CONVERGENCIA IN OECD COUNTRIES: TECHNICAL CHANGE, EFFICIENCY AND PRODUCTIVITY*

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R E S U M E N

El trabajo tiene como objetivo básico analizar la contribución de las distintas fuentes del crecimiento a la convergencia en productividad del trabajo en los países de la OCDE en el periodo 1965-90. Más concretamente, y utilizando dos aproximaciones frontera distintas (índices de productividad de Malmquist y un enfoque de frontera estocástica), se distingue la contribución del cambio técnico y de los cambios de eficiencia a la convergencia en productividad del trabajo. Los resultados obtenidos contradicen los obtenidos en otros trabajos que utilizan aproximaciones no frontera a la medición de la productividad, rechazándose la existencia de convergencia tecnológica, dado que el progreso técnico ha sido mayor en los países con mayor productividad del trabajo.

Palabras Clave: Convergencia, cambio técnico, eficiencia, índice Malmquist de productividad.

A B S T R A C T

The aim of this study is to analyze labor productivity convergence in the countries of the OECD over the period 1965-90. A non-parametric frontier approach is used to calculate the Malmquist productivity index. By breaking it down, the contribution to the growth of labor productivity of technical progress, of changes in efficiency, and of the accumulation of inputs per worker are quantified. Unlike other studies, the results obtained show that technical change has worked against labor productivity convergence, since it has always been greater in the countries with higher labor productivity.

Keywords: Convergence, technical change, efficiency, Malmquist productivity index.

1. INTRODUCTION

The study of convergence between countries in terms of per capita income and labor productivity has given rise to the development of a very wide-ranging literature (see Barro and Sala-i-Martin (1995) for a survey of the empirical evidence). In particular, the existence of convergence, though at a moderate rate, has been profusely documented in the case of the countries of the OECD, this question being at the center of the debate on economic growth.

With the aim of understanding better the forces underlying this process of convergence, a part of the literature has been devoted to analyzing the hypothesis of catching-up in the levels of total factor productivity (TFP) among the countries of the OECD. This catch-up hypothesis claims that poor countries tend to grow faster than rich countries through the international diffusion of knowledge and technology. In the studies in which this hypothesis is tested, TFP growth is due to both diffusion of technology and innovation[1].

However, these studies that relate convergence to TFP usually obtain the latter by means of Törnqvist indices or other proxies such as growth accounting which, in the words of Grosskopf (1993), ignore efficiency. The underlying problem is that these methods, valid only in the case of technical efficiency, and allocative efficiency, lead to biassed estimates of technical progress in the presence of inefficiency. Furthermore, it is not possible to break down the growth of TFP, thus omitting the fact that part of this growth is due to gains in efficiency and not only to technical progress.

There are various studies that, in order to alleviate these problems, have incorporated explicitly the existence of inefficiency in the analysis of the growth of productivity and of

[1] Dowrick and Nguyen (1989), using aggregated data, offer evidence that convergence in TFP (residually defined) has systematically been the main source of convergence in labor productivity during the period 1950-85. Dollar and Wolff (1994) documented the existence of TFP convergence in industrial sectors during the period 1963-85, and attributed to it the greatest part of convergence in labor productivity levels. However, in this case the phenomenon is not systematic, as on the contrary, the process was especially intense during the period 1963-72, becoming more moderate from 1973 onwards. For their part, Bernard and Jones (1996a and b) highlight the existence of convergence in TFP during the period 1977-88, although with exceptions such as the manufacturing sector.

technical progress in the international sphere by the use of frontier techniques[2]. The results obtained in all these studies demonstrate the existence of substantial levels of inefficiency that vary widely among countries and over time, indicating that the omission of inefficiency from the analysis may substantially affect the validity of the results[3].

In general, this second type of literature has concentrated on the growth of TFP and its breakdown into technical progress and changes in efficiency without entering into the analysis of convergence. Fecher and Perelman (1992) consider the unequal level of efficiency to be one of the possible determining variables of the growth of TFP and obtain a systematic negative correlation within each sector for the period as a whole, although the evidence is less robust both at country level and across different periods. Perelman (1995) attempted to explain the causes of the growth of TFP and of its components (technical progress and efficiency) by means of regressions in which unequal efficiency was included together with other explanatory variables, likewise finding evidence favorable to the hypothesis of technological catching-up. Even in these two cases the contribution of TFP to convergence in levels of labor productivity was still not analyzed. Likewise, although Färe et al. (1994) analyze productivity gains and their breakdown into efficiency and technical progress, they do not show their effect on convergence in labor productivity.

To date, there are only two published papers that analyze the importance of efficiency change and technical change on the convergence of labor productivity. Taskin and Zaim (1997) analyze the catching-up hypothesis for a group of countries of the OECD showing that technical change is higher in rich countries while poor countries gave a higher efficiency change. Maudos et al. (1998) utilize also the Malmquist productivity index in the Spanish regions obtaining that technical progress has played against convergence in labor productivity since richer regions have experienced larger rates of technical progress.

In this context, the aim of this study is to analyze labor productivity convergence in the countries of the OECD over the period 1965-90 distinguishing the contribution of the different sources -technical progress, changes in efficiency and accumulation of inputs per worker- by

[2] Thus, Färe et al. (1994) studied the growth of productivity at aggregate level in 17 countries of the OECD during the period 1979-88 by means of Malmquist productivity indices; Fecher and Perelman (1992) used the stochastic frontier approach to evaluate the growth of TFP and analyse its causes with sector data relating to a sample of 13 countries of the OECD during the period 1971-86. Finally, Perelman (1995) estimated the growth of TFP during the period 197-87 in a context of 8 industrial sectors and 11 countries of the OECD using both the stochastic frontier approach and the non-parametric DEA approach.

[3] Färe et al. (1994) and Fecher and Perelman (1992) compare their results to the TFP growth obtained through the standard proxy of growth accounting formulated by means of Törnqvist's index number. In both cases there are significant differences, thus confirming the limitation placed on the estimation of TFP by ignoring the existence of inefficiency.

means of frontier approaches. For this purpose we use both the stochastic approach and the Malmquist productivity index, obtained by means of non-parametric methods of linear programming. With the latter approach, it will be possible to attribute to the accumulation of inputs per worker and to the growth of TFP the part that corresponds to them, distinguishing within TFP the parts corresponding to technical change (due to innovation) and to efficiency change (due to diffusion of technology).

The structure of the paper is as follows. Section 2 sets out the importance of distinguishing the concepts of technical progress and efficiency as well as the implications of adopting a particular approach to the measurement of productivity. Section 3 is devoted to describing the sample used and the results obtained in terms of efficiency, technical change and productivity. Section 4 analyses the importance that gains in efficiency, technical progress and total factor productivity have had in the process of labor productivity convergence. Finally, Section 5 contains the conclusions of the study.

2. 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.), and the index number approach[4] (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 biased. Furthermore, even in the absence of technical inefficiency, the accounting estimation of the growth of TFP would be a biased estimation if the participations used in its calculation are not those that minimize cost, i.e. there is allocative inefficiency[5].

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

[4] See among others Baumol (1986), Baumol and Wolff (1988), Abramovitz (1986, 1990, & 1994), Bernard and Jones (1996a & b), Dollar and Wolff (1994), Wolff (1991).
[5] See a more detailed exposition in Grosskopf (1993).

study we use this frontier approach and compare the results of parametric methods (stochastic frontier approach, SFA) with non-parametric methods (Malmquist index based on DEA).

