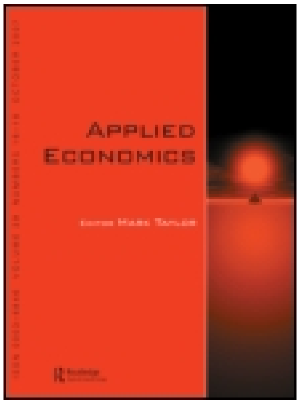

Applied Economics
Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/raec20

Public and private inputs in aggregate production and growth: a cross-country efficiency approach

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Published online: 16 Jul 2013.

Applied Economics, 2013
Vol. 45, No. 32, 4487–4502, http://dx.doi.org/10.1080/00036846.2013.791018

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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 and 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 private capital is important for growth, although public and human capital also contribute positively. A governance indicator, a nondiscretionary input, explains inefficiency. Better governance helps countries to achieve a better performance. Nonparametric and parametric results coincide rather closely on the movements of the countries *vis-à-vis* the possibility frontier and on their relative distances to the frontier.

Keywords: economic growth; public spending; efficiency; data envelopment analysis; Malmquist index

JEL Classification: C14; D24

I. Introduction

Established neoclassical growth models did not consider public inputs for the prospect of long-term growth. Nevertheless, several of growth theory extensions have considered public expenditure as essential for long-term economic growth.[1]

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). TFP 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 and (iii) obtaining TFP as a Solow residual, the change in production that is not explained by changes in production factors.

Moreover, 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, etc.) and also in how TFP changes throughout time. However, TFP

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[1] Aschauer (1989), Barro and Sala i Martin (1995).

estimates obtained in the manner described above heavily depend on the assumptions about the production function.

One of the contributions in this article is that, for a somewhat homogeneous OCED cross section of countries, we replace the macroeconomic production function by a production possibility frontier constructed on the basis of production inputs and output and where efficient countries will be located. 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 one output – GDP per worker – and three inputs – human capital, public physical capital per worker and private physical per worker – and an environmental variable (a nondiscretionary 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.

In addition, we also provide a decomposition of TFP between efficiency and technology changes, as well as the links of TFP changes via GDP growth and the aforementioned inputs.

We use two different methods to estimate the production possibility frontier. First, we apply the semi-parametric analysis with nondiscretionary 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.[2] 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.

Second, we also 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 inefficiency 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. A relevant result is that both approaches deliver similar results and conclusions, a reassuring robustness feature of our analysis, which then overcomes possible limitations of other studies that are more method dependent.

Another contribution of our study is that it relates existing governance conditions to macroeconomic efficiency and factor productivity growth.[3] Indeed, by resorting to the World Bank indicators, our article provides evidence that government effectiveness is an important nondiscretionary 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.

The remainder of the article is organized as follows. Section II briefly reviews the related literature. Section III presents the methodology used in the analysis. Section IV reports and discusses the empirical analysis. Section V concludes the article.

II. Literature

The use of nonparametric 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 and schools, where price data are 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, 2010).

Another related but 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, although they mixed in the sample rather heterogeneous developed and developing countries. 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 capital 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 TFP can be found in Färe *et al.* (1994); Ray and Desli (1997) and Färe *et al.* (1997).

Applications of SFA to infer efficiency changes in aggregate production across countries are even rarer. It is

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

[3] For instance, Baldacci *et al.* (2004) argue that governance-related factor productivity responses increase growth, while Afonso and Jalles (2011) report a positive effect on growth stemming from institutional quality.

worthwhile mentioning the work of Koop *et al*. (2000) for Western economies, Poland and Yugoslavia and of Mastromarco and Ghosh (2009) 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 (2009) estimate a stochastic production frontier for 57 developing countries for the period 1960 to 2000. GDP depends on two production factors, labour and private capital. Efficiency or TFP is driven by technology diffusion interacting with human capital.

Discretionary inputs are those that can be changed at will by the decision-making unit (DMU). Considering a national economy as a DMU, we consider it chooses each period which quantity of production factors it employs (human and physical capital, labour). Nondiscretionary or environment inputs are inputs which are predetermined 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 nondiscretionary input.

