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Technical Change, Efficiency and Productivity

Joaquin Maudos, Jose Manuel Pastor and Lorenzo Serrano

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Correspondence to J. Maudos: Universitat de València
Facultad de CC.EE. y EE. Depto. de Análisis Económico
Ctra. de los Naranjos, s/n. 46022 Valencia
Tel.: 963 828 246 / Fax: 963 930 856 / e-mail: Joaquin.Maudos@uv.es

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** J.M. Pastor y L. Serrano: Universitat de Valencia; Departamento de Análisis Económico. Edificio departamental oriental. Avenida de los Naranjos, s/n; 46022 Valencia (SPAIN). Fax: 34-6-382.82.49. J. Maudos: Instituto Valenciano de Investigaciones Económicas (IVIE). C/ Guardia Civil 22, Esc. 2, 1º; 46020 Valencia (SPAIN). Fax: 34-6-393.08.56.

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A B S T R A C T

The aim of this paper is to analyse the role of human capital in the productivity gains of the countries of the OECD in the period 1965-90, breaking down the productivity gains into technical change and gains in efficiency. For this purpose we use both a stochastic frontier production function and a non-parametric approach and calculate Malmquist indices of productivity. The results obtained indicate the existence of both a level effect and a rate effect (a higher level of human capital affects positively the rate of technical progress) associated with human capital. The differences among countries in endowments of human capital have worked against labour productivity convergence, since the richer countries, thanks to their greater endowment of human capital, have experienced higher rates of technical progress.

Keywords: Technical change, efficiency and productivity.
JEL: D24, O47

R E S U M E N

El objetivo de este trabajo es analizar el papel del capital humano en las ganancias de productividad de los países de la OCDE en el periodo 1965-90, descomponiendo las ganancias de productividad en cambio técnico y ganancias de eficiencia. Para ello se estima tanto una función de producción frontera de carácter estocástica como una aproximación no paramétrica y se calculan índices de Malmquist de productividad. Los resultados obtenidos indican la existencia tanto de un efecto nivel como de un efecto tasa (un mayor nivel de capital humano afecta positivamente a la tasa de progreso técnico) asociada al capital humano. Las diferencias de dotaciones de capital humano entre países han actuado en contra de la convergencia en productividad del trabajo ya que los países más ricos, gracias a su mayor dotaciones de capital humano, han experimentado tasas mayores de progreso técnico.

Palabras clave: Cambio técnico, eficiencia, productividad.
JEL: D24, O47.

1. INTRODUCTION

The literature on the relationship between human capital and growth has a long tradition. Indeed, we can find a concern for these type of questions since the early 1960s with the birth of the theory of human capital. Schultz himself[1] clearly sets out how investment in human capital constitutes one of the main explanatory elements of economic growth. It is responsible, to a large extent, for the divergence observed between the growth of the product and that of the quantity of productive factors used, giving rise to a qualitative improvement of the labour factor which increases its productive capacity and generates economic growth.

Persisting in this idea, investment in human capital was rapidly incorporated into the literature on growth starting with Solow's seminal study (1957). From then onwards, a succession of papers on growth accounting concerned themselves with quantifying the notable contribution to growth of investment in human capital. On the same lines, but using more sophisticated procedures and better information on the educational levels of the population and their impact on productivity, more recent papers have provided the same kind of results.

In general, the studies carried out so far analyse the importance of human capital by means of both the estimation of production functions, including as additional input a proxy variable of human capital, and the estimation of the effect of human capital on total factor productivity (TFP) estimated by the traditional non-parametric approach of index numbers. In the first case, the usual practice in economic literature has consisted of estimating average production functions (estimated by conventional regression methods) rather than genuine frontiers, assuming in consequence that all the units of production are efficient. Obviously the non-fulfilment of this assumption would affect the parameters estimated, and consequently the importance of human capital.

In the second case, the accounting estimation of TFP incorporates the implicit assumption that all individuals are efficient, so TFP growth is interpreted as the movement of the frontier function (technical change). However, in the presence of technical or allocative inefficiency, the accounting estimation of TFP would also be biassed[2], therefore affecting the effect attributed to human capital.

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1 See Schultz (1962).

2 See a more detailed exposition in Grosskopf (1993).

In order to avoid such bias, it is necessary to use frontier techniques that consider the possible existence of inefficient behaviour. Such is the case of the papers by Färe et al. (1994) on the analysis of TFP growth in the countries of the OECD, and by Tashkin and Zain (1997) who show the importance of efficiency gains as a source of labour productivity convergence at an international level during the period 1975-1990. However, in both cases it is assumed that production is carried out using physical capital and labour exclusively, without considering the role of human capital.

Consequently, there are studies which, although they consider the importance of human capital as an additional productive factor, use non-frontier techniques that ignore inefficiency; and on the other hand there are studies which, although they use frontier techniques, do not include human capital as an additional productive factor. This paper solves previous problems by incorporating human capital for the first time as an additional input and analysing its importance by means of frontier techniques considering at the same time its contribution as input (level effect) and as a factor determining the rate of technical change (rate effect). This avoids the possible bias deriving from non-incorporation of efficiency and that deriving from the omission of a relevant input.

The paper is organised as follows. The second section reviews the role of human capital in economic growth, examining the existing empirical evidence. The third section offers a review of frontier techniques for measuring efficiency and productivity, commenting on the disadvantages inherent to their particular use. The fourth section describes the database used and presents the results relating to efficiency, technical progress and productivity, and tests the significance of human capital as productive input. The fifth section analyses the effect of human capital as a determining factor of technical progress and its effect on convergence. Finally the main conclusions of the paper are presented in section six.

2. THE IMPORTANCE OF HUMAN CAPITAL

The theoretical models have incorporated human capital as one of the determining factors of development. Thus, in the case of neo-classical growth models[3], the study by Mankiw, Romer and Weil (1992) offers the generalisation of the Solow model in this line, including a rate of saving in human capital, and offers evidence to confirm its positive

[3] Established on the basis of the contributions by Solow (1956) and Swan (1956).

contribution to growth, reconciling the empirical evidence with the neo-classical model of exogenous growth.

Apart from the neo-classical growth models, the so-called endogenous growth models have also used human capital in their analyses. The central idea of some of these models[4] consists of generating the growth from the existence of non-diminishing returns on the accumulable factors. This property is sometimes established through externalities, thus maintaining the coherence with a context of perfect competition. At all events, the incorporation of an added type of capital is appropriate, especially if it is a factor to which positive externalities can be attributed, as for example in Lucas (1988).

Another type models[5] derives endogenous growth as a result of the development of new ideas and new products, a process that need have no limits. In Romer (1990) the existence of a sector of the economy dedicated to research and development is the mechanism through which sustained growth is reached, so that human capital is the most highly-qualified candidate for generator of this type of progress and therefore becomes a determinant of the economic growth rate. Indeed, human capital can not only drive innovation, but also contribute significantly to the imitation and adoption by one economy of the techniques previously developed by more advanced countries. This question is not new, this type of phenomena having already been analysed in Nelson and Phelps (1966) or Welch (1970).

To sum up, there exist very varied theoretical arguments on which to base the idea that a greater endowment of human capital increases the rate of technical progress by encouraging both innovation and the diffusion of technology and new products. In this sense, any measure that increases human capital would be highly recommendable for its effects on the growth rate. Indeed, this diversity of mechanisms by means of which human capital can influence growth may explain to a large extent its success in the literature. This diversity is an aspect that requires more detailed reflection. Firstly, human capital may contribute to growth in a way analogous to any other factor of production such as the amount of labour or physical capital. In this sense, the higher the level of human capital, ceteris paribus, the grater the production. This, then, is a level effect of human capital as a consequence of which a growth of human capital will generate economic growth. This is the type of effects that are usually considered

[4] For example, Romer (1986) or Lucas (1988).

[5] See, for example, Romer (1987 and 1990).

by the neo-classical growth models and there exists both positive[6] and negative[7] evidence in this respect.

Human capital may also contribute to technical progress by driving both innovation and imitation. In this case, the economic growth rate itself will depend on the level of human capital, due to what is called the rate effect of human capital. Endogenous growth models, though not only they, emphasise these aspects. Kyriacou (1991) and Benhabib and Spiegel (1994) point out that this seems to be the channel through which human capital acts, the significance of the level effect being non-existent or debatable. The evidence offered by Barro and Lee (1994) and Engelbrecht (1997) indicates the existence of both types of effects. In general, the results seem to be sensitive to the specification employed, as well as to the indicator of human capital used[8].

