. In this literature strand, "governance" is measurable and reflects the quality of institutions and economic policies. Acemoglu, Johnson and Robinson (2001) provide empirical evidence favouring the idea that current institutions have a strong influence on current economic performance of countries with a colonial past. These institutions, measured by the average protection against expropriation risk, are shaped by the way settlement occurred in the past, "extractive states" being opposed to "neo-Europe" colonies.

3. Methodology

3.1. DEA and the Malmquist index

The DEA methodology, originating from Farrell's (1957) seminal work and popularised by Charnes, Cooper and Rhodes (1978), assumes the existence of a convex production frontier. The production frontier in the DEA approach is constructed using linear programming methods. The term "envelopment" stems from the fact that the production frontier envelops the set of observations.[2]

The general relationship that we consider is given by the following function for each country *i*:

$$Y_i = f(X_i),\ i=1,...,n \quad (1)$$

where we have Y_i – GDP per worker, our output measure; X_i – the relevant inputs in country *i* (private and public capital per worker, human capital per worker). If $Y_i < f(X_i)$, it is said that country *i* exhibits inefficiency. For the observed input levels, the actual output is smaller than the best attainable one and inefficiency can then be measured by computing the distance to the theoretical efficiency frontier.

The analytical description of the linear programming problem to be solved in the variable-returns to scale hypothesis is sketched below for an output-oriented specification. Suppose there are *k* inputs and *m* outputs for *n* Decision Management Units (DMUs). For the i-th DMU, y_i is the column vector of the inputs and x_i is the

[2] Coelli et al. (1998) and Thanassoulis (2001) offer introductions to DEA.

column vector of the outputs. We can also define X as the $(k \times n)$ input matrix and Y as the $(m \times n)$ output matrix. The DEA model is then specified with the following mathematical programming problem, for a given i-th DMU:[3]

$$\begin{aligned} & Max_{\delta,\lambda}\, \delta \\ & \text{s. to} \quad -\delta y_i + Y\lambda \geq 0 \\ & \qquad\quad x_i - X\lambda \geq 0 \\ & \qquad\quad n1'\lambda = 1 \\ & \qquad\quad \lambda \geq 0 \end{aligned} \quad . \qquad (2)$$

In problem (2), δ is a scalar (that satisfies $1/\delta \leq 1$), more specifically it is the efficiency score that measures technical efficiency. It measures the distance between a country and the efficiency frontier, defined as a linear combination of the best practice observations. With $1/\delta < 1$, the country is inside the frontier (i.e. it is inefficient), while $\delta = 1$ implies that the country is on the frontier (i.e. it is efficient).

The vector λ is a $(n \times 1)$ vector of constants that measures the weights used to compute the location of an inefficient DMU if it were to become efficient, and $n1$ is an n-dimensional vector of ones. The inefficient DMU would be projected on the production frontier as a linear combination of those weights, related to the peers of the inefficient DMU. The peers are other DMUs that are more efficient and are therefore used as references for the inefficient DMU. The restriction $n1'\lambda = 1$ imposes convexity of the frontier, accounting for variable returns to scale. Dropping this restriction would amount to admit that returns to scale were constant. Problem (2) has to be solved for each of the n DMUs in order to obtain the n efficiency scores.

[3] We simply present here the equivalent envelopment form, derived by Charnes et al. (1978), using the duality property of the multiplier form of the original programming model.

Figure 1 presents the DEA production possibility frontier in the simple one input-one output case. Countries A, B and C are efficient countries. Their output scores are equal to 1. Country D is not efficient. Its score [*d2/(d1+d2)*] is smaller than 1.

[Figure 1]

As explained in more detail in the following section, we will deal with a panel data set, observing countries at different points in time. One would normally expect the production frontier to change over time, as well as efficiency scores. Therefore, if a country sees its production changed, usually increased, from year t to year t+1, one would like to decompose the total variation into a part attributed to changes in efficiency and another ascribed to the frontier changes.

The output Malmquist productivity index, *MPI* (Malmquist, 1953) allows this decomposition in a straightforward and intuitive way.[4] For a given country, it is defined as:

$$MPI_{t+1}(y_t, x_t, y_{t+1}, x_{t+1}) = \left[\frac{d_o^t(y_{t+1}, x_{t+1})}{d_o^t(y_t, x_t)} \times \frac{d_o^{t+1}(y_{t+1}, x_{t+1})}{d_o^{t+1}(y_t, x_t)} \right]^{1/2}, \qquad (3)$$

where $d_o^t(y_s, x_s)$ is the output distance score using the frontier at year *t* and inputs and outputs related to year *s*. In particular, $d_o^t(y_t, x_t)$ is the output efficiency score presented in the previous section and is not greater than one. However, $d_o^t(y_s, x_s)$ may be greater than one with $s \neq t$.

The *MPI* may also be written as:

[4] We present here the most important features. See Coelli et al. (1998) for a more detailed explanation.

$$MPI_{t+1}(y_t, x_t, y_{t+1}, x_{t+1}) = \frac{d_o^{t+1}(y_{t+1}, x_{t+1})}{d_o^t(y_t, x_t)} \times \left[\frac{d_o^t(y_{t+1}, x_{t+1})}{d_o^{t+1}(y_{t+1}, x_{t+1})} \times \frac{d_o^t(y_t, x_t)}{d_o^{t+1}(y_t, x_t)} \right]^{1/2}, \quad (4)$$

or, equivalently,

$$MPI_{t+1} = ECI_{t+1} \times TCI_{t+1}, \quad (5)$$

where $ECI_{t+1} = \frac{d_o^{t+1}(y_{t+1}, x_{t+1})}{d_o^t(y_t, x_t)}$ is the efficiency change index and $TCI_{t+1} = \left[\frac{d_o^t(y_{t+1}, x_{t+1})}{d_o^{t+1}(y_{t+1}, x_{t+1})} \times \frac{d_o^t(y_t, x_t)}{d_o^{t+1}(y_t, x_t)} \right]^{1/2}$ is the technology change index.

In the simple one input-one output case, the *MPI* and its decomposition has an intuitive geometrical interpretation, and this can be exemplified in Figure 2.

[Figure 2]

In Figure 2, we can observe for the exemplified DMU that it produces less than feasible under each period's production frontier. The decomposition of the Malmquist index according to equation (5) is given by the distance functions in equations (6) and (7):

$$E = \frac{y_{t+1} / y_r}{y_t / y_p} \quad (6)$$

$$T = \left[\frac{y_{t+1} / y_q}{y_{t+1} / y_r} \times \frac{y_t / y_p}{y_t / y_q} \right]^{1/2}. \quad (7)$$

According to equations (6) and (7), efficiency change (*E*) is the ratio of the output-oriented measure of Farrell technical efficiency in period *t+1* to that in period *t* and technical change (T) is the geometric mean of the shift in technology between period $t+1$ and t.