Indeed, some recent papers have emphasized the importance of institutions and governance as a deep determinant for growth. For instance, Olson *et al*. (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 *et al*. (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.

III. Methodology

DEA and the Malmquist index

The DEA methodology, originating from Farrell's (1957) seminal work and popularized by Charnes *et al*. (1978), assumes the existence of a convex production frontier constructed using linear programming methods.[4]

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

$$Y_i = f(X_i),\ i = 1, \ldots, n \tag{1}$$

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 as output is smaller than the best attainable one.

For an output-oriented specification, suppose there are k inputs and m outputs for n DMUs. For the ith DMU, y_i is the column vector of the inputs and x_i is the column vector of the outputs. We can define X as the $(k \times n)$ input matrix and Y as the $(m \times n)$ output matrix. For a given ith DMU, the DEA model is

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

In Equation 2, δ is a scalar (that satisfies $1/\delta \leq 1$) that 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 of constants $\lambda(n \times 1)$ measures the weights used to compute the location of an inefficient DMU if it were to become efficient. The restriction $n1'\lambda = 1$ imposes convexity of the frontier accounting for variable returns to scale, $n1$ being an n-dimensional vector of ones.

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.

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 total factor productivity index (Malmquist, 1953), *TFP*, allows this decomposition in an intuitive way.[5] For a given country, it is defined as

[4] Coelli *et al*. (2002) and Thanassoulis (2001) offer introductions to DEA.
[5] We present here the most important features. See Coelli *et al*. (2002) for a more detailed explanation.

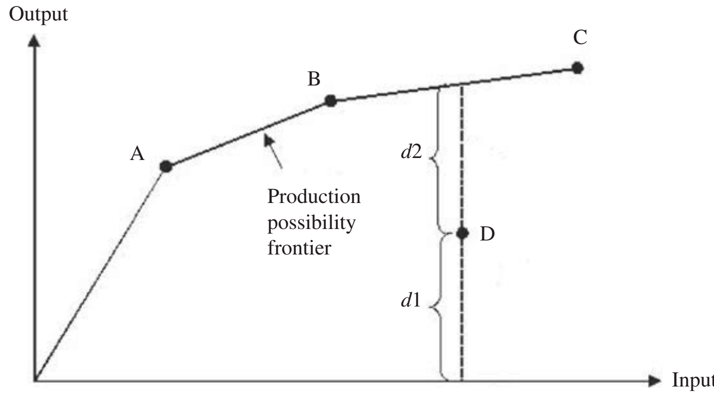

Fig. 1. DEA production possibility frontier

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

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. *TFP* may also be written as

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

or, equivalently,

$$TFP_{t+1} = EC_{t+1} \times TC_{t+1} \quad (5)$$

where $EC_{t+1} = \frac{d_o^{t+1}(y_{t+1}, x_{t+1})}{d_o^t(y_t, x_t)}$ is the efficiency change index and $TC_{t+1} = \left[\frac{d_o^t(y_{t+1}, x_{t+1})}{d_o^{t+1}(y_{t+1}, x_{t+1})} \times \frac{d_o^t(y_t, x_t)}{d_o^{t+1}(y_t, x_t)}\right]^{1/2}$ is the technology change index. In a variable returns to scale framework as ours, the efficiency change index can be further decomposed into a scale effect and a pure efficiency effect. In what follows, this decomposition in not shown but results are available upon request.

The output index, GDP, is defined as follows: $\text{GDP}_{t+1} = \text{TFP}_{t+1} \times \text{Input}_{t+1}$, where Input_{t+1} is an input index that summarizes the time evolution of the quantities of inputs used (human, private and public capital per worker). This input index will be defined later in '*Nonparametric analysis*' section.

One of DEA strengths comes from the fact that no functional form is imposed for the production possibility frontier. However, the method comes also with some weaknesses. Namely, it is very sensitive to outliers, no noise in data or measurement error are accounted for and countries are assumed to be homogeneous in any other aspect except for efficiency and the quantities of used inputs. These are important reasons to assess the robustness of results using an alternative method. The alternative we used, SFA, is presented in the following section.