Note that the frontier is estimated from observed data and because of this it cannot be considered as the "true frontier" but as the "best practice". In this sense, the efficiency measures should be interpreted as relative efficiency regard to the best practice[6].

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.). 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.

Being aware of the limitations that it presents, we will attempt to alleviate them in two ways: a) by adopting the most flexible functional form possible; and b) by testing the sensitivity of the results against different distributional assumptions for the inefficiency term.

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,

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

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}

[6]There is no consensus on which is the best frontier approach because all techniques have their own advantages and disadvantages. The strategy used in this paper is to explain briefly the two most commonly used although for the aim of the paper (to test the catching-up hypothesis differenciating the effect of efficiency change from the technical progress) the stochastic frontier approach has as a main disadvantage that does not allow us to estimate technical change by countries.

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 $exp(u_{it})$[7].

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).

Empirically, the different distributional assumptions for the inefficiency term may lead to different results, at least in terms of the inefficiencies estimated. For this reason it is important to analyze the sensitivity of the results under different alternative assumptions with the aim of choosing the assumption that best fits the data.

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.

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

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.

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[8], let us assume that the transformation function that describes the technology in each period t is:

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

where $y^t=(y_1^t,\ldots,y_N^t)\in R_N^+$ is the vector of outputs and $x^t=(x_1^t,\ldots,x_M^t)\in R_M^+$ 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] $D_o^t(x^t,y^t) = \inf\{\vartheta^{t,t} : (x^t,y^t/\vartheta^{t,t})\in F^t\}=[\sup\{\vartheta^{t,t} : (x^t, \vartheta^{t,t} y^t) \in F^t\}]^{-1}$

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

[8] See Malmquist (1953).

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 $OB/OA=y^{t,t}/y^t=1/\vartheta^{t,t}$.

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.

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

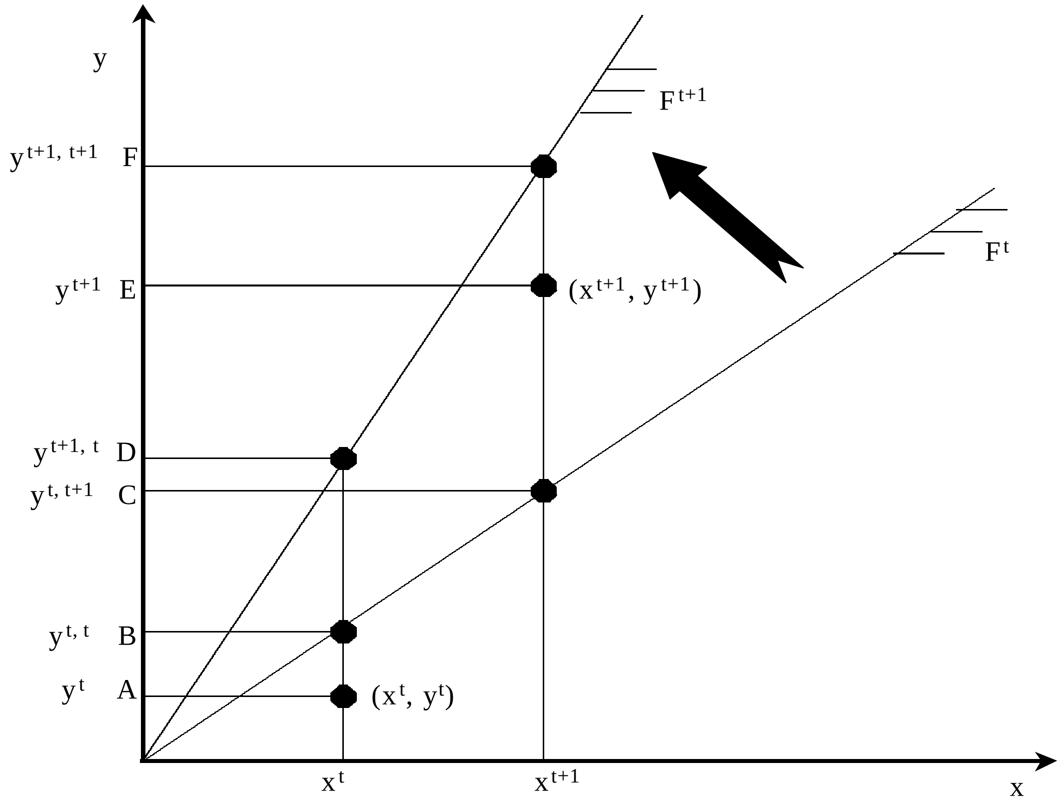
In the above expression, the distance function $D_o^t(x^{t+1},y^{t+1})$ measures the maximum proportional increase in outputs, given the inputs, to make the observation of period $t+1$, (x^{t+1},y^{t+1}), feasible in period t. In the situation represented in figure 1, the observation (x^{t+1},y^{t+1}) 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[9].

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[10]:

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

[9] 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.
[10] See Caves et al. (1982).

Figure 1: Malmquist output-based productivity index



$M_o^t>1$ 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 $t+1$.

Alternatively it is possible to define the Malmquist index by taking the technology of period $t+1$[11]:

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

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

[11] 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.

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 (Grifell and Lovell, 1997).

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:

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

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[12]:

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

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.

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

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

[12] See Berg et al. (1992) and Grifell et al. (1997).

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 $D_o^t(x^t,y^t)$:

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

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[13]:

$$
\begin{aligned}
&\left[D_o^t\left(x_j^{t+1}, y_j^{t+1}\right)\right]^{-1} = Max\,\vartheta_j^{t,t+1} \\
&s.t. \\
&\sum_{k=1}^{K} \lambda_k^t y_{mk}^t \geq y_{mj}^{t+1} \vartheta_j^{t,t+1} \qquad m = 1,\ldots,M \\
&\sum_{k=1}^{K} \lambda_k^t x_{nk}^t \leq x_{nj}^{t+1} \qquad n = 1,\ldots,N \\
&\lambda_k^t \geq 0 \qquad k = 1,\ldots,K
\end{aligned} \tag{[11]}
$$

[13] 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.

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.

3. DATA AND RESULTS

The sample used for the estimation of the frontier production function consists of the countries of the OECD[14] in the period 1965-90 using the Summers and Heston database (Penn World Table, Mark 5.6)[15]. 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; and 3) total capital stock (K) calculated from the non-residential capital per worker.

Table 1 contains the annual growth rates of GDP, capital and employment in the different countries of the OECD. Several sub-periods can be distinguished: the complete period 1965-90 and the sub-periods of growth (1965-73), crisis (1973-85) and recovery (1985-90). The most outstanding feature is the fact that Japan is the country that experienced the highest growth rate in GDP as a result of the intense rate of capital accumulation. On the other hand, employment grew at a rate similar to the average for countries of the OECD, which must consequently be translated into a substantial growth in the capital-labor ratio.

Table 2 shows the average levels of efficiency estimated for the period 1965-90 and for the three sub-periods of the sample using the non-parametric approach described earlier. One outstanding feature is the fact that the USA stands at the frontier throughout the period, while countries like Japan, Finland and Greece present high levels of inefficiency[16].

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[14] The sample used consists of Canada, USA, Japan, Austria, Belgium, Denmark, Finland, France, Germany, Greece, Iceland, Ireland, Italy, Luxembourg, Norway, Portugal, Spain, Sweden, Switzerland, Turkey, UK, Australia and New Zealand.