Human capital is also relevant from another standpoint, more concerned with the discontinuity of the processes of development and the existence of poverty traps. These are situations in which for different reasons, e.g. the inability of an economy to access the most developed technologies by itself, a long-term equilibrium with higher per capita income is impossible. The evidence offered by Kyriacou (1991), Benhabib and Spiegel (1994) and Taskin and Zaim (1997) seems to indicate that there are significant differences in the configuration of growth when countries are analysed in groups according to level of development. Their results suggest that the incidence of human capital seems to depend of the degree of development attained, driving innovation in the developed countries and technological catching-up in the poorer ones.

3. EFFICIENCY, TECHNICAL CHANGE AND PRODUCTIVITY: TECHNIQUES OF MEASUREMENT

The traditional approach to the analysis of productivity by means of non-frontier models, which includes both growth accounting approach (Solow, 1957; Denison, 1972; etc.),

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[6] See Baumol, Blackman and Wolff (1989), Barro (1991), Mankiw, Romer and Weil (1992), Lichtenberg (1994), Barro and Lee (1994) and Murthy and Chien (1997).

[7] See Kyriacou (1991), Benhabib and Spiegel (1994) or Nonneman and Vanhoudt (1996).

[8] In general the use of the percentage of individuals with secondary school complete offers results more favourable to the effect of human capital than that of other educational levels or that of school enrollment rates.

and the index number approach[9] (indices of Divisia, Törnqvist, etc.), incorporate the implied assumption that all individuals are efficient, so that the growth of productivity is interpreted as movement of the frontier function (technical change). However, in the presence of inefficiency the estimation of technical progress would be biassed. Furthermore, even in the absence of technical inefficiency, the accounting estimation of the growth of TFP would be a biassed estimation if the participations used in its calculation are not those that minimize cost, i.e. there is allocative inefficiency[10].

On the other hand, frontier approaches to the analysis of productivity take explicitly into account the possible inefficient behavior of the units analyzed, measuring as inefficiency the potential increase in the observed value of production, this being measured against the maximum technically achievable value defined by frontier of production or technology. In this study we use this frontier approach through both a parametric method (stochastic frontier approach, SFA) and non-parametric methods (DEA).

a) Parametric methods: Stochastic frontier approach (SFA)

The stochastic frontier approach was introduced simultaneously by Aigner et al. (1977) and Meeusen et al. (1977). This approach modifies the standard production function by assuming that inefficiency forms part of the error term. This compound error term therefore includes an inefficiency component and a purely random component that captures the effect of variables that are beyond the control of the production unit being analysed (weather, bad luck, etc.).

The basic stochastic production frontier model posits that the observed production of an economy deviates from the frontier as a consequence of random fluctuations (v_{it}) and of inefficiency (u_{it}). That is to say,

[1] $$LnY_{it}=LnF(X_{it}, \beta)\cdot exp.(v_{it}-u_{it}) \qquad i=1,\ldots,N; \; t=1,\ldots,T$$

where Y_{it} is the observed production and X_{it} is the input vector of country i at time t, β is the vector of parameters to be estimated, and $LnF(X_{it}, \beta)$ is the logarithm of optimum output. The random error term v_{it} is assumed to be independent and identically distributed, and the term u_{it}

9 See among others Baumol (1986), Baumol and Wolff (1988), Abramovitz (1986, 1990, & 1994), Bernard and Jones (1996a & b), Dollar and Wolff (1994) and Wolff (1991).

10 See a more detailed exposition in Grosskopf (1993).

is assumed to be distributed independently of v_{it}. The indicator of efficiency, obtained as the ratio of optimum output to observed output, is obtained as $exp(u_{it})$[11].

Since inefficiencies can only decrease production below the frontier, it is necessary to specify asymmetrical distributions for the inefficiency term. Usually, it is assumed that v_{it} is distributed as a normal with zero average and variance σ^2_v, and u_{it} as a half-normal, truncated normal, exponential, etc.

On the assumption that both components of the error term are distributed independently, the frontier function can be estimated by maximum likelihood, inefficiency being estimated on the basis of the residuals of the regression. More specifically, individual estimations of inefficiency can be obtained by using the distribution of the inefficiency term conditioned to the estimation of the compound error term (Greene, 1993).

Thus, the stochastic frontier approach has as its principal advantage the fact that it allows us to isolate the influence of factors other than efficiency. However, its disadvantages are that it is a parametric approach (it is necessary to impose *a priori* a particular functional form) and that it is necessary to specify distributional assumptions in order to separate the two components of the error term. Moreover, although in this approach the estimation of technical progress can be done easily by introducing time dummies or a trend, it has the disadvantage that technical progress, calculated on the basis of the parameters estimated, is the same for all countries.

b) Non-parametric methods: Malmquist productivity index and DEA

The Malmquist productivity index allows changes in productivity to be broken down into changes in efficiency and technical change. Furthermore, unlike the SFA, it offers a different rate of technical change for each individual, which is more adequate for one of the purposes of this study, the analysis of technical change by countries. Also, if it is estimated using a non-parametric frontier model (data envelopment analysis, DEA), which is the most commonly used approach, it will not be necessary to impose any functional form on the data nor to make distributional assumptions for the inefficiency term, unlike the SFA. The main disadvantage of this approach is that the estimation of inefficiency may show an upward bias, capturing as inefficiency the influence of other factors, such as errors in data measurement, bad luck, weather, etc.

[11] Values higher than unity imply that the country is technically inefficient; the higher the efficiency index the greater the inefficiency.

The Malmquist index uses the notion of distance function, so its calculation requires prior estimation of the corresponding frontier. In this study we use the determinist non-parametric frontier methodology (DEA).

To illustrate the calculation of the Malmquist index[12], let us assume that the transformation function that describes the technology in each period *t* is:

[2] $$F^t = \{(x^t, y^t): x^t \ can\ produce\ y^t\} \qquad t = 1,...,T$$

where $y^t=(y_1^t,\dots,y_N^t)\in R_N^+$ is the vector of outputs and $x^t=(x_1^t,\dots,x_M^t)\in R_M^+$ denotes the vector of inputs both corresponding to period *t*.

Following Shephard (1970) or Caves et al. (1982) technology can be represented alternatively by means of the distance function:

[3] $$D_o^t(x^t,y^t) = inf\{\vartheta^{t,t} : (x^t,y^t/\vartheta^{t,t})\in F^t\}=[sup\{\vartheta^{t,t} : (x^{t+1}, \vartheta^{t,t} y^t) \in F^t\}]^{-1}$$

This function is defined as the reciprocal of the maximum expansion to which it is necessary to subject the vector of outputs of period *t* (y^t), given the level of inputs (x^t), so that the observation stands at the frontier of period *t*. This function characterizes completely the technology in such a way that $D_o^t(x^t,y^t)\leq 1$ if and only if $(x^t, y^t) \in F^t$. Furthermore, $D_o^t(x^t,y^t) = 1$ if and only if the observation stands at the limits of the frontier, which occurs when the observation is efficient in the sense used by Farrell (1957). Figure 1 illustrates the above concepts for a situation with a single output and a single input. The observation (x^t,y^t) stands below the technological frontier of period *t*, which means that it is not technologically efficient. The distance function would be calculated as the inverse of the greater increase in output, given the input, in such a way that the expanded output reaches the technological frontier. In the graph, the maximum output would be represented by $y^{t,t}=y^t/\vartheta^{t,t}$. The value of the distance function of the observation in *t*, with respect to the technology in *t*, $\vartheta^{t,t}$, would be represented by $OA/OB=y^t/y^{t,t}=\vartheta^{t,t}$. Farrell's output-oriented measurement of technical efficiency measures how much output could increase, given the inputs. In figure 1 it can be observed that Farrell's measurement of technical efficiency for the observation (x^t,y^t) is $OB/OA=y^{t,t}/y^t=1/\vartheta^{t,t}$.

[12] See Malmquist (1953).

Note that so far the distance function has been defined for a single period. Specifically, we have compared observations of one period with the technology of the same period. To define the Malmquist index it is necessary to define distance functions with respect to technologies of different periods.

[4] $D_o^t(x^{t+1},y^{t+1}) = inf\{\vartheta^{t,t+1} : (x^t,y^{t+1}/\vartheta^{t,t+1}) \in F^t\}$

In the above expression, the distance function $D_o^t(x^{t+1},y^{t+1})$ measures the maximum proportional increase in outputs, given the inputs, to make the observation of period $t+1$, (x^{t+1},y^{t+1}), feasible in period t. In the situation represented in figure 1, the observation (x^{t+1},y^{t+1}) is outside the feasible set represented by the technology in t, so the value of the distance function will be $OE/OC=y^{t+1}/y^{t,t+1}=\vartheta^{t,t+1}$. In a similar way, it is possible to define the distance function of an observation in t, (x^t,y^t), to make it feasible in relation to a technology current in $t+1$, $D_o^{t+1}(x^t,y^t)$. Note that when comparing observations of one period with technologies of different periods, the distance function may be higher than unity. In particular $D_o^t(x^{t+1},y^{t+1})$ and $D_o^{t+1}(x^t,y^t)$ may be higher than unity if there has been technical progress and technical regression respectively[13].