3.2. Stochastic frontier

The DEA frontier is assumed to be deterministic, and differences between the frontier and actual outputs are fully related to inefficiency. Suppose, alternatively to the DEA approach, that the frontier is stochastic. In that case, such differences may also stem from stochastic noise. Specifically, and after Battese and Coelli (1995) and Coelli et al. (2002), assume the following model:

$$\ln y_{it} = F(X_{it}, \beta) + \eta_{it} + \varepsilon_{it} \tag{8}$$

$$\eta_{it} = \theta z_{it} \tag{9}$$

where i is the country and t the time period. We have:

y_{it} – the output, GDP per worker;

X_{it} – the vector of inputs, private and public capital per worker and human capital;

β – set of production function parameters to be estimated;

ε_i – normally distributed two-sided random error;

η_i – non-negative efficiency effect, assumed to have a truncated normal distribution;

z_i – non-discretionary factors that explain inefficiency;

θ – set of efficiency parameters to be estimated.

We have specified a log linear, Cobb-Douglas function for F(.). Within this setup, and defining $\gamma = \frac{\sigma_\eta^2}{\sigma_\eta^2 + \sigma_\varepsilon^2}$, it is possible to produce a likelihood ratio statistic to test if γ=0, i.e., that there are no random inefficiency effects.

Figure 3 illustrates the SFA production possibility frontier in the simple one input-one output case.

[Figure 3]

4. Empirical analysis

4.1. Data

We use annual data for all inputs and outputs, for a set of OECD countries, covering the period 1970-2000. Our output measure is GDP, measured in units of national currency per PPS (purchasing power standard), per worker. As measures of inputs we include public capital, private capital and human capital. The three measures of capital are also scaled by worker (see the Appendix for further details and sources).[5]

Public capital was computed by using public capital to output ratios provided by Kamps (2006). Private capital was obtained by subtracting public capital from total capital. Human capital is the average years of schooling of the working age population.

Kaufmann, Kraay, and Mastruzzi (2008), based on hundreds of variables from several sources, provide six indicators for six different dimensions of governance: voice and accountability, political stability and absence of violence, government effectiveness, regulatory quality, rule of law, and control of corruption. Therefore, we use such

[5] Using output, private and public capital per employee implicitly assumes constant returns to scale in physical capital and labour and has been a common strategy in the related literature (e.g. Kumar and Russell, 2002, and Krüger, 2003, Henderson and Russell, 2005, and Delgado-Rodríguez and Álvarez-Ayuso, 2008, use physical capital per worker. From a technical point, with this hypothesis one less input is used, so that the occurence of efficiency by default in DEA is less likely and degrees of freedom in econometric estimations are increased.

composite indicator of government effectiveness (also disseminated by the World Bank), as a non-discretionary factor.

4.2. Non-parametric analysis

We report in Table 1 the output-oriented variable returns to scale, technical efficiency scores for each country, for the periods 1970, 1980, 1990 and 2000.[6] From Table 1 it is possible to observe that the number of countries that can be identified as efficient was rather stable throughout time, with seven countries usually on the frontier (Belgium, Canada, Spain, Italy, Japan, Portugal, and the USA), plus Norway in the last period. Moreover, and apart from Canada in 2000, no other country shows up as efficient by default, as can be seen by the listing of the respective peers, also reported in Table 1.

[Table 1]

In addition, it is worthwhile noticing the steady improvement in technical efficiency throughout the time sample for such countries as Ireland, Norway, and Finland, with the first two countries reaching the efficiency frontier in 2000. An opposite development can be seen for the case of Japan that shifts away from the efficiency frontier between 1970 and 2000, and depicting the biggest TFP changes in that period. Interestingly, Färe et al. (1994) who cover the period 1979-1988 for 17 OECD countries, report that the USA is the only country defining the efficiency frontier, while Japan shows up as one of the least technically efficient countries in the country sample, results that we also uncover in our broader sample.

[6] DEA scores and Malmquist indexes computations were done with the software Win4DEAP, written by Tim Coelli, available at http://www.umoncton.ca/desliem/dea/.

Table 2 reports the set of results for the Malmquist indices of efficiency, technology and total factor productivity changes for the period 1970-2000, using GDP per employee as the output measure and three inputs: private and public capital per employee and human capital per employee. The results show that, on average for this set of OECD countries, there was an improvement in total factor productivity (the change was equal to 1.021). On the other hand, the close to unit average technology change implies a small improvement in the underlying technology. Such marginal gains in technology were additionally supported by the increase in efficiency (1.019), in order to produce an increase in total factor productivity throughout the period. Interestingly, the overall increase in total factor productivity in the period 1970-2000 occurred essentially in the 1980s and in the 1990s.[7]

[Table 2]

The change in output can be decomposed into two components: the change in total factor productivity and the quantitative change in the inputs, in other words,

$$\Delta Output = \Delta TFP \times \Delta Input \,. \tag{10}$$

Since we know the change in GDP and we can get the change in Total Factor Productivity from the previous Malmquist set of results, the overall change in the inputs can then be computed as $\Delta Input = \Delta Output / \Delta TFP$. Therefore, we report in Table 3 the

[7] Our results cannot easily be compared to the ones reported, for instance, by Kumar and Russell (2002) since such study covered a different time span 1965-1990, and most importantly mixed both developed and developing contries. Indeed, in that study, several developing countries show up in the efficiency frontier, raising the issue of country non-heterogeneity. On the other hand, the study of Krüger (2003), for the period 1960-1990, while not providing country specific results, reports that technological progress occurred for the OECD countries.

changes in the overall input necessary to attain the output change, given the TFP change.

[Table 3]

As a next step, we can also compute the period changes in each of the inputs that we are considering, private capital, public capital and human capital. Table 4 reports those changes. For instance, and for the sub-period 1970-1980, we can observe for Australia overall period growth rates of 22.8%, 27.6%, and 10.5% respectively in private capital, public capital and human capital.

[Table 4]

In addition, we can also decompose the increase in the inputs into those three types of capital, imposing the restriction that the sum of the coefficients of the three inputs equals unity.[8] The specification is then

$$\Delta Input_i = a_1 PrivK_i + a_2 PubK_i + (1 - a_1 - a_2) HK_i \,. \tag{11}$$

where *PrivK*, *PubK* and *HK* are respectively private, public and human capital. The regression results are shown in Table 5. It is interesting to observe that in the first sub-period, input growth can be attributed to private capital and public capital by around 28% each, while human capital would account for the remaining 44%. However, in the 1980s and in the 1990s the contribution of private capital became more relevant, while public capital was not statistically significant in the case of the 1980s.