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

[16] Technical efficiency is defined as the ratio of the real output to the maximum output that could be produced with the inputs used. In this sense, to measure efficiency accurately it is necessary to correct inputs by the degree of utilization of capital, this information is not available.

Table 1: Average annual growth rates: GDP, capital and employment (%)

	GDP (Y)				*Stock of capital (K)*				*Employment (L)*			
	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	3.93	5.35	3.38	2.99	5.55	6.27	5.19	5.28	2.19	2.74	2.32	1.01
USA	2.77	3.72	2.19	2.62	4.42	6.19	3.46	3.89	1.68	1.88	1.87	0.93
Japan	5.53	9.14	3.60	4.39	8.76	13.45	6.82	5.93	1.02	1.45	0.87	0.71
Austria	3.15	4.81	2.09	3.04	6.28	9.19	5.37	3.80	0.47	-0.13	0.75	0.77
Belgium	2.91	4.63	1.55	3.40	4.08	6.38	3.25	2.41	0.59	0.48	0.74	0.41
Denmark	2.31	3.54	1.82	1.50	4.39	7.17	3.10	3.06	0.99	1.36	0.91	0.60
Finland	3.43	4.73	2.57	3.42	4.71	6.04	4.12	3.97	0.73	0.71	0.83	0.56
France	3.18	5.15	1.88	3.16	5.12	7.87	4.12	3.13	0.87	0.86	0.88	0.87
Germany	2.68	4.01	1.50	3.39	5.33	9.97	3.28	2.79	0.54	-0.07	0.43	1.80
Greece	3.84	7.16	2.37	2.05	5.61	9.57	4.68	1.51	0.52	0.18	0.82	0.35
Iceland	4.16	4.64	4.34	2.93	6.26	6.43	5.53	7.77	2.12	2.37	2.21	1.51
Ireland	4.15	5.02	3.37	4.65	5.33	7.90	5.40	1.04	0.77	0.49	1.22	0.13
Italy	3.56	5.33	2.58	3.07	4.31	6.13	3.67	2.94	0.45	0.25	0.53	0.58
Luxembourg	3.05	4.96	1.77	3.05	4.53	7.35	3.18	3.24	1.39	1.48	1.38	1.26
Norway	3.57	4.10	4.10	1.47	2.44	1.89	2.77	2.53	1.46	1.69	1.44	1.12
Portugal	4.85	7.01	2.42	7.20	5.89	8.89	4.72	3.90	0.89	-0.13	2.14	-0.47
Spain	3.73	6.23	1.54	5.00	6.85	10.19	5.36	5.09	0.73	0.45	0.97	0.62
Sweden	2.21	3.00	1.62	2.35	4.63	6.41	3.06	5.57	0.98	1.29	0.77	0.98
Switzerland	2.11	3.93	0.61	2.83	4.30	6.39	2.99	4.08	0.81	1.35	0.39	0.94
Turkey	5.25	6.43	4.12	6.09	6.60	8.49	6.50	3.80	1.93	1.64	2.04	2.15
UK	2.39	3.21	1.37	3.52	4.03	5.89	2.75	4.14	0.49	0.53	0.47	0.48
Australia	3.59	5.34	2.74	2.80	4.67	6.47	3.70	4.11	2.16	2.63	1.97	1.89
New Zealand	1.95	3.47	1.46	0.67	4.04	4.97	3.94	2.77	1.66	1.98	1.65	1.16
Mean	**3.26**	**4.72**	**2.30**	**3.24**	**5.29**	**7.70**	**4.17**	**4.12**	**1.16**	**1.21**	**1.23**	**0.95**

Table 2: Average technical efficiency (DEA)

	1965-90	*1965-73*	*1973-85*	*1985-90*
Canada	1.140	1.229	1.113	1.063
USA	1.000	1.000	1.000	1.000
Japan	1.624	1.458	1.703	1.708
Austria	1.280	1.166	1.301	1.414
Belgium	1.255	1.352	1.208	1.215
Denmark	1.412	1.352	1.450	1.419
Finland	1.612	1.866	1.531	1.385
France	1.213	1.205	1.211	1.237
Germany	1.300	1.420	1.241	1.248
Greece	1.696	1.681	1.695	1.702
Iceland	1.019	1.033	1.000	1.032
Ireland	1.344	1.347	1.351	1.331
Italy	1.227	1.312	1.199	1.158
Luxembourg	1.135	1.143	1.120	1.161
Norway	1.383	1.585	1.318	1.214
Portugal	1.130	1.100	1.172	1.088
Spain	1.139	1.016	1.177	1.249
Sweden	1.275	1.263	1.282	1.284
Switzerland	1.136	1.160	1.121	1.130
Turkey	1.333	1.207	1.422	1.331
UK	1.057	1.020	1.093	1.029
Australia	1.210	1.262	1.187	1.180
New Zealand	1.263	1.227	1.241	1.355
Mean	**1.269**	**1.278**	**1.267**	**1.258**

Note: Values higher than unity imply that the country is technically inefficient; the higher the index the greater the inefficiency..

The growth rates of TFP as well as those of its two components (technical change and changes in efficiency) are reflected in table 3. The comparison by sub-periods shows the existence of important differences over time. Thus, although in the sub-periods of growth (1965-73) and crisis (1973-85) losses in productivity occurred, in the sub-period 1985-90 productivity grew at an annual rate of 1.29%. Furthermore, the contribution of efficiency (catching-up) and of technical progress (movement of the frontier) was not uniform over time. Whereas in the sub-period of crisis 1973-85 the losses in productivity were due to the fall in efficiency, in the sub-period 1965-73 it is the lack of technical progress that is responsible for the fall in productivity in spite of the gains in efficiency experienced. In the last sub-period, both gains in efficiency and to a lesser extent technical progress were responsible for the gains in productivity.

Table 3: Malmquist index decomposition. Average annual growth rate (%)