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. This noise may arise from measurement errors and idiosyncratic factors that are not explicitly modelled. Specifically, and after Battese and Coelli (1995) and Coelli *et al*. (2002), assume the following model:

$$\ln y_{it} = F(X_{it}, \beta) + \eta_{it} + \varepsilon_{it} \quad (6)$$

$$\eta_{it} = \theta z_{it} \quad (7)$$

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 – nonnegative efficiency effect, assumed to have a truncated normal distribution; z_i – nondiscretionary 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 $\gamma = 0$, i.e. that there are no random inefficiency effects.

Figure 2 illustrates the SFA production possibility frontier in the simple one input–one output case.

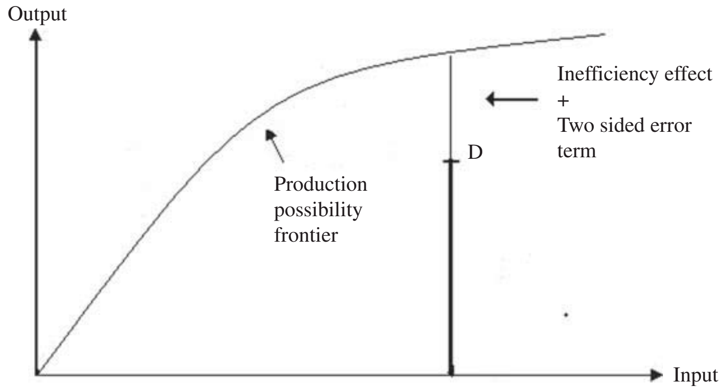

Fig. 2. SFA production possibility frontier

IV. Empirical Analysis

Data

We use data for all inputs and outputs, for a set of OECD countries, covering the period 1970 to 2000, specifically for 1970, 1980, 1990 and 2000.[6] 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, and descriptive statistics).[7]

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

Nonparametric 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.[8] 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, Denmark, Portugal and 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.

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 to 1988 for 17 OECD countries, report that 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.

Table 2 reports the set of results for the Malmquist indices of efficiency, technology and TFP changes for the period 1970 to 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 TFP (the change was equal to 2.1%). 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

[6] Australia, Austria, Belgium, Canada, Germany, Denmark, Spain, Finland, France, UK, Greece, Ireland, Italy, Japan, Netherlands, Norway, Portugal, Sweden and USA.
[7] 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; Krüger, 2003; Henderson and Russell, 2005; 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.
[8] DEA scores and Malmquist index computations were done with the software Win4DEAP, written by Tim Coelli.

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

Note: EC, efficiency change; TC, technology change; TFP, total factor productivity change (TFP = EC*TC).

Table 3. Output, input and TFP indexes

	1970–1980			1980–1990			1990–2000			1970–2000		
	GDP	TFP	Input	GDP	TFP	Input	GDP	TFP	Input	GDP	TFP	Input
Australia	1.189	0.979	1.215	1.121	0.968	1.158	1.199	1.096	1.094	1.598	1.013	1.578
Austria	1.387	0.953	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	1.074	1.215	1.127	1.037	1.087	1.045	1.021	1.024	1.536	1.044	1.471
Denmark	1.198	0.970	1.235	1.189	0.967	1.229	1.202	1.057	1.137	1.710	0.997	1.715
Spain	1.440	1.089	1.322	1.259	1.014	1.242	1.077	0.954	1.128	1.951	1.017	1.919
Finland	1.337	1.026	1.303	1.271	1.012	1.256	1.295	1.180	1.098	2.200	1.070	2.056
France	1.315	1.021	1.288	1.223	1.032	1.185	1.139	1.061	1.074	1.833	1.038	1.766
UK	1.207	1.009	1.196	1.166	1.027	1.135	1.260	1.084	1.162	1.771	1.040	1.703
Greece	1.345	1.047	1.284	1.023	0.887	1.153	1.196	1.040	1.150	1.645	0.988	1.665
Ireland	1.451	1.028	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	0.861	1.698	1.273	0.871	1.462	1.135	0.931	1.219	2.113	0.887	2.382
Netherlands	1.228	1.023	1.201	1.112	1.011	1.100	1.118	1.046	1.069	1.527	1.026	1.488
Norway	1.277	1.050	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	0.945	1.197	1.164	1.056	1.102	1.281	1.041	1.230	1.687	1.012	1.667
USA	1.087	0.987	1.101	1.133	1.054	1.075	1.187	1.058	1.122	1.461	1.033	1.414