On the basis of the above concepts, the Malmquist productivity index based on outputs to analyze productive change between periods t and $t+1$, taking the technology of period t as reference, is defined as[14]:

[5] $M_o^t\left(x^{t+1}, y^{t+1}, x^t, y^t\right) = \frac{D_o^t\left(x^{t+1}, y^{t+1}\right)}{D_o^t\left(x^t, y^t\right)}$

$M_o^t>1$ indicates that the productivity of period $t+1$ is higher than that of period t, since the expansion necessary in the outputs of period $t+1$ for the observation to be feasible in t is lower than that applicable to the outputs of period t. On the other hand, $M_o^t<1$ indicates that productivity has descended between periods t and $t+1$[15].

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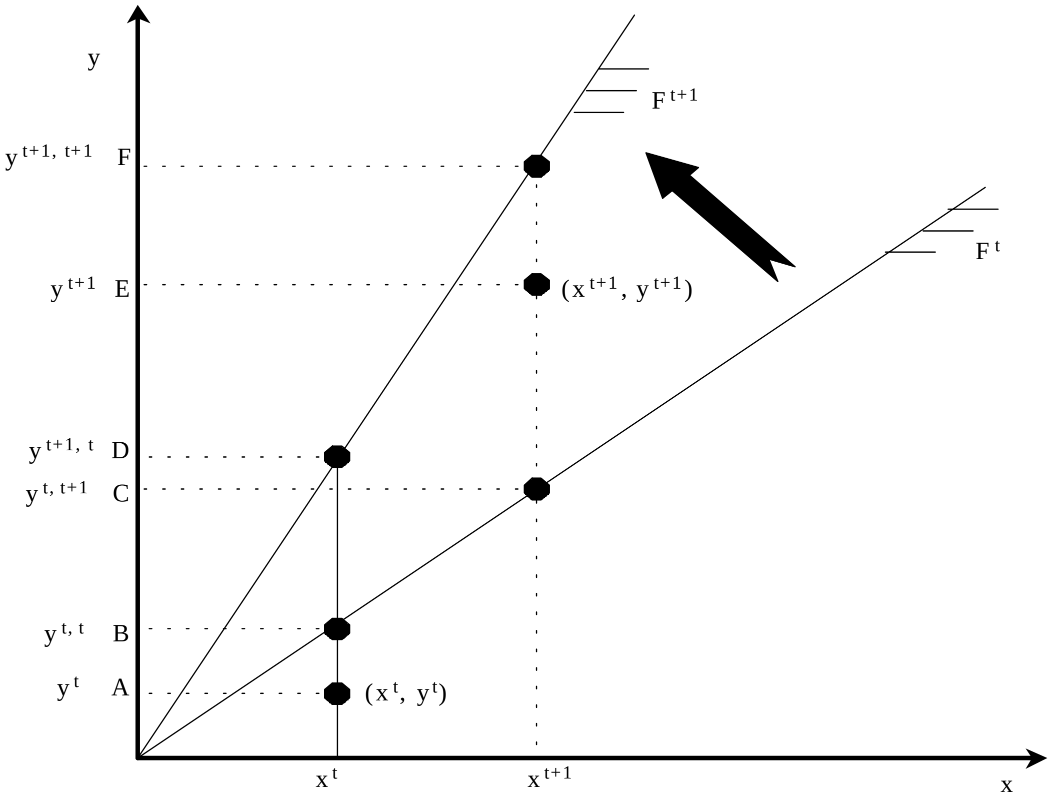
[13] Note that in the situation represented in the graph, $D_o^t(x^{t+1},y^{t+1})>1$, indicating that there has been technical progress.

[14] See Caves et al. (1982).

[15] Alternatively it is possible to define the Malmquist index by taking the technology of period $t+1$: $M_o^{t+1}=D_o^{t+1}(x^{t+1},y^{t+1})/ D_o^{t+1}(x^t,y^t)$. In this case the interpretation is similar. $M_o^t>1$ indicates that the productivity of period $t+1$ is higher than that of period t, since the expansion necessary in the outputs of the period $t+1$ for the observation to be feasible in $t+1$ is lower than that applicable to the outputs of period t.

Figure 1: Malmquist output-based productivity index



In all the above definitions only two periods (*t* and *t+1*) have been considered, and the definitions have been made taking as reference the technology of period *t* or *t+1*. However, when we wish to analyze the productive change of a longer time series, the use of a fixed technology may cause problems the further we get from the base year. Also (Moorsten, 1961), the choice of base year is not neutral in the results. To attempt to solve these problems two methodologies are offered. The first consists of calculating two indices based on pairs of consecutive years which take as base the technology of the two periods *t* and *t+1* and calculating the geometric mean of the two, thus allowing the technology of reference to change, minimizing the problems caused by the change (Färe et al. 1994).

Another procedure, used by Berg et al. (1992) to solve the above-mentioned problems is to consider two frontiers of reference corresponding to the initial and final years, and to take the geometric mean of the two Malmquist indices.

In this study, because the time series used is very long (25 years) we will for the reasons given above use the first of the alternatives:

[6] $$M_o\left(x^{t+1},y^{t+1},x^t,y^t\right)=\left[\left(\frac{D_o^t\left(x^{t+1},y^{t+1}\right)}{D_o^t\left(x^t,y^t\right)}\right)\left(\frac{D_o^{t+1}\left(x^{t+1},y^{t+1}\right)}{D_o^{t+1}\left(x^t,y^t\right)}\right)\right]^{1/2}$$

Re-writing the above expression it is possible to break down the Malmquist index into the catching-up effect and technical change or movement of the frontier:

[7] $$M_o\left(x^{t+1},y^{t+1},x^t,y^t\right)=\frac{D_o^{t+1}\left(x^{t+1},y^{t+1}\right)}{D_o^t\left(x^t,y^t\right)}\left[\left(\frac{D_o^t\left(x^{t+1},y^{t+1}\right)}{D_o^{t+1}\left(x^{t+1},y^{t+1}\right)}\right)\left(\frac{D_o^t\left(x^t,y^t\right)}{D_o^{t+1}\left(x^t,y^t\right)}\right)\right]^{1/2}$$

The catching-up effect or change in relative efficiency between periods *t* and *t+1* is represented by the first ratio, which will be higher than unity if there has been an increase in efficiency. Similarly, the geometric mean of the two ratios between brackets measures the change or movement of technology between periods *t* and *t+1*.

The above breakdown can again be illustrated using figure 1.

[8] $$M_o\left(x^{t+1},y^{t+1},x^t,y^t\right)=\frac{OE/OF}{OA/OB}\left[\left(\frac{OE/OC}{OE/OF}\right)\left(\frac{OA/OB}{OA/OD}\right)\right]^{1/2}=\frac{OE/OF}{OA/OB}\left(\frac{OF}{OC}\cdot\frac{OD}{OB}\right)^{1/2}$$

If the observation has not varied its efficiency between *t* and *t+1*, the first term will be equal to 1 and the productive change experienced between the two periods (M_o) will be explained only by the movement of the frontier. On the other hand, if the second term is 1 (the frontier has not moved), the changes in productivity estimated by M_o will be explained only by the changes in efficiency of firms in the two periods (catching-up). In other cases, the productive changes reflected in M_o will be a mixture of changes in efficiency and movements of the frontier.

The Malmquist index can be calculated in several ways (Caves et al. 1982). In this study, as we have said before, we calculate the Malmquist index using a non-parametric technique of linear programming.

Let us suppose that in each period t there exist $k=1,...,K$ countries which use $n=1,...,N$ inputs (x_{nk}^t) to produce $m=1,...,M$ outputs (y_{mk}^t). The calculation of the Malmquist index for a country j requires calculation of four types of distance function; $D_o^t(x^t,y^t)$, $D_o^{t+1}(x^{t+1},y^{t+1})$, $D_o^t(x^{t+1},y^{t+1})$ and $D_o^{t+1}(x^t,y^t)$.