	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	0.66	0.89	0.66	0.28	0.63	0.60	0.22	1.70	1.29	1.49	0.88	1.98
USA	0.00	0.00	0.00	0.00	0.19	0.13	0.00	0.74	0.19	0.13	0.00	0.74
Japan	-0.28	-0.36	-0.83	1.16	-0.59	-2.21	0.03	0.50	-0.88	-2.57	-0.80	1.66
Austria	-0.72	-0.67	-1.28	0.53	-0.12	-0.79	-0.01	0.65	-0.85	-1.45	-1.29	1.18
Belgium	0.80	1.05	0.43	1.29	0.03	-1.39	0.27	1.70	0.83	-0.34	0.71	2.99
Denmark	-0.31	-0.86	0.10	-0.43	-0.60	-1.37	-0.29	-0.10	-0.91	-2.23	-0.19	-0.53
Finland	1.51	1.86	1.42	1.17	0.16	-0.89	0.22	1.70	1.67	0.97	1.64	2.86
France	0.12	0.33	-0.22	0.60	-0.07	-1.23	-0.01	1.63	0.05	-0.90	-0.23	2.23
Germany	0.60	0.80	0.75	-0.10	0.27	-0.98	0.50	1.70	0.86	-0.18	1.25	1.59
Greece	0.32	1.21	-0.69	1.32	-0.37	-1.05	0.04	-0.28	-0.05	0.16	-0.65	1.04
Iceland	-0.30	0.15	0.00	-1.76	-0.70	-0.95	-0.27	-1.32	-1.00	-0.81	-0.27	-3.08
Ireland	0.73	0.12	-0.36	4.29	-0.23	-1.02	0.32	-0.28	0.50	-0.90	-0.03	4.01
Italy	1.11	1.98	0.48	1.25	-0.53	-1.16	-0.23	-0.25	0.58	0.82	0.25	1.00
Luxembourg	0.23	0.39	-0.12	0.79	-0.46	-1.42	0.10	-0.26	-0.23	-1.02	-0.02	0.53
Norway	1.03	0.57	2.33	-1.35	1.10	1.84	0.35	1.70	2.13	2.41	2.69	0.34
Portugal	0.57	0.98	-1.11	3.95	-1.45	-2.85	-0.86	-0.64	-0.89	-1.88	-1.97	3.31
Spain	-0.68	-0.28	-2.04	1.93	-0.45	-1.65	0.22	-0.15	-1.14	-1.93	-1.82	1.78
Sweden	-0.18	-0.78	0.28	-0.32	-0.12	-1.48	0.03	1.70	-0.30	-2.26	0.31	1.37
Switzerland	0.23	0.74	-0.11	0.20	1.13	1.84	0.42	1.70	1.35	2.58	0.31	1.89
Turkey	0.27	0.79	-1.20	2.94	-1.51	-2.85	-0.97	-0.65	-1.24	-2.06	-2.17	2.29
UK	0.00	-0.09	-0.48	1.28	-0.31	-0.82	0.20	-0.69	-0.31	-0.91	-0.28	0.59
Australia	0.34	0.88	0.45	-0.78	1.16	1.84	0.49	1.70	1.50	2.71	0.94	0.91
New Zealand	-0.66	0.28	-0.94	-1.52	0.01	-0.16	-0.13	0.62	-0.65	0.12	-1.07	-0.89
Mean	**0.23**	**0.43**	**-0.11**	**0.73**	**-0.12**	**-0.78**	**0.03**	**0.57**	**0.11**	**-0.35**	**-0.08**	**1.29**

(*)Positive values indicate gains in efficiency..

By countries, important differences can again be observed. Thus, in the particular case of Japan, the losses in productivity until 1985 were due both to losses of efficiency and the absence of technical progress, although productivity grew in the last sub-period as a consequence, above all, of the important gains in efficiency. On the other hand, the USA's gains in TFP in the sub-period 1985-90 were due exclusively to technical progress.

We would also highlight the behavior of Canada, Finland, Italy, Norway, Switzerland and Australia since in all the sub-periods they experienced gains in productivity. On the other hand, Denmark and Iceland suffered losses of productivity in all the sub-periods.

The results obtained are similar to those of Färe et al. (1994) who observed improvements in efficiency (catching-up) in the case of the Japanese economy in the period 1979-1988. However, unlike this last study, other countries of the sample experienced improvements in efficiency greater than those of the Japanese economy. The reasons for this discrepancy may be diverse: firstly, the different period of time analysed; and secondly, the different sample of countries considered. Nevertheless, in spite of the discrepancies, the results are in agreement as regards the high levels of inefficiency of the Japanese economy.

Since the growth rate of labor productivity can be broken down as the sum of the growth rate of efficiency, the rate of technical progress and the contribution of the increase in the inputs used per worker[17], it is of interest to analyze the sources of growth of labor productivity. Table 4 shows the growth rate of labor productivity and of its three components for the countries of the OECD and for the different sub-periods of time considered.

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[17] In principle we can evaluate the contribution of inputs to growth from *t* to *t+1* for the technology current in each of these periods, and obtain an appropriate estimate by means of a geometric mean of the two. Following the representation of figure 1:

$$\left(\frac{y^{t,t+1}}{y^{t,t}}\frac{y^{t+1,t+1}}{y^{t+1,t}}\right)^{1/2} = \left(\frac{OC}{OB}\frac{OF}{OD}\right)^{1/2}$$

Thus, growth (y^{t+1}/y^{t}) can be broken down multiplicatively into the growth of TFP (Malmquist index) and the contribution of the accumulation of inputs:

$$\frac{y^{t+1}}{y^{t}} = M_o\left(x^{t+1}, y^{t+1}, x^{t}, y^{t}\right)\left(\frac{y^{t,t+1}}{y^{t,t}}\frac{y^{t+1,t+1}}{y^{t+1,t}}\right)^{1/2} = \frac{OE}{OA}$$

In the same way the growth of labor productivity is broken down multiplicatively into the Malmquist index and the contribution of the accumulation of inputs per worker.

Table 4: Decomposition of labor productivity growth: Average annual changes (%)

	1965-90					*1965-73*				
	Efficiency	*Technical Change*	*Inputs*	*TFP*	*Y/L*	*Efficiency*	*Technical Change*	*Inputs*	*TFP*	*Y/L*
Canada	0.66	0.63	0.45	1.29	1.74	0.89	0.60	1.13	1.49	2.62
USA	0.00	0.19	0.90	0.19	1.08	0.00	0.13	1.71	0.13	1.84
Japan	-0.28	-0.59	5.34	-0.88	4.51	-0.36	-2.21	10.26	-2.57	7.69
Austria	-0.72	-0.12	3.52	-0.85	2.67	-0.67	-0.79	6.39	-1.45	4.93
Belgium	0.80	0.03	1.49	0.83	2.31	1.05	-1.39	4.50	-0.34	4.16
Denmark	-0.31	-0.60	2.23	-0.91	1.32	-0.86	-1.37	4.41	-2.23	2.18
Finland	1.51	0.16	1.03	1.67	2.70	1.86	-0.89	3.05	0.97	4.02
France	0.12	-0.07	2.27	0.05	2.31	0.33	-1.23	5.19	-0.90	4.29
Germany	0.60	0.27	1.28	0.86	2.14	0.80	-0.98	4.26	-0.18	4.08
Greece	0.32	-0.37	3.37	-0.05	3.32	1.21	-1.05	6.82	0.16	6.98
Iceland	-0.30	-0.70	3.04	-1.00	2.04	0.15	-0.95	3.07	-0.81	2.27
Ireland	0.73	-0.23	2.88	0.50	3.38	0.12	-1.02	5.43	-0.90	4.53
Italy	1.11	-0.53	2.53	0.58	3.11	1.98	-1.16	4.26	0.82	5.08
Luxembourg	0.23	-0.46	1.89	-0.23	1.66	0.39	-1.42	4.51	-1.02	3.48
Norway	1.03	1.10	-0.01	2.13	2.12	0.57	1.84	0.00	2.41	2.41
Portugal	0.57	-1.45	4.84	-0.89	3.96	0.98	-2.85	9.02	-1.88	7.14
Spain	-0.68	-0.45	4.14	-1.14	3.00	-0.28	-1.65	7.71	-1.93	5.78
Sweden	-0.18	-0.12	1.53	-0.30	1.23	-0.78	-1.48	3.97	-2.26	1.71
Switzerland	0.23	1.13	-0.04	1.35	1.31	0.74	1.84	0.00	2.58	2.58
Turkey	0.27	-1.51	4.56	-1.24	3.32	0.79	-2.85	6.85	-2.06	4.79
UK	0.00	-0.31	2.20	-0.31	1.90	-0.09	-0.82	3.59	-0.91	2.68
Australia	0.34	1.16	-0.08	1.50	1.42	0.88	1.84	0.00	2.71	2.71
New Zealand	-0.66	0.01	0.94	-0.65	0.29	0.28	-0.16	1.37	0.12	1.49
MEAN	**0.23**	**-0.12**	**2.19**	**0.11**	**2.30**	**0.43**	**-0.78**	**4.24**	**-0.35**	**3.98**