[Table 5]

We performed a sensitivity analysis with alternative specifications for the inputs in the DEA and Malmquist efficiency computations. First, we included only private capital and public capital as inputs; second we included total non-human capital, putting together public and private capital, and human capital as the only two inputs (results are reported in tables A1 to A4 in the Appendix).

Using a specification with only two inputs (private capital and public capital), five countries are still on the frontier, Belgium, Canada, Spain, Portugal, and the USA (as in the baseline specification), plus Norway in the last period and Japan in the first period (as before), plus Denmark in the last three periods. Now, Italy is no longer in the efficiency frontier. Not considering human capital as an input provides an average increase in TFP only in the period 1990-2000 and decreases in the periods 1970-1980 and 1990-2000, which implies that human capital is a relevant input for the analysis. In addition, for the entire time sample, positive efficiency gains are reported together with losses stemming from the technology component of TFP.

Using a specification with two inputs (total non-human capital and human capital) the number of countries on the frontier ranges from four countries (Belgium, Italy, Portugal and the USA) in 1990 to seven countries in 2000 (Belgium, Denmark, Ireland, Italy, Norway, Portugal and the USA). Regarding TFP, when considering total non-human capital and human capital as inputs, it allows to uncover, for the entire period, positive efficiency and technology gains and increases in TFP in all sub-periods.

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[8] Delgado-Rodríguez and Álvarez-Ayuso (2008) followed a similar procedure, but did not impose the unit sum restriction.

4.3. Parametric analysis

Regarding our stochastic frontier analysis, we use the following baseline panel data specification

$$\ln GDP_{it} = \beta_0 + \beta_1 \ln PrivK_{it} + \beta_2 \ln PubK_{it} + \beta_3 HK_{it} + \eta_{it} + \varepsilon_{it} \qquad (12)$$

where *i* and *t* index respectively countries and time, GDP is GDP per employee, *PrivK*, *PubK* and *HK* are respectively private, public and human capital per employee. In (12), ε_{it} is a normally distributed random error, while η_{it} stands for a non-negative inefficiency effect, assumed to have a truncated normal distribution. Inefficiency effects can be explained by non-discretionary factors. In our case we assess whether the exogenous factor *wbg* , which is an indicator of government effectiveness of the World Bank, plays a role in explaining inefficiency scores.

The estimation of (12) produces estimates for the following parameters: the βs, the coefficients associated to the inputs; θ, the constant associated to inefficiency; σ_ε and σ_η the standard deviations of respectively ε_{it} and $\bar{\eta}_{it}$. We report in Table 6 the results for the stochastic frontier estimation, including also a time trend.[9]

[Table 6]

From Table 6 we observe that the inefficiency component of the model is not statistically significant at the 10 percent level. Indeed, the LR statistic equals 2.44, and

[9] The model is estimated by maximum likelihood using the software Frontier, version 4.1c, written by Tim Coelli, available at http://www.uq.edu.au/economics/cepa/frontier.htm.

the critical value at 10 percent for a mixed chi-square distribution with 2 degrees of freedom is 3.808 (according to the tabulation of Kodde and Palm, 1986).

The coefficients for the three types of capital are all positive and statistically significant. For instance, a one percent increase in private capital results in a 0.538 percent increase in output. In addition, a one percent increase in public and in human capital leads respectively to a 0.118 and 0.014 percent increase in output.[10]

Table 7 reports the stochastic frontier estimates of technical efficiency, per year, while Figure 4 illustrates the volatility of these efficiency measures. It is interesting to observe the high correlations between the SFA technical efficiency estimates (Table 7) and the DEA technical efficiency scores (Table 1) computed previously. Moreover, the patterns already mentioned for such countries as Ireland, Finland and Norway (towards the frontier) and Japan (away from the frontier) are also confirmed with the stochastic analysis.

[Table 7]

[Figure 4]

In order to assess whether technical efficiency is related to better governance, we use a composite indicator of government effectiveness of the World Bank (see Kaufmann et al., 2008) and test its contribution to efficiency. The results in Table 8 show, for the period 1990-2000 (the government effectiveness indicator is an average for the years 1996-2000), a positive effect of improved government effectiveness in increasing technical efficiency and TFP, although not statistically significant in the

[10] In the Annex we report additional SFA estimations without considering a time trend, which confirm these results.

latter case. A positive effect from government effectiveness can also be found for the SFA efficiency changes in the period 1990-2000.[11]

[Table 8]

5. Conclusion

In a cross section of OECD countries we replace the macroeconomic production function by a production possibility frontier, TFP being the composite effect of efficiency scores and possibility frontier changes. We consider, for the periods 1970, 1980, 1990, 2000, one output, GDP per worker, and three inputs, human capital, public physical capital per worker and private physical per worker. We use a semi-parametric analysis, computing Malmquist productivity indexes, and we also resort to stochastic frontier analysis.

Our results show that: i) private capital is important for growth, and contributes in a significant manner to output accumulation; ii) public and human capital contributions are usually estimated as positive, but, depending on the specification, were not always significant from a statistical point a view; iii) a governance indicator (government effectiveness), a non-discretionary input, explains inefficiency. Indeed, our results support the idea that better governance helps countries to achieve a better performance and to operate closer to the production possibility frontier.

Deterministic and stochastic estimation methods provided similar results and conclusions. Notably, non-parametric and parametric results coincide rather closely on the countries movements vis-à-vis the possibility frontier and on their relative distances to the frontier. The number of countries that can be nominated as efficient was rather

[11] The shorter timespan availability for the government effectiveness variable prevents us from using it directely in the estimation of (8).

stable throughout the period, with six or seven countries usually on the frontier (Belgium, Canada, Spain, Italy, Japan, Portugal, and the USA).

Our results have several policy implications. Our estimations imply that policy may matter for growth by at least three different channels. One is public investment. The public capital elasticity is imprecisely estimated. Our estimates and their variability are consistent with other results concerning the effects of public investment across countries. With other data and methods, we found that both patterns of crowding in (public investment stimulating private investment and growth) and of crowding out are to be found in the recent experience of industrialised countries.[12] The policy content of these results has to be seen with caution – macroeconomic analysis can be no substitute for the careful evaluation of each public project on its own merits.

The second channel by which policy operates is governance. Our governance indicator (government effectiveness) depends on policy in the broad sense of the word, i.e., results not only from policy measures, but also from the way institutions are at the same time shaped by history and designed by contemporaneous men and women.

