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Convergence in OECD countries: technical change, efficiency and productivity

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The aim of this study is to analyse labour productivity convergence in the OECD countries over the period 1975–90. A nonparametric frontier approach is used to calculate the Malmquist productivity index. By breaking it down, the contribution in the growth of labour 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 labour productivity convergence, since it has always been greater in the countries with higher labour productivity.

I. INTRODUCTION

The study of convergence between countries in terms of per capita income and labour 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 OECD countries, this question being at the centre 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 analysing the hypothesis of catching-up in the levels of total factor productivity (TFP) among the OECD countries. 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 biased 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

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[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 labour 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 labour 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, 1996b) highlight the existence of convergence in TFP during the period 1977–88, although with exceptions such as the manufacturing sector.

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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 favourable to the hypothesis of technological catching-up. Even in these two cases the contribution of TFP to convergence in levels of labour productivity was still not analysed. Likewise, although Färe *et al.* (1994) analyse productivity gains and their breakdown into efficiency and technical progress, they do not show their effect on convergence in labour productivity.

To date, as far as we know, there is only one paper that analyses the importance of efficiency change and technical change on the convergence of labour productivity. Taskin and Zaim (1997) analyse the catching-up hypothesis for a group of countries of the OECD over the period 1975–90 showing that technical change is higher in rich countries while poor countries gave a higher efficiency change.

In this context, the aim of this study is to analyse labour productivity convergence in the OECD countries over the period 1975–90 distinguishing the contribution of the different sources – technical progress, changes in efficiency and accumulation of inputs per worker – by means of a frontier approach. For this purpose we use the Malmquist productivity index, obtained by means of nonparametric methods of linear programming. With this 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 II 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 III is devoted to describing the sample used and the results obtained in terms of efficiency, technical change and productivity. Section IV analyses the importance that gains in efficiency, technical progress and total factor productivity have had in the process of labour productivity convergence, Finally, Section V contains the conclusions of the study.

II. EFFICIENCY, TECHNICAL CHANGE AND PRODUCTIVITY: THE MALMQUIST PRODUCTIVITY INDEX

The traditional approach to the analysis of productivity by means of nonfrontier 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 behaviour of the units analysed, 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 the Malmquist productivity index based on data envelopment analysis (DEA).

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[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 1977–87 in a context of 8 industrial sectors and 11 countries of the OECD using both the stochastic frontier approach and the nonparametric 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.

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

[5] See a more detailed exposition in Grosskopf (1993).

The Malmquist productivity index (Malmquist, 1953) allows changes in productivity to be broken down into changes in efficiency and technical change. Furthermore, unlike the stochastic frontier approach (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 nonparametric 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 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 nonparametric frontier methodology (DEA).

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

$$\begin{aligned} D_0^t(x^t,y^t) &= \inf\{\vartheta^{t,t} : x^t, y^t/\vartheta^{t,t}) \in F^t\} \\ &= [\sup\{\vartheta^{t,t} : (x^t, \vartheta^{t,t} y^t) \in F^t\}]^{-1} \end{aligned} \tag{1}$$

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.

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 $D_0^t(x^t,y^t) \leqslant 1$ if and only if $(x^t,y^t) \in F^t$. Furthermore, $D_0^t(x^t,y^t) = 1$ 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 Fig. 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 functions with respect to technologies of different periods.

$$D_0^t(x^{t+1},y^{t+1}) = \inf\{\vartheta^{t,t+1} : (x^{t+1}, y^{t+1}/\vartheta^{t,t+1}) \in F^t\} \tag{2}$$

In the above expression, the distance function $D_0^t(x^{t+1}y^{t+1})$ 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 Fig. 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 $t+1$, $D_0^{t+1}(x^t,y^t)$.[6]

On the basis of the above concepts, the Malmquist productivity index based on outputs to analyse productive change between periods t and $t+1$, taking the technology of period t as reference, is defined as:[7]

$$M_0^t(x^{t+1},y^{t+1},x^t,y^t) = \frac{D_0^t(x^{t+1},y^{t+1})}{D_0^t(x^t,y^t)} \tag{3}$$

$M_0^t > 1$ indicates that the productivity of period $t+1$ is higher than that of period t, since the expansion necessary