Making use of the property whereby the distance of output is equal to the reciprocal of the Farrell output-oriented technical efficiency measurement (Färe and Lovell, 1978) we have that for $D_o^t(x^t,y^t)$:

[9]
$$\begin{aligned}
&\left[D_o^t\left(x_j^t, y_j^t\right)\right]^{-1} = Max\,\vartheta_j^{t,t} \\
&s.t. \\
&\sum_{k=1}^{K}\lambda_k^t y_{mk}^t \geq y_{mj}^t \vartheta_j^{t,t} \qquad m=1,...,M \\
&\sum_{k=1}^{K}\lambda_k^t x_{nk}^t \leq x_{nj}^t \qquad n=1,...,N \\
&\lambda_k^t \geq 0 \qquad k=1,...,K
\end{aligned}$$

The calculation of $D_o^{t+1}(x^{t+1},y^{t+1})$ is obtained in a similar way but substituting t for $t+1$. Finally, the calculation of the first of the distances referred to two different moments in time $D_o^t(x^t,y^t)$ is done in the following way[16]:

[16] In which constant returns to scale have been imposed. This imposition is sufficient to guarantee that the solution of the problem of optimisation exists when using observations of different periods of time. With variable returns to scale the solution is not guaranteed.

$$[10] \qquad \begin{aligned} &\left[D_o^t\left(x_j^{t+1}, y_j^{t+1}\right)\right]^{-1} = Max\vartheta_j^{t,t+1} \\ &s.t. \\ &\sum_{k=1}^{K} \lambda_k^t y_{mk}^t \geq y_{mj}^{t+1}\vartheta_j^{t,t+1} \qquad m = 1,\ldots,M \\ &\sum_{k=1}^{K} \lambda_k^t x_{nk}^t \leq x_{nj}^{t+1} \qquad n = 1,\ldots,N \\ &\lambda_k^t \geq 0 \qquad k = 1,\ldots,K \end{aligned}$$

Note that the observation (x^{t+1},y^{t+1}) is compared with the technology in *t*, formed by the set of observations existing in *t*, so it may occur that the observation is not feasible, given the technology current in *t* (F^t) and the solution is greater than unity.

The second, $D_o^{t+1}(x^t,y^t)$, is done in the same way but substituting *t* for *t+1* and *t+1* for *t*.

4. DATA AND RESULTS

The sample used for the estimation of the frontier production function consists of the countries of the OECD in the period 1965-90 using the Summers and Heston database (Penn World Table, Mark 5.6)[17] and Barro and Lee (1993)[18]. The variables for each country are: 1) aggregated output measured by real Gross Domestic Product (GDP) (Y), expressed in international prices; 2) aggregated labor input (L) measured by total employment, computed from real GDP per worker; 3) total capital stock (K) calculated from the non-residential capital per worker; and 4) human capital stock (H) calculated as the number of schooling years completed by the occupied population obtained as a product of the average schooling years of the population over 25 years of age[19] (proxy of the per capita endowment of human capital (h)), and the number of workers. The principal descriptive statistics of the variables used appear in table 1.

The empirical studies on the importance of human capital in the explanation of differences in productivity between countries are usually based on the estimation of production

[17] This is an updated version of Summers and Heston (1991).

[18] The sample used consists of Canada, USA, Japan, Austria, Belgium, Denmark, Finland, France, Germany, Greece, Iceland, Ireland, Italy, Netherlands, Norway, Portugal, Spain, Sweden, Switzerland, Turkey, UK, Australia and New Zealand. Luxemboug is exlcuded because of lack of data on human capital.

[19] Barro and Lee (1993) only offer this datum every five years. The intermediate years have been estimated by interpolation.

functions, into which are introduced as well as labour and physical capital a proxy variable of human capital. In this sense, it is usual practice to use Cobb-Douglas production functions in which it is also usual to impose the assumption of constant returns to scale.

However, it is well-known that the assumption that the technology underlying the production function is of the Cobb-Douglas type has a restrictive effect. For this reason, the strategy adopted in this paper is to estimate a more flexible (translogarithmic) production function which nests the Cobb-Douglas function as a particular case, which would be no more than a restricted case of the translog specification. This specification would be as follows:

[11]
$$\begin{aligned} LnY_{it} &= \beta_0 + \beta_L LnL_{it} + \beta_K LnK_{it} + \beta_H LnH_{it} + \\ &(1/2)\beta_{LL} LnL_{it}^2 + (1/2)\beta_{KK} LnK_{it}^2 + (1/2)\beta_{HH} LnH_{it}^2 \\ &\beta_{LK} LnL_{it} LnK_{it} + \beta_{LH} LnL_{it} LnH_{it} + \beta_{KH} LnK_{it} LnH_{it} + \sum_{t=65}^{90} \lambda_t TE_t + v_{it} - u_{it} \end{aligned}$$

where Y=output (GDP), K=stock of physical capital, L=employment and H=stock of human capital (total number of person years of education emboid in those workers). In addition, temporary effects (*TE*) are introduced into the estimation to reflect the effects of technical progress.

Columns (1) and (2) of table 2[20] show the results of the estimation of the equation with and without human capital using the stochastic frontier approach with a Cobb-Douglas specification. Comparison of the two models shows the importance of human capital in the explanation of the differences in labour productivity among the countries of the OECD, its elasticity (0.329) being similar to the elasticity of labour (0.309). Also it is not possible to reject the hypothesis of constant returns to scale in all the inputs. However, the results that appear in columns (3) and (4) show the specification bias inherent to the Cobb-Douglas function given the high significance both of the squares of the variables and of their crossed products[21], as well as the importance of human capital. More particularly, in model (4) human capital presents statistically significant elasticity in the average values of the sample of 0.09 (t-ratio 2.704), this elasticity being much lower than that corresponding to the Cobb-Douglas specification.

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[20] The results correspond to the model in which the inefficiency component is distributed as a half-normal, the results being similar in the truncated-normal and exponential models.

[21] The test value of the Cobb-Douglas specification (model 3) against translog (model 4) distributed according to a Chi-squared with 6 degrees of freedom, is equal to 222.9, so the Cobb-Douglas specification is rejected.

Table 1: Labor productivity, capital labor-ratio and human capital

	Labor productivity (Y/L)				*Capital-labor ratio (K/L)*				*Human capital (h=H/L)*			
	1965	**1990**	**1965-90**	**Annual growth rate**	**1965**	**1990**	**1965-90**	**Annual growth rate**	**1965**	**1990**	**1965-90**	**Annual growth rate**
Canada	22245	34380	28313	1,74%	18427	42745	30586	3,37%	7,8	10,34	9,46	1,13%
USA	28051	36771	32411	1,08%	17507	34705	26106	2,74%	9,25	12	10,80	1,04%
Japan	7333	22624	14979	4,51%	5272	36480	20876	7,74%	7,07	9,2	7,79	1,05%
Austria	13682	26700	20191	2,67%	8097	34562	21329,5	5,81%	3,96	7,44	6,30	2,52%
Belgium	17790	31730	24760	2,31%	15307	36646	25976,5	3,49%	7,81	8,75	8,26	0,45%
Denmark	17955	24971	21463	1,32%	14147	33125	23636	3,40%	10,02	11,21	10,31	0,45%
Finland	13938	27350	20644	2,70%	16960	45767	31363,5	3,97%	7,73	9,79	8,97	0,95%
France	17027	30357	23692	2,31%	12289	35600	23944,5	4,25%	4,84	6,88	5,70	1,41%
Germany	17282	29509	23396	2,14%	15157	50116	32636,5	4,78%	7,93	8,83	8,35	0,43%
Grecee	7721	17717	12719	3,32%	6570	23476	15023	5,09%	4,95	7,66	6,13	1,75%
Iceland	15010	24978	19994	2,04%	7760	21877	14818,5	4,15%	5,89	7,98	6,89	1,21%
Ireland	10322	24058	17190	3,38%	6925	21660	14292,5	4,56%	6,45	8,15	7,20	0,94%
Italy	14163	30797	22480	3,11%	12054	31640	21847	3,86%	4,77	6,16	5,41	1,02%
Netherlands	20628	31242	25935	1,66%	14766	32380	23573	3,14%	5,58	8,56	7,71	1,71%
Norway	17233	29248	23241	2,12%	37653	48135	42894	0,98%	5,58	7,93	6,98	1,41%
Portugal	6189	16637	11413	3,96%	3387	11819	7603	5,00%	2,2	3,61	2,94	1,98%
Spain	12451	26364	19408	3,00%	5912	27300	16606	6,12%	3,81	6,25	5,06	1,98%
Sweden	20870	28389	24630	1,23%	15808	39409	27608,5	3,65%	7,67	9,48	8,66	0,85%
Switzerland	23660	32812	28236	1,31%	30708	73459	52083,5	3,49%	6,87	8,87	7,90	1,02%
Turkey	3765	8632	6199	3,32%	2365	7589	4977	4,66%	2,05	3,35	2,49	1,96%
UK	16645	26755	21700	1,90%	8742	21179	14960,5	3,54%	7,17	8,7	8,01	0,77%
Australia	21246	30312	25779	1,42%	20249	37854	29051,5	2,50%	8,94	10,12	9,89	0,50%
New Zeal..	23658	25413	24536	0,29%	18248	33080	25664	2,38%	9,42	11,18	10,88	0,69%
Mean	**17063**	**28843**	**22953**	**2,10%**	**12002**	**33680**	**22841**	**4,13%**	**6,42**	**8,37**	**7,48**	**1,06%**