Finally, our results are consistent with the importance of human capital formation for growth. There is evidence of a positive macroeconomic return for human capital investment, even if in the SFA specification the human capital coefficient does not come out as statistically significant. Some countries in our sample, even if they are close to or at the efficiency frontier (Portugal, Spain) are probably limited in their growth prospects by their relative human capital scarcity.

Regarding future work developments, a possible step further could be the computation of a parametric Malmquist index, using alternative approaches (e.g. Fuentes et al., 2001, and Orea, 2004).

[12] See Afonso and St. Aubyn (2009).

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Appendix – Data sources

Original series	Ameco codes
Gross Domestic Product at 2000 prices, thousands national currency 1/	1.1.0.0.OVGD
Net capital stock at 2000 prices: total economy 1/	1.0.0.0.OKND
Employment, persons: all domestic industries (National accounts) 1/	1.0.0.0.NETD
GDP purchasing power parities, Units of national currency per PPS (purchasing power standard) 1/	1.0.212.0.KPN
Human capital (average years of schooling of the working age population)	2/
Government net capital stock, volume	3/
Private total net capital stock, volume	Our computation
Government effectiveness 4/	

1/ Series from the European Commission AMECO database.
2/ Cohen and Soto (2007).
3/ Kamps (2006).
4/ Kaufmann et al. (2008), World Bank.

Table 1 – Output-oriented DEA VRS technical efficiency scores
(output: GDP per employee; inputs: private and public capital, human capital)

	1970	Peers	1980	Peers	1990	Peers	2000	Peers
Australia	0.932	FI, CA, NL	0.937	CA, US, PR	0.924	CA, BE, PT	0.970	DK, IR, PT
Austria	0.897	CA, US, JP, PT	0.905	DK, US, PT	0.854	US, BE, PT	0.817	US, IT, BE
Belgium	1.000	BE	1.000	BE	1.000	BE	1.000	BE
Canada	1.000	CA	1.000	CA	1.000	CA	1.000	CA
Germany	0.846	BE, CA	0.906	BE, PT	0.891	IT, BE	0.814	DK, BE, US
Denmark	0.999	US, NL, PT	1.000	DK	1.000	DK	1.000	DK
Spain	1.000	ES	1.000	ES	1.000	ES	0.943	IT, PT, IR
Finland	0.812	ES, BE, CA	0.852	ES, BE, PT	0.864	BE, CA, ES	0.915	BE, US, IR
France	0.942	ES. US, IT, CA	0.935	US, IT	0.941	IT, US	0.920	NO, IT, US
UK	0.825	US, IT, ES, PT	0.858	PT, US, DK	0.898	BE, US, PT	0.968	DK, IR, PT
Greece	0.915	US, IT, ES, PT	0.884	BE, ES, IT	0.782	ES, CA, PT	0.749	PT, IR, IT
Ireland	0.744	US, CA, JP, PT	0.737	US, BE, PT	0.765	BE, US, IT	1.000	IR
Italy	1.000	IT	1.000	IT	1.000	IT	1.000	IT
Japan	1.000	JP	0.984	DK, PT	0.877	DK, US, PT	0.775	US, DK
Netherlands	0.912	US, IT, PR	0.919	BE, US, IT	0.869	US, IT, BE	0.871	IR, US, PT
Norway	0.882	BE, CA	0.917	BE. US	0.955	IT, US	1.000	NO
Portugal	1.000	PR	1.000	PT	1.000	PT	1.000	PT
Sweden	0.929	BE, CA	0.900	BE, ES	0.975	CA, PT	0.881	BE, IR
USA	1.000	US	1.000	US	1.000	US	1.000	US
Average	0.928		0.933		0.926		0.928	
Countries on the frontier	7		7		7		8	

Note: VRS – variable returns to scale.

Table 2 – Malmquist efficiency, technology, and total factor productivity change indices (Output-oriented): 1970-2000 (output; GDP; inputs: private and public capital, human capital)

	1970-1980			1980-1990			1990-2000			1970-2000		
	EC	TC	TFP	EC	TC	TFP	EC	TC	TFP	EC	TC	TFP
Australia	1.061	0.922	0.979	0.988	0.980	0.968	1.138	0.963	1.096	1.061	0.955	1.013
Austria	1.032	0.924	0.953	0.980	1.012	0.992	0.954	1.041	0.993	0.988	0.991	0.979
Belgium	1.000	1.009	1.009	1.000	1.059	1.059	1.000	1.042	1.042	1.000	1.036	1.036
Canada	1.000	0.952	0.952	0.954	0.991	0.945	1.139	0.935	1.065	1.028	0.959	0.986
Germany	1.111	0.967	1.074	0.999	1.039	1.037	1.028	0.993	1.021	1.045	0.999	1.044
Denmark	1.063	0.913	0.970	1.000	0.967	0.967	1.000	1.057	1.057	1.021	0.977	0.997
Spain	1.046	1.040	1.089	1.000	1.014	1.014	0.913	1.044	0.954	0.985	1.033	1.017
Finland	1.032	0.995	1.026	0.989	1.023	1.012	1.174	1.005	1.180	1.062	1.008	1.070
France	0.994	1.027	1.021	0.970	1.063	1.032	1.040	1.020	1.061	1.001	1.036	1.038
UK	1.098	0.919	1.009	1.070	0.960	1.027	1.115	0.972	1.084	1.094	0.950	1.040
Greece	0.992	1.055	1.047	0.869	1.020	0.887	0.961	1.083	1.040	0.939	1.053	0.988
Ireland	1.063	0.968	1.028	1.038	1.057	1.098	1.312	1.064	1.396	1.131	1.029	1.164
Italy	1.000	1.099	1.099	1.000	1.066	1.066	1.000	1.016	1.016	1.000	1.060	1.060
Japan	0.981	0.878	0.861	0.894	0.975	0.871	0.883	1.054	0.931	0.918	0.966	0.887
Netherlands	1.036	0.987	1.023	0.949	1.065	1.011	1.008	1.038	1.046	0.997	1.029	1.026
Norway	1.056	0.994	1.050	1.030	1.052	1.084	1.180	1.024	1.208	1.087	1.023	1.112
Portugal	1.000	0.958	0.958	1.000	0.945	0.945	0.947	0.948	0.897	0.982	0.950	0.933
Sweden	0.943	1.002	0.945	1.068	0.989	1.056	1.051	0.990	1.041	1.019	0.994	1.012
USA	1.029	0.959	0.987	1.028	1.026	1.054	1.000	1.058	1.058	1.019	1.014	1.033
Average	1.027	0.976	1.007	0.990	1.015	1.055	1.038	1.017	1.058	1.019	1.003	1.021

Notes: EC – Efficiency Change; TC – Technology Change; TFP – Total Factor Productivity change (TFP=EC*TC).