	1973-85					*1985-90*				
	Efficiency	*Technical Change*	*Inputs*	*TFP*	*Y/L*	*Efficiency*	*Technical Change*	*Inputs*	*TFP*	*Y/L*
Canada	0.66	0.22	0.18	0.88	1.06	0.28	1.70	0.00	1.98	1.98
USA	0.00	0.00	0.33	0.00	0.33	0.00	0.74	0.96	0.74	1.70
Japan	-0.83	0.03	3.53	-0.80	2.73	1.16	0.50	2.03	1.66	3.68
Austria	-1.28	-0.01	2.62	-1.29	1.34	0.53	0.65	1.09	1.18	2.27
Belgium	0.43	0.27	0.10	0.71	0.81	1.29	1.70	0.00	2.99	2.99
Denmark	0.10	-0.29	1.11	-0.19	0.92	-0.43	-0.10	1.44	-0.53	0.91
Finland	1.42	0.22	0.11	1.64	1.74	1.17	1.70	0.00	2.86	2.86
France	-0.22	-0.01	1.23	-0.23	1.00	0.60	1.63	0.07	2.23	2.30
Germany	0.75	0.50	-0.18	1.25	1.07	-0.10	1.70	0.00	1.59	1.59
Greece	-0.69	0.04	2.21	-0.65	1.56	1.32	-0.28	0.67	1.04	1.70
Iceland	0.00	-0.27	2.41	-0.27	2.14	-1.76	-1.32	4.51	-3.08	1.43
Ireland	-0.36	0.32	2.18	-0.03	2.15	4.29	-0.28	0.50	4.01	4.51
Italy	0.48	-0.23	1.80	0.25	2.05	1.25	-0.25	1.49	1.00	2.49
Luxembourg	-0.12	0.10	0.41	-0.02	0.39	0.79	-0.26	1.27	0.53	1.79
Norway	2.33	0.35	-0.03	2.69	2.66	-1.35	1.70	-0.00	0.34	0.34
Portugal	-1.11	-0.86	2.26	-1.97	0.29	3.95	-0.64	4.35	3.31	7.66
Spain	-2.04	0.22	2.39	-1.82	0.57	1.93	-0.15	2.61	1.78	4.39
Sweden	0.28	0.03	0.54	0.31	0.85	-0.32	1.70	-0.00	1.37	1.37
Switzerland	-0.11	0.42	-0.09	0.31	0.22	0.20	1.70	-0.00	1.89	1.89
Turkey	-1.20	-0.97	4.25	-2.17	2.08	2.94	-0.65	1.65	2.29	3.93
UK	-0.48	0.20	1.18	-0.28	0.90	1.28	-0.69	2.45	0.59	3.04
Australia	0.45	0.49	-0.17	0.94	0.77	-0.78	1.70	0.00	0.91	0.91
New Zealand	-0.94	-0.13	0.87	-1.07	1.19	-1.52	0.62	0.41	-0.89	-0.49
MEAN	**-0.11**	**0.03**	**1.27**	**-0.08**	**1.19**	**0.73**	**0.57**	**1.11**	**1.29**	**2.40**

The analysis by sub-periods shows that for the average of the OECD, the fastest rate of growth of labor productivity occurred in the period of growth (1965-73), due to the intense rate of capital accumulation (4.24%), the contributions of efficiency (0.43%) and technical progress (-0.78%) being negligible. On the other hand, in the period 1985-90 the average gains in efficiency (0.73%) explain around 30% of the growth in labor productivity (2.40%).

Concentrating once again on the USA and Japan, the results enable us to observe the greatest growth of labor productivity in Japan (4.51%), this substantial growth being a consequence of the high process of capitalization of the Japanese economy (its contribution being 5.34%), the negative influence of efficiency and technical progress being negligible. Nevertheless, in the sub-period 1985-90 almost a third of Japan's labor productivity growth (3.68%) was due to gains in efficiency (1.16%). On the other hand, the growth of labor productivity in the USA (1.70%) was much lower as a result of the reduced growth of the capital-labor ratio (0.96%).

The results of table 4 also enable us to observe the importance of explicitly considering efficiency as a source of productivity growth. Thus, in countries like Greece, Ireland, Portugal, Spain, Turkey and the UK, the gains in efficiency explain a high percentage of gains in labor productivity in the period 1985-90, which is illustrative of the bias remarked upon in non-frontier approaches to the analysis of productivity.

In order to test the robustness of the results obtained by means of the non-parametric approach, we estimated a translogarithmic production function of a stochastic nature under three alternative distributional assumptions (half-normal, normal-truncated and exponential). More specifically, the translog production function to be estimated adopts the following specification:

$$\text{Ln}\, Y_{it} = \beta_0 + \beta_L \,\text{Ln}\, L_{it} + \beta_K \,\text{Ln}\, K_{it} + (1/2)\beta_{LL} \,\text{Ln}\, L_{it}^2 + (1/2)\beta_{KK} \,\text{Ln}\, K_{it}^2 + \beta_{LK} \,\text{Ln}\, L_{it} \,\text{Ln}\, K_{it} + \sum_{t=65}^{90} \lambda_t TE_t + v_{it} - u_{it} \quad [\,12\,]$$

where *TE* are temporary effects that capture the effect of technical progress[18], and u_{it} and v_{it} are inefficiency and the error term, respectively.

[18] The measurement of technical progress through temporary effects is more flexible than the introduction of a trend, as it allows us to obtain a different rate of technical progress at each moment in time.

Table 5 contains the estimation of the production function under the three alternative distributional assumptions for the inefficiency term: Half-normal (HN), truncated-normal (TN), and exponential (EXP). Note that the parameters estimated are similar irrespective of the distributional assumption adopted and that both the squares of the variables capital and labor and their crossed product are highly significant, which indicates the rejection of the Cobb-Douglas specification adopted in other studies (Fecher and Perelman, 1992).

Table 5: Translog stochastic production function: parameter estimates

	Half-normal (HN)	***Truncated (TN)***	***Exponential (EXP)***
Constant	20.070	19.987	19.957
	(468.394)	*(807.100)*	*(848.758)*
LnK	0.4573	0.4329	0.4382
	(18.100)	*(21.862)*	*(24.142)*
LnL	0.5886	0.6238	0.6233
	(23.076)	*(31.107)*	*(34.199)*
0.5LnK²	-0.3636	-0.3873	-0.3779
	(-7.380)	*(-13.856)*	*(-15.657)*
0.5LnL²	-0.4463	-0.4032	-0.3796
	(-8.036)	*(-11.825)*	*(-12.281)*
LnKLnL	0.4140	0.4089	0.3939
	(8.223)	*(14.525)*	*(15.730)*
Log-lik.	356.8233	350.6413	351.4883
σ^2_V	0.00001	0.00135	0.00238
σ^2_u	0.06813	0.13355	0.02468
σ_u / σ_V	89.059	9.9298	
	(0.231)	*(3.582)*	
μ/σ_u		1.1711	
		(0.904)	
Theta			6.3657
			(16.212)

Note: a) t-student in parentheses.
b)Time dummies have been introduced into the estimation.

Table 6 contains the average levels of the efficiency indicator corresponding to the truncated-normal model[19]. The comparison of the results with those that appear in table 2 shows that the average inefficiency of the sample is lower in the stochastic approach, a result that may be due to the fact that the non-parametric estimation is upwardly biased because it captures random factors as inefficiency[20]. Nevertheless, the evolution of efficiency over time (figure 2) is similar in all the approaches.