Note: Input = GDP/TFP.

increase in efficiency (+1.9%) in order to produce an increase in TFP throughout the period. Interestingly, the overall increase in TFP in the period 1970 to 2000 occurred essentially in the 1980s and 1990s.[9] Countries that were clearly above average in what concerns TFP growth were Ireland (+16.4%), Norway (+11.2%) and Finland (+7.0%). In any of these cases, efficiency change was more important than technology change – e.g. Ireland changed 13.1% in efficiency and 2.9% only in technology.

We compute the output index from the observed change in GDP. As the TFP index is available from the previous Malmquist set of results, the overall change in the inputs can then be computed as Input = GDP/TFP. Therefore, we report in Table 3 the overall input index consistent with the observed output index, given the computed TFP change.

We want to assess the contribution of each of the inputs that we are considering, private capital, public capital and human capital, to this overall input index. Table 4 reports the changes in each of these inputs in index terms. For instance, and for the subperiod 1970 to 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. In what concerns the longer period, it can be noted that some countries displayed considerable growth in both private and public capital – this is the case of Japan, which more than trebled its physical capital stocks, but also of Portugal and Spain. The two Iberian countries were also among the champions on what concerns human capital growth. This evolution is consistent with what one would expect from converging economies. The US case is also of note. Public capital almost did not grow, leading authors like Aschauer (1989) to point out this as a possible reason for the lack of productivity growth.

To decompose the overall input change into those three types of capital, we impose the restriction that the sum of the coefficients of the three inputs equals unity.[10] The specification is then

$$\text{Input}_i = a_1 \text{PrivK}_i + a_2 \text{PubK}_i + (1 - a_1 - a_2)\text{HK}_i \tag{8}$$

where PrivK, PubK and HK are, respectively, private, public and human capital indexes. Coefficient estimates were obtained by ordinary least squares, and regression

[9] 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 nonheterogeneity. On the other hand, the study of Krüger (2003), for the period 1960 to 1990, while not providing country-specific results, reports that technological progress occurred for the OECD countries.

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

Table 4. Input indexes

	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

results are shown in Table 5. It is interesting to observe that in the first subperiod, 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 1990s, the contribution of private capital became more relevant, while public capital was not statistically significant in the case of the 1980s.

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 nonhuman capital, putting together public and private capital, and human capital as the only two inputs (results are reported in Tables B1–B4 in the Appendix).

Using a specification with only two inputs (private capital and public capital), several countries still show up, in some years, on the frontier, such as Belgium, Canada, Spain, Portugal and USA (as in the baseline specification), plus Norway in the last period and Japan in the first period (as before), as well as 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 to 2000 and decreases in the periods 1970 to 1980 and 1990 to 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.

Table 5. Total input decomposition

	Private capital (α_1)	Public capital (α_2)	Human capital ($1-\alpha_1-\alpha_2$)	R^2	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)			

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

Using a specification with two inputs (total nonhuman capital and human capital), the number of countries on the frontier ranges from four countries (Belgium, Italy, Portugal and USA) in 1990 to seven countries in 2000 (Belgium, Denmark, Ireland, Italy, Norway, Portugal and USA). Regarding TFP, when considering total nonhuman 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 subperiods.