Table 3 – Output, input and TFP variations (index changes)

	1970-1980			1980-1990			1990-2000			1970-2000		
	ΔGDP	ΔTFP	ΔInput	ΔGDP	ΔTFP	ΔInput	ΔGDP	ΔTFP	ΔInput	ΔGDP	ΔTFP	ΔInput
Australia	1.189	0.922	1.215	1.121	0.968	1.158	1.199	1.096	1.094	1.598	1.013	1.578
Austria	1.387	0.924	1.456	1.233	0.992	1.243	1.205	0.993	1.214	2.061	0.979	2.106
Belgium	1.356	1.009	1.344	1.209	1.059	1.141	1.163	1.042	1.116	1.906	1.036	1.839
Canada	1.065	0.952	1.118	1.098	0.945	1.162	1.151	1.065	1.081	1.346	0.986	1.365
Germany	1.304	0.967	1.215	1.127	1.037	1.087	1.045	1.021	1.024	1.536	1.044	1.471
Denmark	1.198	0.913	1.235	1.189	0.967	1.229	1.202	1.057	1.137	1.710	0.997	1.715
Spain	1.440	1.040	1.322	1.259	1.014	1.242	1.077	0.954	1.128	1.951	1.017	1.919
Finland	1.337	0.995	1.303	1.271	1.012	1.256	1.295	1.180	1.098	2.200	1.070	2.056
France	1.315	1.027	1.288	1.223	1.032	1.185	1.139	1.061	1.074	1.833	1.038	1.766
UK	1.207	0.919	1.196	1.166	1.027	1.135	1.260	1.084	1.162	1.771	1.040	1.703
Greece	1.345	1.055	1.284	1.023	0.887	1.153	1.196	1.040	1.150	1.645	0.988	1.665
Ireland	1.451	0.968	1.412	1.370	1.098	1.248	1.434	1.396	1.027	2.850	1.164	2.448
Italy	1.365	1.099	1.242	1.262	1.066	1.184	1.162	1.016	1.144	2.003	1.060	1.889
Japan	1.462	0.878	1.698	1.273	0.871	1.462	1.135	0.931	1.219	2.113	0.887	2.382
Netherlands	1.228	0.987	1.201	1.112	1.011	1.100	1.118	1.046	1.069	1.527	1.026	1.488
Norway	1.277	0.994	1.216	1.253	1.084	1.156	1.266	1.208	1.048	2.025	1.112	1.821
Portugal	1.289	0.958	1.346	1.206	0.945	1.277	1.209	0.897	1.348	1.880	0.933	2.016
Sweden	1.131	1.002	1.197	1.164	1.056	1.102	1.281	1.041	1.230	1.687	1.012	1.667
USA	1.087	0.959	1.101	1.133	1.054	1.075	1.187	1.058	1.122	1.461	1.033	1.414

Note: ΔInput=ΔGDP/ΔTFP.

Table 4 – Input variations (index changes)

	1970-1980			1980-1990			1990-2000			1970-2000		
	Private capital	Public capital	Human capital	Private capital	Public capital	Human capital	Private capital	Public capital	Human capital	Private capital	Public capital	Human capital
Australia	1.228	1.276	1.105	1.198	0.969	1.046	1.117	1.032	1.026	1.644	1.275	1.186
Austria	1.506	1.545	1.110	1.328	1.134	1.062	1.340	0.992	1.044	2.679	1.737	1.231
Belgium	1.313	2.042	1.114	1.141	1.366	1.086	1.217	0.969	1.081	1.824	2.702	1.307
Canada	1.119	0.935	1.117	1.197	1.057	1.066	1.073	1.107	1.058	1.437	1.094	1.260
Germany	1.332	1.453	1.136	1.111	1.003	1.044	1.076	0.947	0.980	1.592	1.380	1.163
Denmark	1.243	1.275	1.094	1.239	0.945	1.046	1.147	0.907	1.057	1.765	1.094	1.210
Spain	1.716	1.595	1.142	1.304	1.438	1.134	1.100	1.263	1.126	2.462	2.896	1.458
Finland	1.321	1.623	1.192	1.353	1.367	1.131	1.025	1.290	1.088	1.831	2.861	1.467
France	1.471	1.352	1.165	1.263	1.179	1.109	1.128	1.160	1.036	2.096	1.848	1.338
UK	1.201	1.291	1.121	1.151	0.884	1.061	1.201	1.048	1.069	1.660	1.196	1.272
Greece	1.720	1.331	1.145	1.167	1.193	1.128	1.128	1.176	1.137	2.264	1.868	1.468
Ireland	1.716	1.525	1.116	1.396	1.206	1.066	1.072	0.754	1.067	2.569	1.387	1.269
Italy	1.411	1.302	1.173	1.273	1.383	1.143	1.186	1.136	1.135	2.130	2.046	1.522
Japan	1.763	2.139	1.081	1.490	1.247	1.065	1.243	1.388	1.057	3.266	3.702	1.216
Netherlands	1.346	1.240	1.100	1.130	0.956	1.043	1.076	0.914	1.058	1.636	1.083	1.213
Norway	1.370	1.383	1.122	1.204	1.335	1.066	1.050	1.217	1.014	1.732	2.247	1.212
Portugal	1.403	1.274	1.357	1.286	1.385	1.061	1.285	1.634	1.231	2.317	2.885	1.772
Sweden	1.224	1.349	1.129	1.245	1.113	1.069	1.172	1.337	0.973	1.786	2.010	1.175
USA	1.130	0.928	1.082	1.088	1.023	1.035	1.151	1.096	1.001	1.415	1.040	1.121

Table 5 – Decomposition of the change in total input

	Private capital (α_1)	Public capital (α_2)	Human capital ($1-\alpha_1-\alpha_2$)	R-square	N
1970-1980	0.277 ***	0.276 ***	0.446 #	0.77	19
	(3.63)	(4.50)			
1980-1990	0.733 ***	-0.025	0.293 #	0.79	19
	(11.65)	(-0.37)			
1990-2000	0.652 ***	0.183 ***	0.165 #	0.89	19
	(11.82)	(5.36)			
1970-2000	0.556 ***	0.116	0.328 #	0.80	19
	(6.93)	(1.61)			

Note: t-statistics in brackets.
*, ** and *** denote level of significance indicating 10%, 5% and 1% respectively.
#,Wald test rejects the null $(1-\alpha_1-\alpha_2)=0$ at the 1% level of significance.