Table 6: Average efficiency (SFA-TN)

	1965-90	*1965-73*	*1973-85*	*1985-90*
Canada	1.0456	1.0816	1.0293	1.0213
USA	1.0556	1.0388	1.0603	1.0672
Japan	1.6826	1.5029	1.7875	1.7347
Austria	1.1278	1.0932	1.1337	1.1710
Belgium	1.0951	1.1784	1.0570	1.0448
Denmark	1.2099	1.2016	1.2249	1.1796
Finland	1.3998	1.5921	1.3455	1.2052
France	1.1447	1.1641	1.1331	1.1407
Germany	1.3218	1.3801	1.3034	1.2761
Greece	1.5471	1.5643	1.5330	1.5388
Iceland	1.1026	1.1766	1.0629	1.0729
Ireland	1.2453	1.2837	1.2373	1.2143
Italy	1.1668	1.2795	1.1274	1.0782
Luxembourg	1.0299	1.0446	1.0194	1.0282
Norway	1.3216	1.6097	1.2250	1.0760
Portugal	1.1638	1.0854	1.1937	1.2333
Spain	1.0949	1.0204	1.1140	1.1747
Sweden	1.0985	1.1017	1.0981	1.0920
Switzerland	1.1121	1.1764	1.0917	1.0468
Turkey	1.4173	1.1227	1.5192	1.6639
UK	1.0562	1.0366	1.0738	1.0446
Australia	1.0832	1.1315	1.0636	1.0452
New Zealand	1.0780	1.0705	1.0597	1.1178
Mean	**1.2000**	**1.2146**	**1.1954**	**1.1855**

Note: Values higher than unity imply that the country is technically inefficient; the higher the index the greater the inefficiency.

[19] The results are very similar in the other models. Thus, for the average of the period 1965-90, the correlation between the efficiency indices of models HN and TN is 0.97, between HN and EXP it is 0.96, between HN and DEA it is 0.73, between TN and EXP it is 0.99, between TN and DEA it is 0.64, and between EXP and DEA it is 0.63.

[20] It is difficult to assess a priori the effect of this biass on the sources of convergence of the next section. The best would be to use a non-parametric stochastic approach, if such technique is not reliable at the moment.

The evolution of efficiency over time shows that although the USA was one of the most efficient countries of the sample in the period 1965-73, it has gradually lost the leadership until it stands at levels of inefficiency similar to the European average, and below Canada. Japan continues to be one of the least efficient countries, although it has reduced differences with the other countries after the oil crisis shock of 1973[21].

The results in terms of the cumulative effect of technical progress are very similar in all the methods as can be appreciated in figure 3. Thus, whereas until the mid-1970s there was technical regress, from then onwards the existence of technical progress can be clearly appreciated[22].

4. SOURCES OF CONVERGENCE

The use of techniques that incorporate into the analysis of growth the existence of inefficiency in the utilization of the factors of production has enabled us to break down in an appropriate way the economic growth of the countries of the OECD. Thus, we have verified that, while in some cases the predominant source of growth was the accumulation of factors of production, in others it was TFP. Also, we have been able to distinguish which part of the growth of TFP was due to movement of the technological frontier (technical change) and which part was due to evolution in relation to the technological frontier (change in efficiency).

This breakdown makes it possible to analyze in detail the process of convergence in labor productivity experienced by the countries of the OECD during the period 1965-1990. Earlier studies have highlighted the systematic contribution of TFP to the convergence of these countries, attributing it to the effect of technical progress. (Dowrick and Nguyen, 1989; Dollar and Wolff, 1994; Abramovitz, 1994; Bernard and Jones, 1996 a & b; among others). However, these studies do not consider the existence of inefficiency as one of the components of TFP.

[21] The different behaviour of efficiency with regard to DEA may be due to the fact that in SFA it is necessary to impose a common rate of technical progress.
[22] Observe that the results are similar to those obtained for the period 1979-88 by Färe et al. (1994), who show the existence of technical progress.

Figure 2: Efficiency in OECD countries: 1965-90

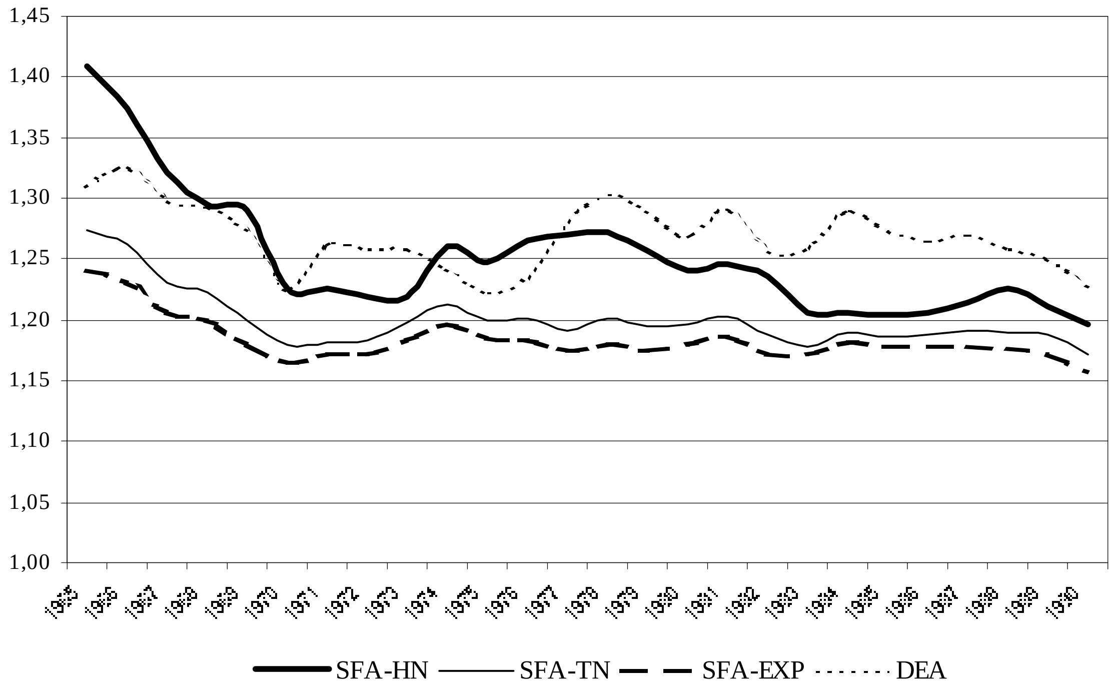
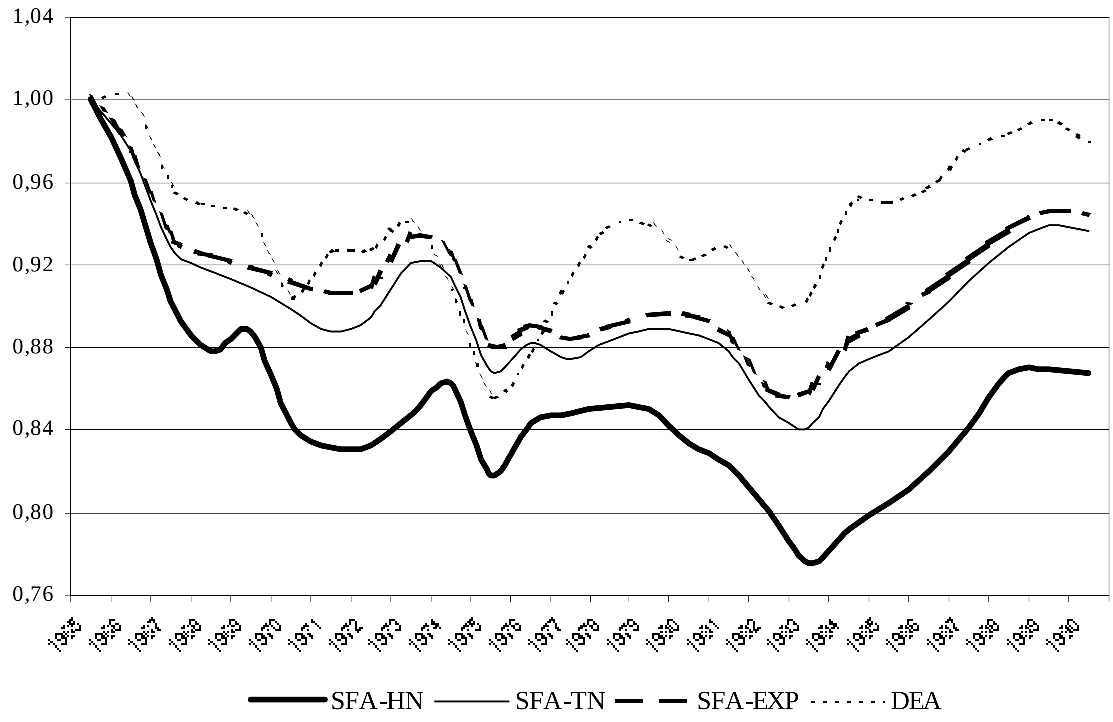