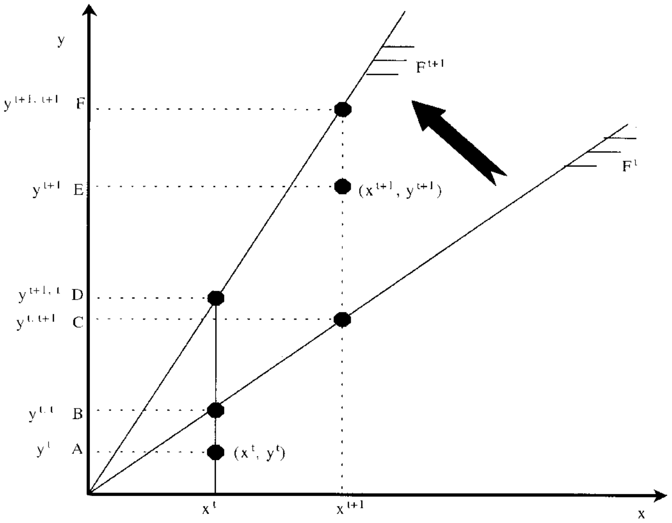

Fig. 1. *Malmquist output-based productivity index*

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[6] Note that when comparing observations of one period with technologies of different periods, the distance function may be higher than unity. In particular $D_0^t(x^{t+1},y^{t+1})$ and $D_0^{t+1}(x^t,y^t)$ may be higher than unity if there has been technical progress and technical regression respectively. Note that in the situation represented in the graph, $D_0^t(x^{t+1},y^{t+1}) > 1$, indicating that there has been technical progress.

[7] See Caves *et al.* (1982).

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, $M_0^t < 1$ 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 $t+1$:[8]

$$M_0^{t+1}(x^{t+1},y^{t+1},x^t,y^t) = \frac{D_0^{t+1}(x^{t+1},y^{t+1})}{D_0^{t+1}(x^t,y^t)} \tag{4}$$

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 analyse 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 (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:

$$M_0(x^{t+1},y^{t+1},x^t,y^t) = \left[\left(\frac{D_0^t(x^{t+1},y^{t+1})}{D_0^t(x^t,y^t)}\right) \times \left(\frac{D_0^{t+1}(x^{t+1},y^{t+1})}{D_0^{t+1}(x^t,y^t)}\right)\right]^{1/2} \tag{5}$$

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:[9]

$$M_0(x^{t+1},y^{t+1},x^t,y^t) = \frac{D_0^{t+1}(x^{t+1},y^{t+1})}{D_0^t(x^t,y^t)} \times \left[\left(\frac{D_0^t(x^{t+1},y^{t+1})}{D_0^{t+1}(x^{t+1},y^{t+1})}\right) \times \left(\frac{D_0^t(x^t,y^t)}{D_0^{t+1}(x^t,y^t)}\right)\right]^{1/2} \tag{6}$$

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 priods t and $t+1$.

The above breakdown can again be illustrated using Fig. 1.

$$M_0(x^{t+1},y^{t+1},x^t,y^t) = \frac{OE/OF}{OA/OB}\left[\left(\frac{OE/OC}{OE/OF}\right)\left(\frac{OA/OB}{OA/OD}\right)\right]^{1/2} = \frac{OE/OF}{OA/OB}\left(\frac{OF}{OC}\cdot\frac{OD}{OB}\right)^{1/2} \tag{7}$$

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_0) 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_0 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_0 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 nonparametric technique of linear programming. Let us suppose that in each period t there exist $k = 1,\ldots,K$ countries which use $n = 1,\ldots,N$ inputs (x_{nk}^t) to produce $m = 1,\ldots,M$ outputs (y_{mk}^t). The calculation of the Malmquist index for a country j requires calculation of four types of distance function; $D_0^t(x^t,y^t)$, $D_0^{t+1}(x^{t+1},y^{t+1})$, $D_0^t(x^{t+1},y^{t+1})$ and $D_0^{t+1}(x^t,y^t)$.

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 $D_0^t(x^t,y^t)$:

$$\begin{aligned}
&[D_0^t(x_j^t,y_j^t)]^{-1} = \mathrm{Max}\,\vartheta_j^{t,t} \\
&s.t. \\
&\sum_{k=1}^{K} \lambda_k^t y_{mk}^t \geq y_{mj}^t \vartheta_j^{t,t} \qquad m = 1,\ldots,M \\
&\sum_{k=1}^{K} \lambda_k^t x_{nk}^t \leq x_{nj}^t \qquad n = 1,\ldots,N \\
&\lambda_k^t \geq 0 \qquad k = 1,\ldots,K
\end{aligned} \tag{8}$$

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[8] In this case the interpretation is similar. $M_0^t > 1$ 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.

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

The calculation of $D_0^{t+1}(x^{t+1},y^{t+1})$ 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 $D_0^1(x^{t+1},y^{t+1})$ is done substituting t for $t+1$ on the right hand side of the inequalities. Similarly, $D_0^{t+1}(x^t,y^t)$ is calculated substituting $t+1$ for t on the left hand side of the inequalities.