Table 6 – Stochastic frontier estimation results (with time trend)

	Coefficient	Standard-error	t-statistic
Production function			
Constant	0.744	0.418	1.78 **
lnPrivK	0.538	0.133	4.04 ***
lnPubK	0.118	0.053	2.23 ***
HK	0.014	0.009	1.69 **
Trend	0.047	0.024	1.95 **
Inefficiency			
Constant	0.080	0.287	0.28
$\hat{\sigma}_{\varepsilon}^2$	0.935		
γ	0.744	0.418	1.78 **
LR-statistic ($\gamma=0$)#	2.44		
N. of observations	76		
N. of cross-sections	19		

The LR statistic critical value at 10% for a mixed chi-square distribution with 2 degrees of freedom is 3.808, according to the tabulation of Kodde and Palm (1986). *, ** and *** denote level of significance indicating 10%, 5% and 1% respectively.

Table 7 – SFA efficiency scores (with time trend)

	1970	1980	1990	2000	Average	Ranking (average)
Australia	0.921	0.896	0.867	0.922	0.901	8
Austria	0.856	0.851	0.839	0.820	0.842	13
Belgium	0.963	0.969	0.977	0.974	0.971	2
Canada	0.979	0.956	0.904	0.932	0.943	3
Germany	0.821	0.820	0.825	0.800	0.817	16
Denmark	0.936	0.915	0.923	0.966	0.935	4
Spain	0.969	0.945	0.932	0.877	0.931	6
Finland	0.799	0.810	0.791	0.913	0.828	15
France	0.909	0.879	0.874	0.871	0.883	9
UK	0.820	0.815	0.841	0.896	0.843	12
Greece	0.877	0.805	0.704	0.725	0.778	19
Ireland	0.729	0.709	0.748	0.970	0.789	18
Italy	0.920	0.944	0.944	0.928	0.934	5
Japan	0.916	0.854	0.810	0.747	0.832	14
Netherlands	0.893	0.859	0.853	0.874	0.870	11
Norway	0.851	0.828	0.854	0.960	0.873	10
Portugal	0.948	0.930	0.898	0.841	0.904	7
Sweden	0.860	0.794	0.766	0.829	0.812	17
USA	0.977	0.964	0.974	0.983	0.975	1
Correlation with Malmquist DEA TE scores	0.956	0.901	0.791	0.860	0.894	

Table 8 – Efficiency and government effectiveness (1990-2000)

Dependent variable	Constant	Government effectiveness	R-square	N
Technical efficiency change	0.844 *** (8.35)	0.112 ** (2.04)	0.20	19
TFP change	0.891 *** (8.37)	0.100 (1.65)	0.14	19
SFA efficiency change	0.095 (1.42)	0.071 * (1.87)	0.17	19

Note: t-statistics in brackets.

*, ** and *** denote level of significance indicating 10%, 5% and 1% respectively.

Figure 1 – DEA production possibility frontier

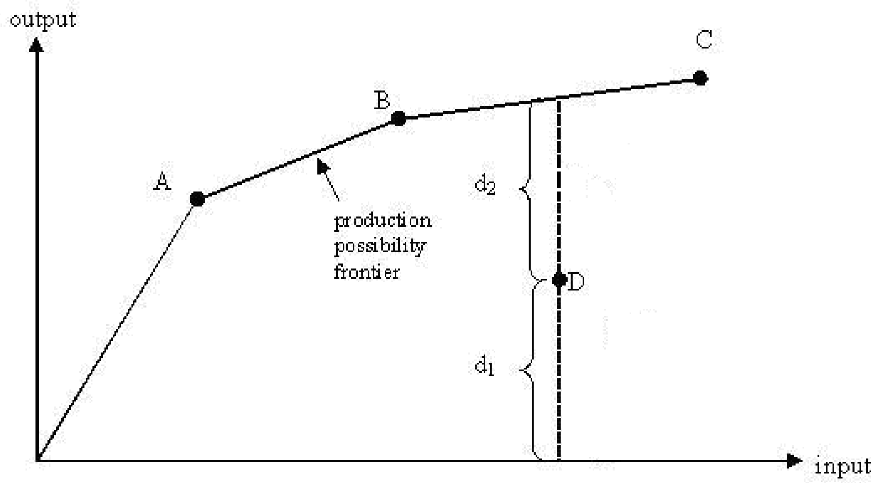


Figure 2 – Malmquist Productivity Index (constant returns to scale example)