Figure 3: Technical change in OECD countries: 1965-90



The analysis of the influence that each of the sources of growth (technical change, catching-up in efficiency and increase in inputs per worker) may have had on convergence in the OECD is the subject of this section. In the case of absolute convergence it interests us to know whether the growth of labor productivity due to each of these factors has been greater in the countries with lower initial labor productivity, in which case this factor will have contributed to convergence; lower in the countries with lower initial labor productivity, in which case it will have generated divergence; or has no connection with the initial situation, in which case it will not have any effect on convergence.

In each period we can estimate by means of ordinary least squares (OLS) the regression of the average growth of labor productivity during the period, and of each of its components, on the logarithm of the initial labor productivity. The effect on convergence will depend on the sign of the parameter that accompanies the log of initial productivity. A negative sign indicates convergence and a positive one indicates divergence. Also, it is easy to see that the total convergence parameter is equal to the sum of the parameters corresponding to the sources of growth, so we can break down labor productivity convergence into the contributions due to technical progress, to changes in efficiency, and to the utilization of more inputs per worker.

In particular, we can estimate the relative contribution of each factor to convergence between years 0 and T by taking logarithmic differences between the two and by means of the following regressions:

$$[\,13\,] \quad \left(\frac{dy_i}{T}\right) = c + b \cdot \log y_{io} + u_i$$

$$[\,14\,] \quad \left(\frac{dy_{Ei}}{T}\right) = c_E + b_E \cdot \log y_{io} + u_{Ei}$$

$$[\,15\,] \quad \left(\frac{dy_{TCi}}{T}\right) = c_{TC} + b_{TC} \cdot \log y_{io} + u_{TCi}$$

$$[\,16\,] \quad \left(\frac{dy_{TFPi}}{T}\right) = c_{TFP} + b_{TFP} \cdot \log y_{io} + u_{TFPi}$$

[17] $$\left(\frac{dy_{Ii}}{T}\right) = c_I + b_I \cdot \log y_{io} + u_{Ii}$$

where log y_{i0}, the logarithm of the initial labor productivity level, is always the only repressor. The dependent variable is the annual rate of growth of labor productivity in equation [13], the contribution to that growth of gains in efficiency (E) in equation [14], the average contribution of technical progress (TC) in equation [15], the average contribution of TFP growth in equation [16], and the average contribution of the accumulation of inputs per worker in equation [17]. Furthermore, the following relationship is established among these parameters:

[18] $$\hat{b} = \hat{b}_E + \hat{b}_{TC} + \hat{b}_I = \hat{b}_{TFP} + \hat{b}_I$$

Table 7 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%). Of greater interest is the analysis of the breakdown of this process of convergence in terms of the different sources of growth.

Column 2 offers the effect on convergence induced by the change in efficiency. As can be observed, the cumulative effect over the period as a whole (-0.09%) is negligible and is not statistically significant. Something similar occurs in the sub-period 1965-73, also with a negligible effect (-0.22%). However, in the period 1973-85 the change in efficiency was indeed significant and was an important source of divergence (+0.97%). During the period of international economic crisis the countries with higher levels of labor productivity experienced gains in efficiency in relative terms, demonstrating a greater capacity for adjustment to the various shocks suffered by the industrialized countries. On the other hand, during the period 1985-90 efficiency was a significant source of convergence (-2.87%), due to the fact that it is now the countries with lowest labor productivity that improve their efficiency in relative terms. In short, the contribution of efficiency to labor productivity convergence is characterized by its variability, since in some periods it generates divergence and in others convergence, and by its ever greater magnitude.

Table 7: Convergence in labor productivity and its sources.

Period	*(1)* *Total*	*Sources of convergence*			
		(2) **Efficiency**	**(3)** **Technical progress**	**(4)=(2)+(3)** **TFP**	**(5)** **Inputs per worker (K/L)**
1965-90	-0.0177	-0.0009	0.0101	0.0092	-0.0269
	(-7.74)	(-0.34)	(4.65)	(2.29)	(-6.71)
	[0.72]	[0.01]	[0.51]	[0.20]	[0.68]
1965-73	-0.0285	-0.0022	0.0178	0.0155	-0.0440
	(-5.58)	(-0.67)	(4.10)	(2.49)	(-5.44)
	[0.60]	[0.02]	[0.44]	[0.23]	[0.59]
1973-85	-0.0104	0.0097	0.0065	0.0162	-0.0266
	(-2.63)	(1.97)	(4.21)	(2.94)	(-6.41)
	[0.25]	[0.16]	[0.46]	[0.29]	[0.66]
1985-90	-0.0303	-0.0287	0.0164	-0.0123	-0.0180
	(-3.70)	(-3.89)	(3.09)	(-1.37)	(-2.43)
	[0.39]	[0.42]	[0.31]	[0.08]	[0.22]

Note: t-student in parentheses. R^2 in squared brackets. Column 1: Average annual rate of absolute convergence of labor productivity according to equation (1). Columns 2-5: Contribution to convergence of each of the components of growth according to equations (13)-(17).

The effect of technical change is shown in column 3. The results indicate that technical change 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 relative technical progress. Thus, the effect over the period as a whole was +1.01%, being somewhat higher in the sub-periods of expansion 1965-73 (+1.78%) and 1985-90 (+1.64%), and less during the crisis 1973-85 (+0.65%). 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 change is adapted to the characteristics of this type of economy. For all these reasons technical change benefits in the short term especially the more developed countries[23].