Note: Labor productivity and capital-labor ratio expressed in thousands of dollars of 19985.
Source: Summers and Heston (1991) [PWT 5.6] and Barro and Lee (1993)

Table 2: Stochastic production function

	Model 1 C-D without H		*Model 2* C-D with H		*Model 3* Translog without H		*Model 4* Translog with H	
	Param.	**t-student**	**Param.**	**t-student**	**Param.**	**t-student**	**Param.**	**t-student**
Constant	19.9140	543.06	19.8650	734.46	20.0700	468.39	20.0160	639.90
Ln*K*	0.5600	39.98	0.3715	17.02	0.4574	18.10	0.4115	14.10
Ln*L*	0.4468	29.37	0.3090	26.57	0.5887	23.08	0.6394	23.74
Ln*H*			0.3294	12.45			0.0887	2.57
LnK^2					-0.3636	-7.38	-0.4961	-7.12
LnL^2					-0.4464	-8.04	-0.5428	-8.44
LnH^2							-1.0968	-4.97
Ln*LLn*K***					0.4141	8.22	0.5305	8.00
Ln*LLnH**							-0.4624	-4.31
LnH*Ln*K*							0.4611	4.44
σ^2_u / σ^2_v	2.9260	4.99	5.5791	3.80	89.0590	0.23	46.6690	0.51
$\sigma^2_u + \sigma^2_v$	0.2979	16.91	0.2901	19.66	0.2610	26.94	0.2433	29.90
N. obs.	598		598		598		598	
Log-lik.	150.4574		228.8128		356.8233		402.8102	
σ^2_v	0.0093		0.0026		0.0000		0.0000	
σ^2_u	0.0795		0.0816		0.0681		0.0592	

Another outstanding feature is the increase in the importance of inefficiency in the explanation of the variance of the compound error term of the estimation. Thus, in the translog estimation practically all the variance of the error term ($\sigma^2_u+\sigma^2_v$) is explained by inefficiency, which shows the small bias that would be incurred in the event of using a deterministic approach.

Table 3 shows the average levels of efficiency of the countries of the OECD for the period as a whole, corresponding to the translog estimation with human capital (column 1) and without human capital (column 2). It is important to note, first, the existence of high levels of inefficiency in certain countries (Japan, Greece, Finland, etc), which shows the importance of not ignoring the differences in efficiency in the analysis of productivity gains. Second, there are substantial differences among countries, USA, the Netherlands and the UK being the most efficient countries of the OECD. Third, on occasions (in countries with low levels of human capital such as Italy, Portugal and Turkey) there are important differences between the efficiency estimated with human capital and without it, which shows the importance of incorporating it as an additional productive factor in the production function for a correct evaluation of efficiency[22].

[22] Unlike the practice adopted in the studies by Färe et al. (1994), Fecher and Perelman (1995) and Taskin and Zaim (1997).

Table 3: efficiency levels (stochastic frontier approach)

	With human capital	*Without human capital*
Canada	1.070	1.073
USA	1.043	1.063
Japan	1.728	1.695
Austria	1.171	1.195
Belgium	1.142	1.146
Denmark	1.237	1.275
Finland	1.480	1.473
France	1.117	1.195
Germany	1.385	1.402
Greece	1.644	1.656
Iceland	1.160	1.174
Ireland	1.330	1.344
Italy	1.136	1.215
Netherlands	1.036	1.039
Norway	1.275	1.368
Portugal	1.122	1.270
Spain	1.080	1.119
Sweden	1.157	1.156
Switzerland	1.109	1.157
Turkey	1.357	1.455
UK	1.069	1.067
Australia	1.128	1.136
New Zealand	1.081	1.113
Mean	**1.204**	**1.236**

In order to test empirically the significance of human capital in the DEA model the Banker[23] test was used, indicating that, similarly to the parametric techniques, human capital is statistically significant[24].

[23] Banker (1996) proposes several tests to evaluate the significance of the variables introduced into the DEA models, on the basis of their asymtotic properties. Among others, Banker (1996) proposed tests to evaluate the significance of a variable Z introduced into the model. The tests are based on the comparison of a basic model that includes the inputs (X) and the outputs (Y) with a model that also includes the variable being tested (Z). If the inefficiency is distributed as a half-normal, the test is distributed as an F:

$$T_{HN} = \sum_{j=1}^{N}\left[\vartheta_j\left(X_j;Y_j\right)-1\right]^2 \Big/ \sum_{j=1}^{N}\left[\vartheta_j\left(X_j,Z_j;Y_j\right)-1\right]^2 \sim F_{N,N}$$

[24] The probability of rejection of the null hypothesis is 5.54E-8. This result is robust at other alternative distributions of the inefficiency term.

Using the approach described in section 2 (Malmquist productivity indices), table 4 shows the growth rate of TFP and its breakdown into technical change and changes in efficiency of the countries of the OECD considering, as well as labour and physical capital, human capital given its importance as an additional productive factor.

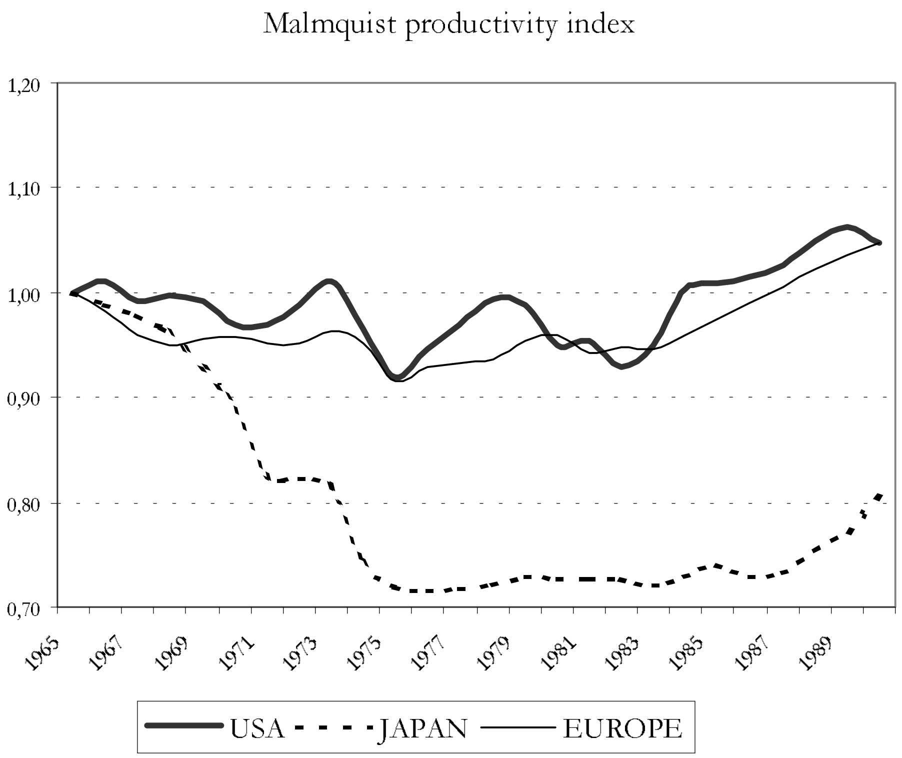
For the average of the countries considered, the results show different behaviours during the period analysed (1965-1990), with respect both to the growth rate of TFP and to the importance of the sources of growth (technical change *vs* catching-up). Thus, while in the sub-periods of growth (1965-73) and recovery (1985-90) improvements occur in productivity (much greater in the latter sub-period), in the period of crisis (1973-85) hardly any improvement of productivity occurs. Furthermore, the relative importance of technical change and of gains in efficiency is variable in time, notably the relative importance of technical progress in the sub-period 1985-1990 (1.209%) and of efficiency gains in the sub-period 1965-1973.