Parametric analysis

Regarding our SFA, we use the following baseline panel data specification:

$$\ln \mathrm{GDP}_{it} = \beta_0 + \beta_1 \ln \mathrm{PrivK}_{it} + \beta_2 \ln \mathrm{PubK}_{it} + \beta_3 \mathrm{HK}_{it} + \eta_{it} + \varepsilon_{it} \tag{9}$$

where i and t index are, respectively, countries and time, GDP is GDP per employee, PrivK, PubK and HK are, respectively, private, public and human capital per employee. In Equation 9, ε_{it} is a normally distributed random error, while η_{it} stands for a nonnegative inefficiency effect, assumed to have a truncated normal distribution. Inefficiency effects can be explained by nondiscretionary 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 Equation 9 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.[11]

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

The coefficients for the three types of capital are all positive and statistically significant. For instance, a 1% increase in private capital results in a 0.538% increase in output. In addition, a 1% increase in public and in human capital leads, respectively, to a 0.118% and 0.014% increase in output.[12]

Table 7 reports the stochastic frontier estimates of technical efficiency per year, while Fig. 3 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, implying that a similar set of countries is nearer the efficient production frontier.[13] 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 6. Stochastic frontier estimation results (with time trend)

	Coefficient	SE	*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
$\hat{\sigma}^2_\varepsilon$	0.935		
γ	0.744	0.418	1.78**
LR statistic ($\gamma = 0$)[#]	2.44		
No. of observations	76		
No. of cross sections	19		

Notes: [#]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.

[11] 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
[12] In the Appendix, we report additional SFA estimations without considering a time trend, which confirm these results.
[13] Using only SFA-related analysis for the period 1908 to 1990 and not splitting the capital input into private and public components, Koop *et al.* (2000) report that the most efficient countries are the Netherlands, Canada, Belgium, Australia, Luxembourg and USA.

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	

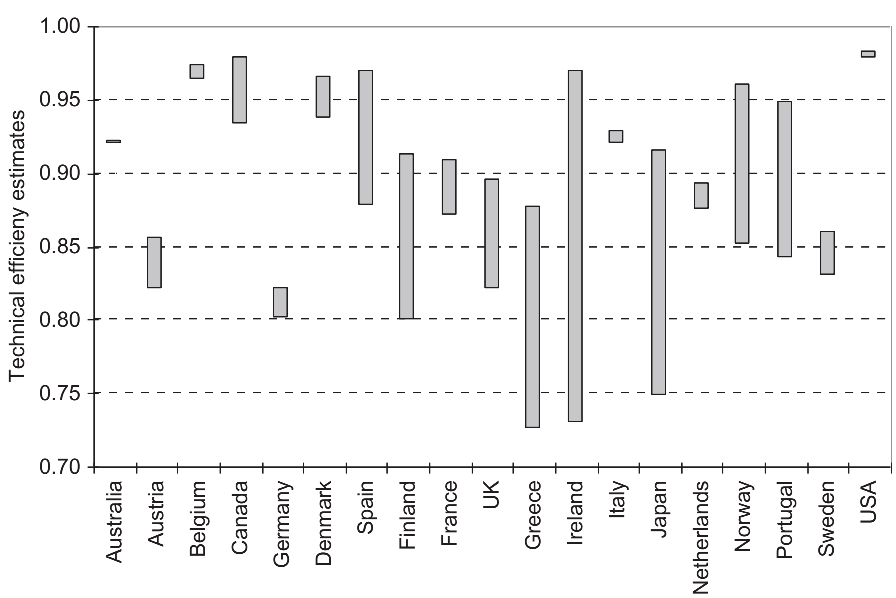

Fig. 3. SFA efficiency scores, with time trend (1970, 1980, 1990 and 2000)

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 to 2000 (the government effectiveness indicator is an average for the years 1996 to 2000), a positive effect of improved government effectiveness in increasing technical efficiency and TFP, although not statistically significant in the latter case. A positive effect from government effectiveness can also be found for the SFA efficiency changes in the period 1990 to 2000.[14]

The point that government effectiveness is a relevant nondiscretionary input for growth, either with a parametric or with a nonparametric approach, is then picked up by our analysis. The intuition is that the supply of

[14] The shorter timespan availability for the government effectiveness variable prevents us from using it directely in the estimation of Equation 9.