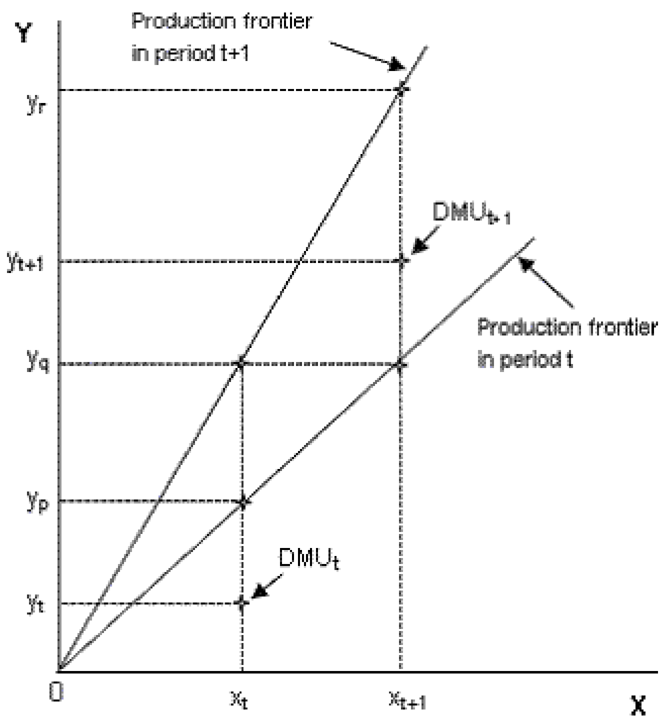


Figure 3 – SFA production possibility frontier

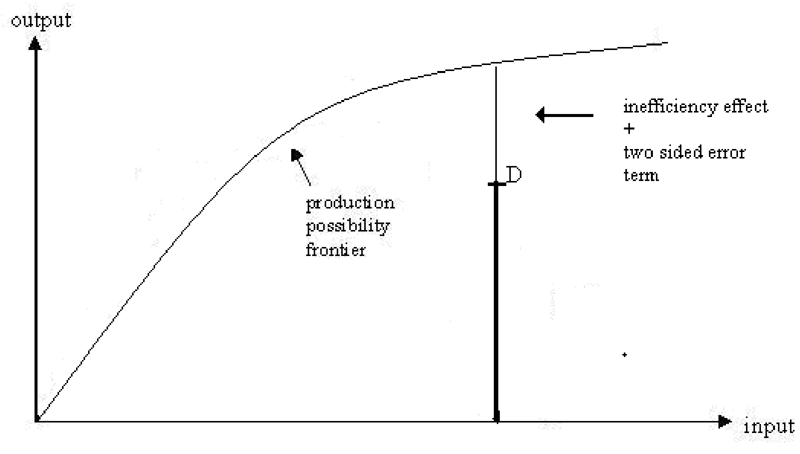
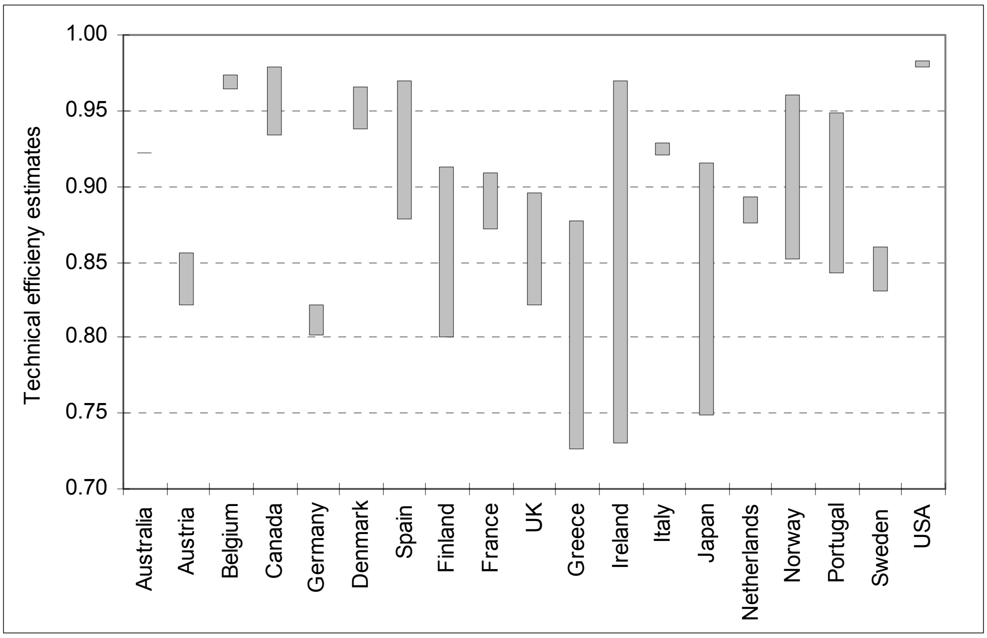


Figure 4 – SFA efficiency scores, with time trend (1970, 1980, 1990, 2000)



Annex – Additional estimates

Table A1 – Output-oriented DEA VRS technical efficiency scores (output: GDP per employee; inputs: private and public capital)

	1970	1980	1990	2000
Australia	0.932	0.937	0.924	0.970
Austria	0.886	0.890	0.832	0.806
Belgium	1.000	1.000	1.000	1.000
Canada	1.000	1.000	1.000	1.000
Germany	0.846	0.906	0.891	0.814
Denmark	0.989	1.000	1.000	1.000
Spain	1.000	1.000	0.995	0.851
Finland	0.812	0.852	0.862	0.915
France	0.878	0.907	0.941	0.896
UK	0.825	0.858	0.898	0.968
Greece	0.862	0.860	0.772	0.710
Ireland	0.732	0.694	0.759	1.000
Italy	0.884	0.961	1.000	0.976
Japan	1.000	0.984	0.877	0.775
Netherlands	0.877	0.873	0.857	0.837
Norway	0.882	0.917	0.955	1.000
Portugal	1.000	1.000	1.000	1.000
Sweden	0.929	0.900	0.975	0.881
USA	1.000	1.000	1.000	1.000
Average	0.912	0.923	0.923	0.916
Countries on the frontier	6	6	6	7

Note: VRS – variable returns to scale.

Table A2 – Malmquist efficiency, technology, and total factor productivity change indices (Output-oriented: 1970-2000; output; GDP; inputs: private and public capital)

	1970-1980			1980-1990			1990-2000			1970-2000		
	EC	TC	TFP	EC	TC	TFP	EC	TC	TFP	EC	TC	TFP
Australia	1.077	0.897	0.966	0.993	0.950	0.944	1.138	0.961	1.094	1.068	0.936	0.999
Austria	1.059	0.868	0.919	0.967	0.964	0.933	0.907	1.032	0.936	0.976	0.952	0.929
Belgium	0.848	0.936	0.794	1.113	0.945	1.053	1.043	0.967	1.009	0.995	0.949	0.945
Canada	1.062	0.904	0.961	0.977	0.943	0.921	1.139	0.935	1.065	1.057	0.927	0.981
Germany	1.077	0.905	0.975	1.074	0.948	1.018	1.046	0.956	1.001	1.066	0.936	0.998
Denmark	1.129	0.851	0.961	1.000	0.963	0.963	1.000	1.057	1.057	1.041	0.953	0.993
Spain	0.914	0.939	0.858	1.026	0.925	0.949	1.002	0.946	0.948	0.979	0.937	0.918
Finland	0.949	0.952	0.903	0.999	0.939	0.939	1.246	0.961	1.197	1.057	0.951	1.005
France	0.998	0.901	0.898	1.024	0.948	0.971	1.013	0.990	1.003	1.012	0.946	0.956
UK	1.123	0.890	1.000	1.073	0.954	1.024	1.115	0.972	1.084	1.104	0.938	1.035
Greece	0.862	0.941	0.811	0.955	0.907	0.866	1.141	0.910	1.038	0.979	0.919	0.900
Ireland	0.960	0.887	0.852	1.036	0.954	0.987	1.517	0.963	1.462	1.147	0.934	1.071
Italy	1.066	0.911	0.971	1.046	0.945	0.988	1.016	0.974	0.990	1.043	0.943	0.983
Japan	0.981	0.846	0.830	0.890	0.959	0.854	0.871	1.048	0.913	0.913	0.947	0.865
Netherlands	1.061	0.866	0.919	1.027	0.964	0.990	0.997	1.055	1.051	1.028	0.958	0.985
Norway	1.018	0.915	0.931	1.099	0.944	1.037	1.152	1.008	1.161	1.088	0.955	1.039
Portugal	1.000	0.958	0.958	1.000	0.903	0.903	0.947	0.941	0.891	0.982	0.934	0.917
Sweden	0.859	0.987	0.849	1.192	0.874	1.041	1.051	0.911	0.958	1.025	0.923	0.946
USA	1.119	0.872	0.976	1.085	0.962	1.044	0.975	1.059	1.033	1.058	0.962	1.017
Average	1.005	0.906	0.910	1.028	0.941	0.968	1.061	0.980	1.033	1.031	0.942	0.971

Notes: EC – Efficiency Change; TC – Technology Change; TFP – Total Factor Productivity change (TFP=EC*TC).