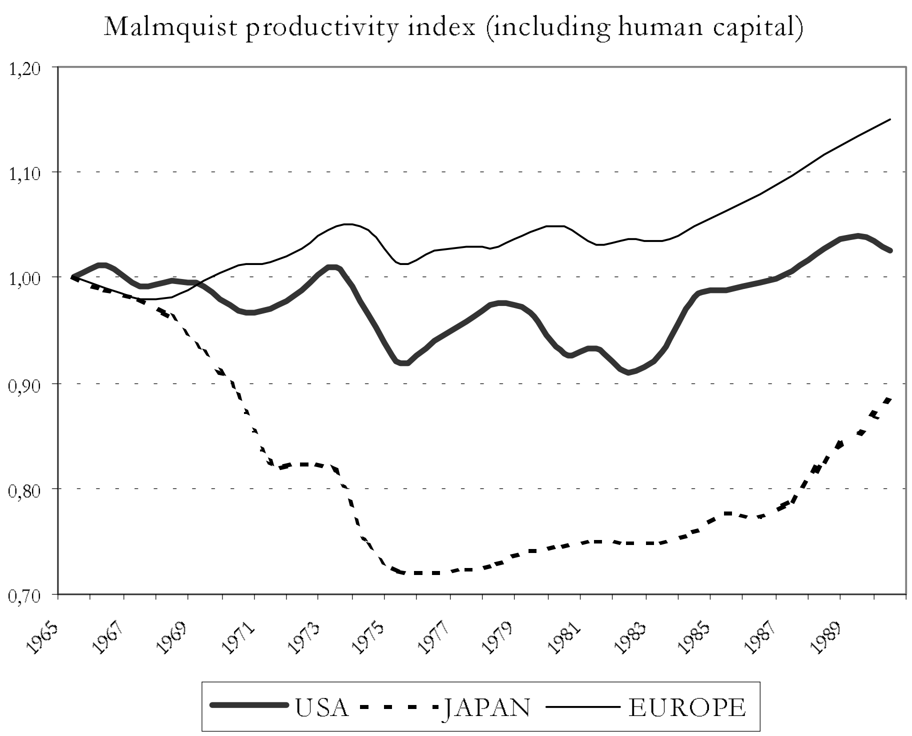
By countries, important differences are again observed. Thus, in the case of Japan, the losses of productivity until 1985 are due both to losses of efficiency and to the absence of technical progress, even though productivity grew above the average for the countries of the OECD in the last sub-period, due both to the important gains in efficiency (1.105%) and to technical progress (1.507%). Also, the productivity gains of the USA in this last sub-period are due exclusively to technical change.

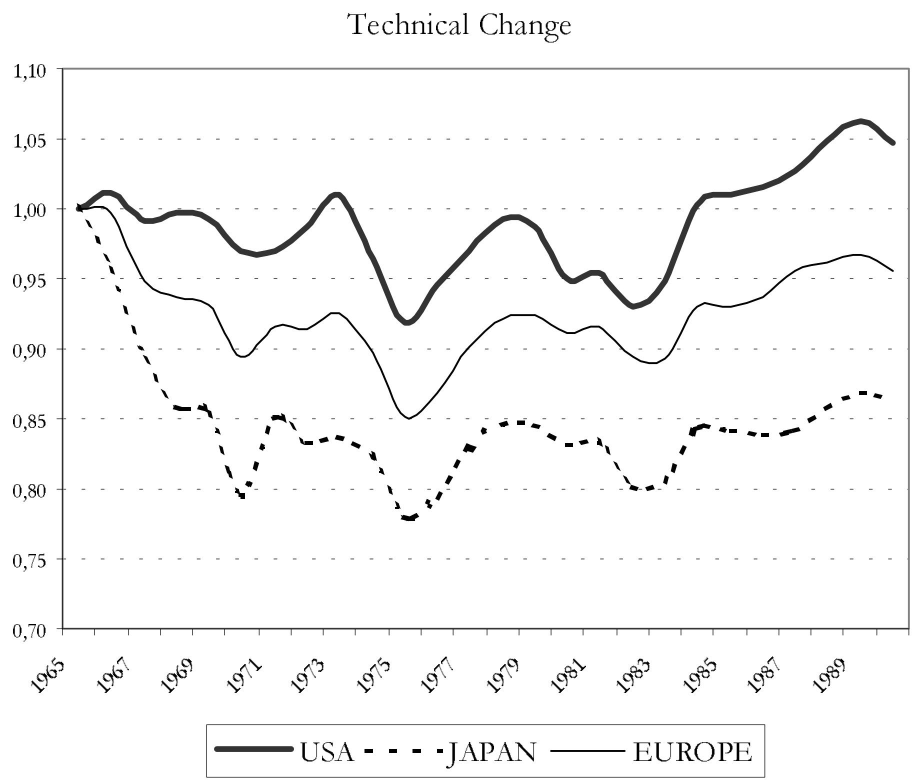
Also outstanding is the behaviour of Canada, Belgium, Finland, France, Germany, Italy, Netherlands, Norway, Sweden and Australia which in all the sub-periods experienced important gains in productivity. Denmark and Iceland, on the contrary, experienced losses in all the sub-periods considered.

With the aim of testing the possible bias remarked upon in the estimation of productivity gains and their breakdown into technical change and gains in efficiency when the role of human capital is not explicitly considered, figure 2 compares the cumulative evolution of the Malmquist productivity index and its breakdown into technical change and efficiency for the USA, Japan and Europe, including or excluding human capital. The results indicate that excluding human capital causes an important change in the relative positions of the USA and Europe, the position of Europe improving considerably when we consider human capital. The breakdown of TFP into technical change and efficiency allows it to be appreciated that this change in relative positions is due to the higher rate of technical change in Europe when we explicitly consider human capital as an additional productive factor, which shows the importance of this factor for the correct evaluation of the behaviour of productivity and of its sources of growth.

Figure 2: Cumulated results: Total factor productivity, technical change an d catching-up






Technical Change
1,10
1,05
1,00
0,95
0,90
0,85
0,80
0,75
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1965
1967
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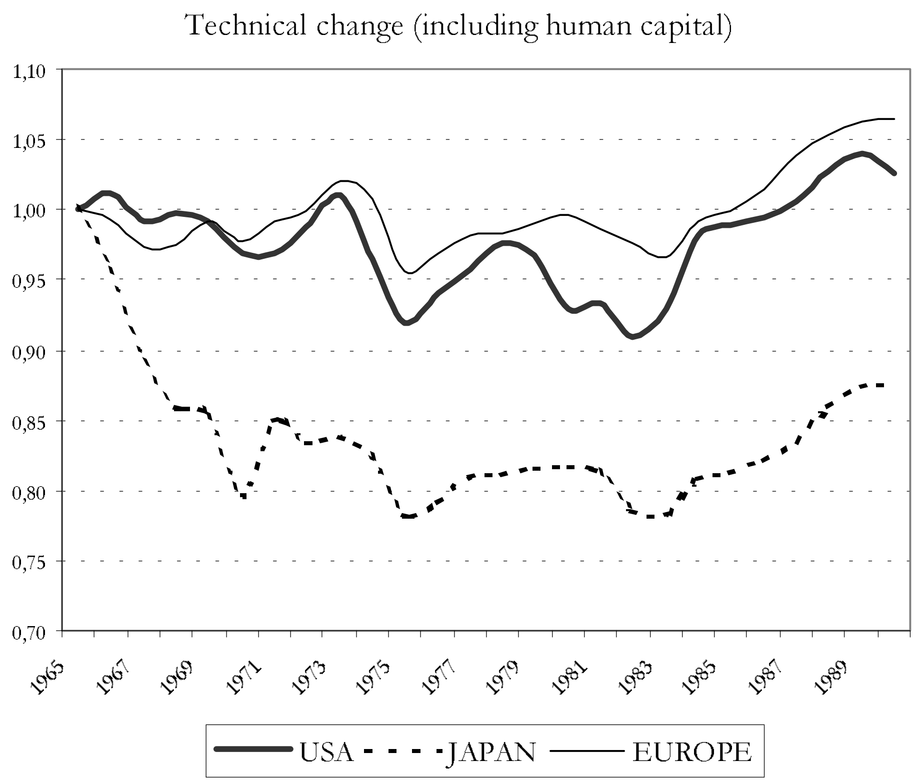
USA
JAPAN
EUROPE