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

Dependent variable	Constant	Government effectiveness	R^2	N
Technical efficiency change	0.844***	0.112**	0.20	19
	(8.35)	(2.04)		
TFP change	0.891***	0.100	0.14	19
	(8.37)	(1.65)		
SFA efficiency change	0.095	0.071*	0.17	19
	(1.42)	(1.87)		

Notes: *t*-Statistics in brackets.
*, ** and *** denote level of significance indicating 10%, 5% and 1%, respectively.

public services to the economy, notably to entrepreneurs and to the private sector, when done more effectively (less red tape, better rule of law, better regulation institutions, etc.) will enhance the efficient use of resources in the economy as well (along the lines of what Olson *et al.*, 2000, claimed as well).

V. 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 and 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 SFA. One of the contributions of the article is exactly the fact that are able to deal with criticisms that other articles sometimes encounter, notably the lack of robustness of the results or the fact that they are simply contingent on the methodology used. Therefore, our results proved to be robust to the method used, both a nonparametric analysis and a parametric 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 and (iii) a governance indicator (government effectiveness), a nondiscretionary 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, nonparametric and parametric results coincide rather closely on the movements of the countries *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 stable throughout the period, with six or seven countries usually on the frontier (Belgium, Canada, Spain, Italy, Japan, Portugal and 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 industrialized countries (Afonso and St. Aubyn, 2009). 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 and 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; Orea, 2002).

Acknowledgements

We are grateful to Jürgen von Hagen, Geraint Johnes, Martin Larch, Ad van Riet and Emmanuel Thanassoulis, participants at DG ECFIN Workshop 'The Quality of Public Finances and Economic Growth' (Brussels), 3rd Meeting of the Portuguese Economic Journal (Funchal), 3rd Workshop on Efficiency and Productivity Analysis (Porto) and 37th Eastern Economic Association Annual Meetings (New York), and to two anonymous referees for helpful comments and suggestions on previous versions. The opinions expressed herein are those of the authors and do not necessarily reflect those of the ECB or the Eurosystem. UECE is financed by FCT (Fundação para a Ciência e a Tecnologia) under Strategic Project PEst-E/EGE/UI0436/2011.

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Appendix A: Data

Data codes and sources

Original series	Ameco codes
GDP at 2000 prices, thousands national currency[a]	1.1.0.0.OVGD
Net capital stock at 2000 prices: total economy[a]	1.0.0.0.OKND
Employment, persons: all domestic industries (National accounts)[a]	1.0.0.0.NETD
GDP purchasing power parities, units of national currency per PPS (purchasing power standard)[a]	1.0.212.0.KPN
Human capital (average years of schooling of the working age population)	[b]
Government net capital stock, volume	[c]
Private total net capital stock, volume	Our computation
Government effectiveness[d]	

Notes: [a]Series from the European Commission AMECO database.
[b]Cohen and Soto (2007).
[c]Kamps (2006).
[d]Kaufmann *et al*. (2008), World Bank.

Table A2. Descriptive statistics

Year average	1970	1980	1990	2000
GDP PPS	28.109	35.648	42.422	50.565
Government net capital stock	14.768	19.996	22.715	25.015
Private total net capital stock	61.607	84.122	103.457	117.791
Human capital	8.94	10.08	10.82	11.42
Employment, 1000 persons	13 809	15 492	17 280	19 404

Appendix B: Additional Estimates

Table B1. 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 B2. 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

Note: EC, efficiency change; TC, technology change; TFP, total factor productivity change (TFP = EC*TC).

Table B3. 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 B4. 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

Note: EC, efficiency change; TC, technology change; TFP, total factor productivity change (TFP = EC*TC).

Table B5. Stochastic frontier estimation results (without time trend)

	Coefficient	SE	*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 ($\gamma = 0$)[#]	3.670		
No. of observations	76		
No. of cross sections	19		

Notes: [#]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.
[a]Series from the European Commission AMECO database.

Table B6. 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	