Column 4 shows the results corresponding to TFP. Given that the growth of TFP is

[23] Taskin and Zaim (1997) obtain the same result.

the aggregation of the change in efficiency and of technical change, its contribution to convergence is equivalent to the net effect of both. Consequently its cumulative effect in the period was divergent (+0.92%) due to technical progress, contradicting the evidence offered by earlier studies (Dowrick and Nguyen, 1989; Dollar and Wolff, 1994; Bernard and Jones, 1996b; Wolff, 1991; etc.). The same thing happens in the sub-period 1965-73 (+1.55%) for identical reasons. During the sub-period 1973-85 it continued to generate divergence (+1.62%) since the effects of the change in efficiency and of technical progress reinforced each other in this sense. However, during the last sub-period TFP appeared to generate a slight convergence, although this result is not significant. This is because the convergence induced by the behavior of efficiency is partly offset by the divergence due to technical progress.

Finally, the effect of the accumulation of inputs per worker, which could be associated with the typical neo-classical mechanism of convergence, can be appreciated in column 5. This is a systematic and significant source of convergence both in the period as a whole (-2.69%) and in each of the sub-periods: 1965-73 (-4.40%); 1973-85 (-2.66%) and 1985-90 (-1.80%). Thus, the accumulation of factors of production was greater in the countries with lower initial levels of labor productivity and as a result the latter has tended to converge in the OECD. However, the results show that its contribution is becoming less and less.

It is now possible to look more closely at the evolution of labor productivity in the OECD. Thus, the magnitude of convergence in the sub-period 1965-73 is similar to that of the sub-period 1985-90. However, the situations are very different. In the first case it is due to the intense convergence effect of the accumulation of factors, in the second it is more the effect of change in efficiency, with a greater relative approach to the technological frontier by the less developed countries of the OECD, than of the ever-weaker influence of factor accumulation. Also of note is the divergent effect caused by technical change. This phenomenon, together with the poorer countries´ apparent lesser flexibility against shocks reflected by the data on efficiency during the sub-period 1973-85, may explain in large measure the slowness of convergence. Since growth is consubstantial with the progressive movement of the technological frontier it can be considered that divergence is linked to growth due to the very nature of the latter. Thus, long term growth cannot be achieved by means of improvements in efficiency, but only by means of technical change.

The results obtained have enabled us to break down the contribution to labor productivity convergence of the different sources of growth, among them change in efficiency, although the evolution of the inequalities of efficiency between countries remains to be analysed. With this aim, figure 4 shows the evolution of the standard deviation of efficiency over the whole period. However, this process of convergence was not uniform, as periods of convergence (intense until the early 1970s and in the late 1980s) co-existed with periods of divergence or lack of convergence.

5. CONCLUSIONS

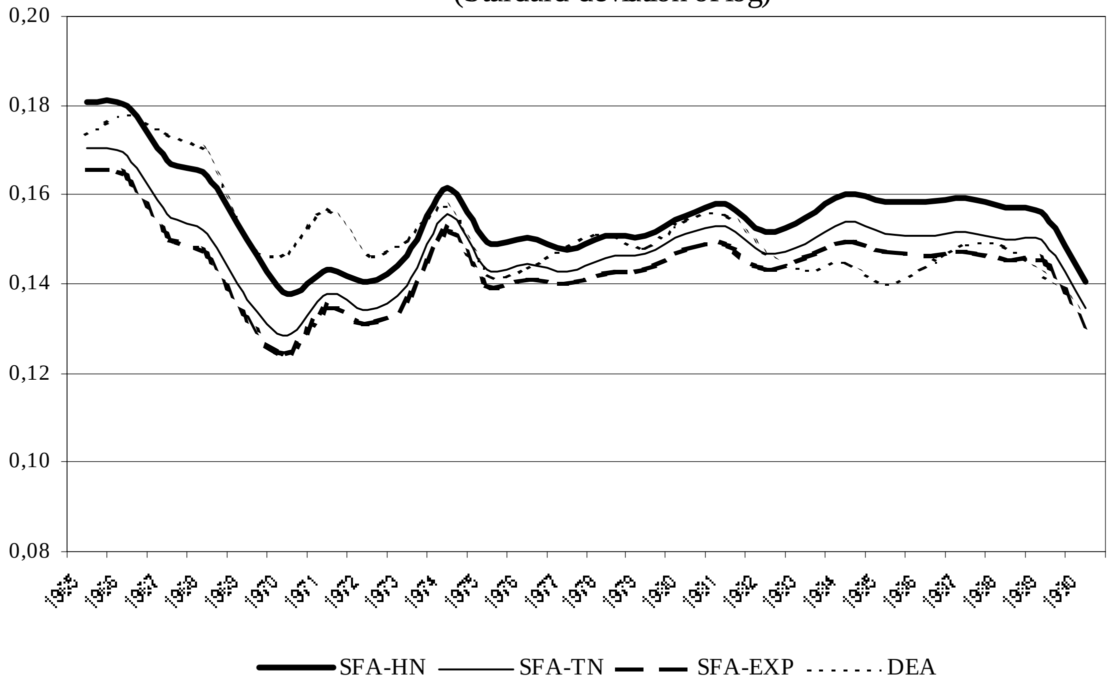
The studies that have analyzed the process of convergence in the countries of the OECD have shown the importance of the assimilation and diffusion of technology as a mechanism of labor productivity convergence. Thus, studies such as that of Dowrick and Nguyen (1989) show that the process of technological catching-up has contributed to labor productivity convergence in the countries of the OECD, its contribution being even higher than capital intensity in the period 1960-73.

The studies that have analysed the importance of technological convergence are generally based on the study of TFP, this being estimated by means of non-frontier approaches (growth accounting or index numbers). However, the problem presented by this approach to the measurement of TFP is that it obtains biased estimates of technical progress in the presence of inefficiency. Consequently, technical progress cannot be identified with gains in TFP in the presence of inefficiency.

In this context the aim of this study has been to analyze the importance of efficiency change (diffusion) and technical change (innovation) in the process of labor productivity convergence observed in the countries of the OECD, using for this purpose two frontier approaches to the measurement of productivity.

The results obtained show the existence of substantial levels of inefficiency in the countries of the OECD, although there was a reduction of these levels in the period analysed. The comparison of levels of efficiency between countries shows the existence of substantial inequalities, Japan being the most inefficient country in the sample, well above the European average, the USA and Canada.

Figure 4: Sigma convergence in efficiency in OECD countries: 1965-90
(Stardard deviation of log)



The results are contrary to those obtained in earlier studies that do not consider the existence of inefficiency in their analysis. Thus, far from there being a process of technological catching-up, technical change worked against labor productivity convergence in all the sub-periods considered, since technical progress has always been greater in the richer countries. Thus, the results suggest that countries with low initial labor productivity levels catch up at a faster rate and countries with relatively high labor productivity levels benefit from technological progress.

Nevertheless, the breakdown of gains in productivity into gains in efficiency and technical progress shows that, in the sub-period 1985-90, efficiency was an important mechanism of labor productivity convergence, its contribution being even more important than the accumulation of capital (capital intensity).

Thus, the results obtained contradict those of other studies that show the greater gains in TFP by the poorer countries as favoring labor productivity convergence. On the contrary, the results obtained in this study show that it is the rich countries that have experienced greatest growth in TFP (particularly through greater technical progress), consequently acting as a mechanism of divergence. In conclusion, far from there having been a mechanism of contagion by means of technology transfer, the main mechanism of convergence has been the greater rate of capital accumulation of the poorer countries.

As a final conclusion, it is important to remark that in the long term economic growth is possible only if there exist innovators that shift the frontier of technology although efficiency gains (catching up) can be an important source of growth in the short term.

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