Technical change (including human capital)
1,10
1,05
1,00
0,95
0,90
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0,80
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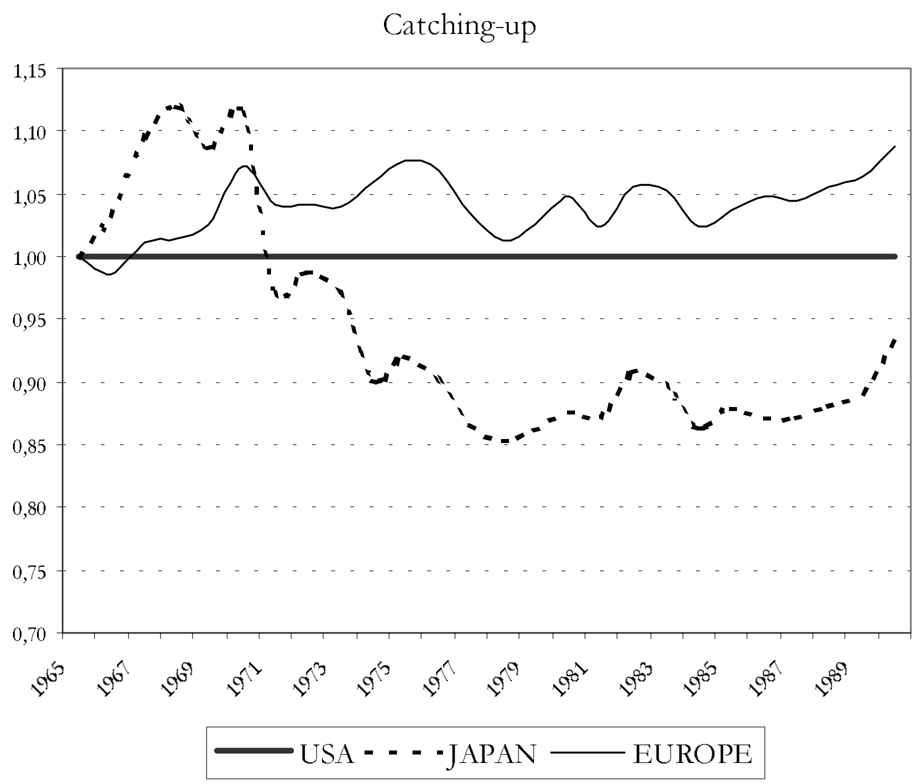
Catching-up
1,15
1,10
1,05
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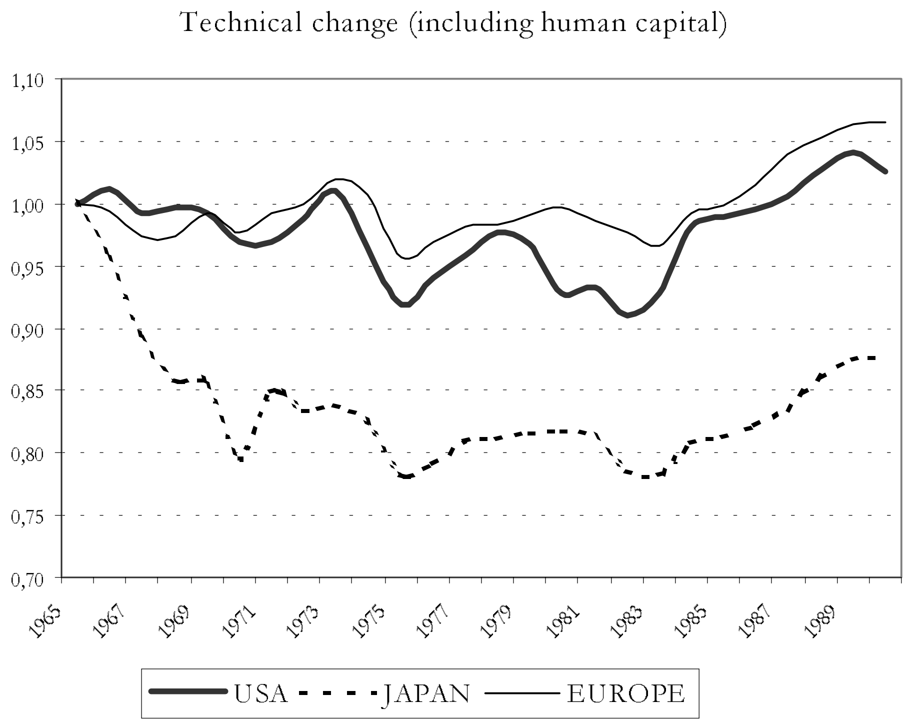
Technical change (including human capital)
1,10
1,05
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USA
JAPAN
EUROPE

Table 4: Malmquist index decomposition. Average annual growth (%)

	Efficiency Change (*)				*Technical Change*				*Malmquist Index*			
	1965-90	**1965-73**	**1973-85**	**1985-90**	**1965-90**	**1965-73**	**1973-85**	**1985-90**	**1965-90**	**1965-73**	**1973-85**	**1985-90**
Canada	0.415	-0.043	0.878	0.038	1.046	1.245	0.658	1.661	1.461	1.201	1.535	1.700
USA	0.000	0.000	0.000	0.000	0.103	0.127	-0.177	0.736	0.103	0.127	-0.177	0.736
Japan	0.041	-0.342	-0.147	1.105	-0.528	-2.205	-0.259	1.507	-0.487	-2.546	-0.406	2.612
Austria	-0.731	-1.754	-0.381	0.067	0.784	0.868	0.227	1.987	0.053	-0.885	-0.154	2.054
Belgium	1.062	1.810	0.626	0.909	0.552	0.313	0.181	1.827	1.614	2.123	0.807	2.736
Denmark	-0.279	-0.858	0.352	-0.866	-0.541	-1.371	-0.474	0.624	-0.820	-2.228	-0.122	-0.242
Finland	1.406	1.611	1.488	0.880	0.586	1.053	-0.204	1.736	1.992	2.664	1.284	2.616
France	0.001	0.477	-0.269	-0.115	1.168	1.863	0.323	2.083	1.168	2.340	0.054	1.968
Germany	0.893	1.395	1.115	-0.442	0.461	0.366	-0.049	1.839	1.355	1.761	1.066	1.397
Greece	0.496	1.415	-0.077	0.400	-0.393	-0.615	-0.502	0.225	0.103	0.800	-0.580	0.625
Iceland	-0.201	0.131	0.000	-1.212	-0.584	-0.864	-0.226	-0.997	-0.785	-0.733	-0.226	-2.209
Ireland	0.810	0.159	-0.047	3.909	-0.208	-0.958	0.192	0.033	0.602	-0.799	0.144	3.942
Italy	0.826	1.451	0.753	0.000	0.677	0.730	0.345	1.389	1.503	2.181	1.098	1.389
Netherlands	-0.214	-0.580	-0.022	-0.089	0.537	0.634	0.203	1.184	0.323	0.054	0.181	1.095
Norway	0.284	-1.568	2.417	-1.869	1.084	2.247	-0.052	1.948	1.368	0.678	2.365	0.079
Portugal	0.568	1.775	-0.422	1.014	-0.078	-0.245	-1.414	3.396	0.490	1.530	-1.836	4.410
Spain	-0.279	0.000	-0.742	0.387	-0.671	-0.752	-1.143	0.594	-0.950	-0.752	-1.886	0.980
Sweden	-0.096	-0.458	0.291	-0.448	0.644	0.958	-0.007	1.704	0.548	0.500	0.284	1.256
Switzerland	-0.091	0.000	-0.255	0.155	1.025	2.522	-0.304	1.821	0.934	2.522	-0.559	1.976
Turkey	0.267	1.118	-0.906	1.720	-1.354	-2.814	-1.175	0.551	-1.087	-1.695	-2.082	2.271
UK	0.000	-0.086	-0.476	1.279	-0.269	-0.815	0.221	-0.575	-0.269	-0.901	-0.254	0.704
Australia	0.471	0.618	0.911	-0.819	0.838	1.593	-0.009	1.661	1.309	2.211	0.902	0.842
New Zealand	-0.629	0.280	-0.937	-1.342	0.100	-0.019	-0.141	0.871	-0.528	0.261	-1.078	-0.472
MEAN	**0.218**	**0.285**	**0.180**	**0.203**	**0.216**	**0.168**	**-0.165**	**1.209**	**0.435**	**0.453**	**0.016**	**1.412**

5. HUMAN CAPITAL, TECHNICAL CHANGE AND CONVERGENCE

As we have seen in the previous section, human capital is a relevant input in the countries of the OECD together with employment and physical capital. However, human capital is not a productive input in the same way as the others. It is logical to suppose that a positive relationship may exist between the endowment of human capital of an economy and its capacity to develop and incorporate new techniques, more complex and productive. Naturally, other factors apart from the endowment of human capital may influence the rate of technical change. Thus, it is reasonable to suppose that the economies close to the technological frontier (most efficient) are those that devote most effort to innovation and that adopt them with greatest ease.