Table A3 – Output-oriented DEA VRS technical efficiency scores (output: GDP per employee; inputs: total capital and human capital)

	1970	1980	1990	2000
Australia	0.931	0.930	0.884	0.914
Austria	0.870	0.864	0.828	0.815
Belgium	0.977	1.000	1.000	1.000
Canada	1.000	1.000	0.919	0.930
Germany	0.808	0.877	0.873	0.768
Denmark	0.947	0.945	0.966	1.000
Spain	1.000	1.000	0.990	0.940
Finland	0.786	0.828	0.777	0.901
France	0.941	0.935	0.940	0.919
UK	0.816	0.843	0.882	0.899
Greece	0.914	0.856	0.725	0.745
Ireland	0.724	0.721	0.764	1.000
Italy	1.000	1.000	1.000	1.000
Japan	1.000	0.863	0.784	0.711
Netherlands	0.895	0.919	0.864	0.859
Norway	0.828	0.872	0.949	1.000
Portugal	1.000	1.000	1.000	1.000
Sweden	0.834	0.799	0.769	0.836
USA	1.000	1.000	1.000	1.000
Average	0.909	0.908	0.890	0.907
Countries on the frontier	6	6	4	7

Note: VRS – variable returns to scale.

Table A4 – Malmquist efficiency, technology, and total factor productivity change indices (Output-oriented: 1970-2000; output; GDP; inputs: total capital and human capital)

	1970-1980			1980-1990			1990-2000			1970-2000		
	EC	TC	TFP	EC	TC	TFP	EC	TC	TFP	EC	TC	TFP
Australia	1.063	0.946	1.005	1.016	0.980	0.996	1.089	1.008	1.098	1.056	0.977	1.032
Austria	1.063	0.958	1.018	1.008	1.023	1.031	0.993	1.032	1.025	1.021	1.003	1.024
Belgium	1.086	1.018	1.106	1.006	1.051	1.058	0.999	1.031	1.030	1.030	1.033	1.064
Canada	0.994	0.970	0.964	0.965	0.993	0.957	1.066	1.003	1.069	1.007	0.989	0.996
Germany	1.087	0.985	1.070	1.017	1.032	1.050	0.982	1.026	1.008	1.028	1.014	1.043
Denmark	1.027	0.938	0.963	1.109	0.951	1.055	1.088	1.014	1.103	1.074	0.967	1.039
Spain	1.051	1.017	1.069	0.980	1.051	1.030	0.924	1.036	0.957	0.983	1.035	1.018
Finland	1.090	0.977	1.065	0.972	1.033	1.004	1.172	1.034	1.211	1.075	1.014	1.090
France	0.984	1.051	1.034	0.991	1.050	1.040	1.035	1.028	1.064	1.003	1.043	1.046
UK	1.089	0.943	1.027	1.127	0.953	1.074	1.064	1.011	1.076	1.093	0.969	1.059
Greece	0.951	1.077	1.023	0.855	1.049	0.897	1.019	1.033	1.053	0.939	1.053	0.989
Ireland	1.131	1.001	1.132	1.056	1.055	1.115	1.319	1.037	1.368	1.164	1.031	1.200
Italy	1.000	1.108	1.108	1.000	1.072	1.072	1.000	1.018	1.018	1.000	1.066	1.066
Japan	0.819	0.931	0.763	0.992	0.979	0.971	0.914	1.020	0.932	0.906	0.976	0.884
Netherlands	0.997	1.034	1.032	0.987	1.053	1.039	1.042	1.026	1.068	1.008	1.038	1.046
Norway	1.048	0.998	1.046	1.031	1.045	1.077	1.172	1.029	1.206	1.082	1.024	1.107
Portugal	1.000	0.939	0.939	1.000	0.976	0.976	0.916	1.010	0.925	0.971	0.974	0.946
Sweden	0.978	0.987	0.965	0.967	1.034	1.000	1.123	1.034	1.162	1.021	1.018	1.039
USA	1.008	0.999	1.007	1.042	1.028	1.071	1.049	1.024	1.074	1.033	1.017	1.050
Average	1.022	0.992	1.014	1.055	1.021	1.026	1.046	1.024	1.072	1.024	1.012	1.037

Notes: EC – Efficiency Change; TC – Technology Change; TFP – Total Factor Productivity change (TFP=EC*TC).

Table A5 – Stochastic frontier estimation results (without time trend)

	Coefficient	Standard-error	t-statistic
Production function			
Constant	0.464	0.364	1.276
lnPrivK	0.602	0.0396	15.191 ***
lnPubK	0.141	0.0674	2.089 ***
HK	0.0249	0.0140	1.777 **
Inefficiency			
Constant	0.185	0.0750	2.463 ***
$\hat{\sigma}_\varepsilon^2$	0.0141		
γ	0.9997		
LR-statistic (γ=0)#	3.670		
N. of observations	76		
N. of cross-sections	19		

The LR statistic critical value at 10% for a mixed chi-square distribution with 2 degrees of freedom is 3.808, according to the tabulation of Kodde and Palm (1986). *, ** and *** denote level of significance indicating 10%, 5% and 1% respectively.

Table A6 – SFA efficiency scores (without time trend)

	1970	1980	1990	2000	Average	Ranking (average)
Australia	0.816	0.804	0.801	0.887	0.827	8
Austria	0.785	0.780	0.784	0.784	0.783	12
Belgium	0.903	0.918	0.961	0.977	0.940	2
Canada	0.902	0.879	0.843	0.901	0.881	7
Germany	0.713	0.715	0.745	0.756	0.732	19
Denmark	0.852	0.845	0.878	0.969	0.886	5
Spain	0.956	0.910	0.905	0.867	0.910	4
Finland	0.740	0.753	0.740	0.889	0.780	13
France	0.829	0.802	0.811	0.834	0.819	9
UK	0.729	0.736	0.788	0.865	0.779	14
Greece	0.826	0.751	0.666	0.702	0.736	18
Ireland	0.670	0.647	0.696	0.979	0.748	16
Italy	0.853	0.886	0.898	0.897	0.883	6
Japan	0.857	0.784	0.747	0.698	0.772	15
Netherlands	0.791	0.770	0.792	0.845	0.800	10
Norway	0.750	0.733	0.774	0.922	0.795	11
Portugal	0.991	0.971	0.954	0.894	0.953	1
Sweden	0.766	0.712	0.702	0.790	0.742	17
USA	0.874	0.871	0.925	0.996	0.916	3
Correlation with DEA output-oriented TE scores	0.891	0.863	0.801	0.926	0.895	

Figure A1 – SFA efficiency scores, without time trend (1970, 1980, 1990, 2000)