The breakdown of economic growth as above enables us to test those hypotheses in the case of the countries of the OECD, an estimation of technical change by countries being available. For this purpose we estimate equations such as:

[12] $$TC_i = \alpha + \gamma \cdot Ln(h_i) + \delta \cdot Ln(INEF_i) + e_i$$

where TC_i is the mean rate of technical change for country *i*, *h* the endowment of human capital per worker of the period in economy *i*, $INEF_i$ average inefficiency of *i*, and *e* a disturbance term.

Column 1 of table 5 offers the estimated effect of human capital on technical change over the whole period. Overall, human capital has driven the average rate of technical progress to a significant extent. The estimated coefficient of 0.008 means that an additional 10% of human capital leads to a rise of 0.08% in the average rate of technical change, a variation that, accumulated over the period 1965-1990, would imply an increase of more than 20% in total factor productivity (TFP). Also, the countries furthest from the technological frontier (less efficient) seem to experience lower rates of growth of technical progress, as indicated by the negative values estimated for δ.

Table 5: Effect of Human Capital on technical change

Period	*1965-90*	*1965-73*	*1973-85*	*1985-90*
Ln(h)	0.0082 (2.237)	0.0125 (2.003)	0.0087 (3.842)	-0.4548 (-0.515)
Ln(INEF)	-0.0174 (-2.048)	-0.0222 (-1.326)	-0.0073 (-1.634)	-0.0109 (-0.764)
R^2	0.288	0.172	0.426	0.053

Note: Heteroscedastic consistent t-ratio in parentheses.

However, the influence of human capital does not seem to have maintained the same intensity over the whole of the period analysed, as can be appreciated in the other columns of table 5. The figures were especially relevant during the sub-period of growth 1965-1973 (0.0125) although they decreased somewhat during the period of crisis 1973-1985 (0.0087), being statistically significant nevertheless in both cases. If the initial intensity had been maintained, 10% more human capital would have meant 36% more productivity due to greater technical progress. On the other hand, in the last sub-period there does not seem to be any significant relationship between human capital and technical change.

The importance of human capital as a determining factor of technical change allows us to understand better the pattern of slow convergence followed by the countries of the OECD, the more developed countries having experienced higher rates of technical change thanks to their greater endowments of human capital. To illustrate this matter we will apply the classical analytical method of absolute beta-convergence by means of regressions, as:

[13] $$\hat{y}_i = a_y + b_y \cdot Ln(y_{0i}) + u_{yi}$$

[14] $$\hat{T}C_i = a_{TC} + b_{TC} \cdot Ln(y_{0i}) + u_{TCi}$$

[15] $$\hat{T}C_i^h = a_h + b_h \cdot Ln(y_{0i}) + u_{hi}$$

[16] $$\hat{T}C_i^r = a_r + b_r \cdot Ln(y_{0i}) + u_{ri}$$

where $\hat{y}_i$ is the average rate of growth of labour productivity of country i from 0 to T, $\hat{T}C_i$ the average rate of technical change, $\hat{T}C_i^h$ the rate of technical change explained by the endowment of human capital obtained from the results of Table 5, and $\hat{T}C_i^r$ the residual rate of technical change not explained by human capital $\left(\hat{T}C_i^r = \hat{T}C_i - \hat{T}C_i^h\right)$.

Thus b_y is the rate of total labour productivity convergence and b_{TC} the rate of convergence attributable to technical change. The latter is due to the effect of the endowment of human capital on technical change (b_h) and to residual technical change (b_r)[25].

Table 6 offers the results for the period 1965-90 and for the sub-periods 1965-73, 1973-85 and 1985-90. In column 1 we can observe convergence in the levels of labor productivity over the whole period. Its cumulative magnitude (-1.77%) and its time pattern, agree with the results habitually offered by the literature (see Barro and Sala-i-Martin, 1995). Thus, convergence was more intense in the period 1965-73 (-2.85%) than during the crisis of 1973-85 (-1.04%) and recovered again in the final sub-period (-3.03%).

Table 6: Labour productivity convergence and its components

Period	*(1) Total*	*(2) Technical Change*	*(3) Human capital*	*(4) Residual*
1965-90	-0.0177 (-3.579) [0.719]	0.0091 (4.585) [0.414]	0.0051 (4.865) [0.666]	0.0039 (1.743) [0.093]
1965-73	-0.0285 (-2.707) [0.597]	0.0183 (4.384) [0.436]	0.0085 (4.856) [0.656]	0.0098 (1.946) [0.139]
1973-85	-0.0104 (-2.335) [0.247]	0.0083 (4.244) [0.398]	0.0067 (6.980) [0.650]	0.0015 (0.933) [0.021]
1985-90	-0.0303 (-2.417) [0.394]	0.0021 (0.269) [0.005]	- - -	- - -

Note: Heteroscedastic consistent t-ratio in parentheses. R^2 in squared brackets.
Column 1: Average annual rate of absolute convergence of labor productivity.
Columns 2-4: Contribution to convergence of technical change and its components (human capital (3) and the residual contribution (4).

The effect of technical progress is shown in column 2. The results indicate that, contrary to the results obtained in other papers (Dowrick and Nguyen, 1989; Dollar and Wolff, 1994; Bernard and Jones, 1996b; Wolff, 1991; etc.), technical progress was a systematic and significant source of divergence. Both in the period as a whole and in each of the sub-periods considered, the countries with highest initial productivity experienced greater

[25] It is easy to prove that $b_{TC} = b_h + b_r$

relative technical progress. Thus, the effect over the period as a whole was +0.91%, being somewhat higher in the sub-period 1965-73 (+1.83%), and less during the sub-period 1973-85 (+0.83%), the effect becoming not significant during sub-period 1985-90 (+0.21%). This result seems reasonable if it is considered that it is the most developed countries that make the innovations. This means that they are the first to adopt them, and also that technical progress is adapted to the characteristics of this type of economy. For all these reasons technical progress benefits in the short term especially the more developed countries.

Examining column 3, we can see that human capital has generated a significant divergence by means of its effect on technical change (+0.51%). In fact this effect represents more than half the divergence that we had attributed to technical change. Technical change not explained by human capital, according to the results of column 4, is at the limits of significance. Examining the sub-periods in which there was a significant relationship between human capital and technical change, we find similar situations. Thus, during the sub-period 1965-1973, the divergent contribution of the rate effect of human capital (+0.85%) is significant and represents 40% of the divergence attributable to technical change. Finally in the period of crisis 1973-1985 that effect continues to be significant an remains at similar levels (+0.68%), being solely responsible for the fact that technical change generates divergence, as the specific value offered by the residual effect is very low and not significant.

To sum up, human capital seems to have had a positive contribution to the growth of the countries of the OECD, since as well as being an important input of the productive process (level effect) it also drove technical change (rate effect) even though the latter effect sees to have greatly weakened towards the end of the period. Indeed the rate of growth followed by these countries is in large part determined by this effect. The differences with respect to endowments of human capital have led to divergent rates of technical change, and therefore less intensive convergence.

6. CONCLUSIONS

The studies made so far have analysed the importance of human capital both by means of the estimation of production functions that include human capital as an additional productive factor and by means of the estimation of the effect of human capital on TFP, the latter being estimated by the traditional non-parametric approach of index numbers.

However, in both cases it is implicitly assumed that all the units of production (in our case countries) are efficient, so that technical progress is identified with productivity gains. However, in the presence of inefficiency the estimation of TFP will be biassed, thus affecting the possible effect of human capital on TFP.

This study has confirmed the importance of human capital in the growth of productivity in the OECD, explicitly incorporating into the analysis the importance of efficiency as a source of variation in TFP other than technical progress.

The results for the period 1965-1990 show the existence of both a level effect (human capital is an additional input in the production function) and a rate effect (human capital favours the assimilation of technical progress) associated with human capital. Thus, the estimation of a stochastic translog production function shows a statistically significant product elasticity of human capital and non-parametric techniques confirm its significance as input.

Indeed, the analysis of the breakdown of TFP growth into technical change and variations in efficiency shows the importance of considering human capital as an additional productive factor. Thus, non-consideration of human capital causes an important change in the relative positions of the USA and Europe, the position of Europe improving considerably in terms of productivity when we consider human capital as input. Furthermore, the breakdown of change in TFP into technical change and variations in efficiency allows it to be appreciated that this modification of relative positions is due to Europe's higher rate of technical change when we explicitly consider human capital.

In this sense, the results show that human capital has significantly driven the rate of technical change, its magnitude being especially important in the period of growth 1965-1973. This phenomenon, together with the fact that human capital was greater in the countries that were initially richer, implies that human capital has been a significant source of divergence.

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