III. DATA AND RESULTS

The sample used for the estimation of the frontier production function consists of the countries of the OECD[10] in the period 1975–90 using the Summers and Heston database (*Penn World Table*, Mark 5.6).[11] The variables for each country are: (1) aggregated output measured by real Gross Domestic Product (GDP) (Y), expressed in international prices; (2) aggregated labour input (L) measured by total employment, computed from real GDP per worker; and (3) total capital stock (K) calculated from the nonresidential capital per worker.

Table 1 contains the annual growth rates of GDP, capital and employment in the different countries of the OECD. 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–labour ratio.

Table 2 shows the average levels of efficiency estimated for the period 1975–90 using the nonparametric approach described earlier. One outstanding feature is the fact that the USA stands at the frontier throughout the period, while countries like Japan and Greece present high levels of inefficiency.[12]

The growth rates of TFP as well as those of its two components (technical change and changes in efficiency) are reflected in Table 3. For the average of the OECD countries, the productivity gains are due to technical progress, being negligible the negative contribution of efficiency changes. However, in some countries (Finland, Ireland, Italy, and Portugal) efficiency gains explain more than a half of their productivity gains.

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 1979–88. 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: first, 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 labour 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,[13] it is of interest to analyse the sources of growth of labour productivity. Table 3 shows the growth rate of labour productivity and of its three components for the countries of the OECD.

For the mean of the countries of the OECD, the results obtained show how productivity gains explain around 40% of growth in labour productivity, the contribution of efficiency change (−0.04%) being negligible.

Concentrating on the USA and Japan, the results enable us to observe the greatest growth of labour productivity in Japan (3.50%), this substantial growth being a consequence of the high process of capitalization of the Japanese economy (its contribution being 2.76%). On the other hand, the growth of labour productivity in the USA

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

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

[12] 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.

[13] 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 Fig. 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:

$$\frac{y^{t+1}}{y^t} = M_0(x^{t+1},y^{t+1},x^t,y^t)\left(\frac{y^{t,t+1}}{y^{t,t}}\frac{y^{t+1,t+1}}{y^{t+1,t}}\right)^{1/2} = \frac{OE}{OA}$$

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

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

	Y	*K*	*L*
Canada	3.27	5.11	1.75
USA	2.83	3.40	1.51
Japan	4.23	6.06	0.73
Austria	2.48	4.47	0.76
Belgium	2.23	2.64	0.61
Denmark	2.15	2.72	0.75
Finland	2.92	3.79	0.73
France	2.49	3.44	0.88
Germany	2.49	2.97	0.93
Greece	2.50	3.11	0.71
Iceland	3.90	5.84	1.85
Ireland	3.77	3.77	0.83
Italy	3.00	3.13	0.56
Netherlands	2.20	2.92	1.33
Norway	3.19	2.66	1.25
Portugal	4.22	4.12	1.06
Spain	2.49	4.74	0.88
Sweden	1.70	3.67	0.79
Switzerland	1.91	3.04	0.63
Turkey	4.08	5.28	2.11
UK	2.47	2.95	0.48
Australia	2.88	3.74	1.85
New Zealand	1.17	2.97	1.31
Mean	2.81	3.76	1.06

Table 2. *Average technical efficiency*

	1975–90
Canada	1.092
USA	1.000
Japan	1.714
Austria	1.349
Belgium	1.202
Denmark	1.446
Finland	1.470
France	1.220
Germany	1.231
Greece	1.702
Iceland	1.012
Ireland	1.341
Italy	1.180
Netherlands	1.133
Norway	1.264
Portugal	1.150
Spain	1.216
Sweden	1.283
Switzerland	1.127
Turkey	1.412
UK	1.079
Australia	1.181
New Zealand	1.294
Mean	1.265

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

Table 3. *Decomposition of labour productivity growth: average annual changes (%)*

	Efficiency	Technical change	Inputs	TFP	*Y*/*L*
Canada	0.14	1.44	0.06	1.58	1.53
USA	0.00	0.88	0.45	0.88	1.33
Japan	0.08	0.66	2.76	0.74	3.50
Austria	−0.87	0.80	1.79	−0.07	1.72
Belgium	0.30	1.41	0.08	1.71	1.63
Denmark	0.01	0.46	0.92	0.47	1.40
Finland	0.86	1.24	0.09	2.10	2.19
France	−0.06	1.25	0.44	1.18	1.62
Germany	0.24	1.47	−0.14	1.70	1.56
Greece	0.08	0.42	1.30	0.50	1.80
Iceland	−0.59	−0.19	2.83	−0.77	2.06
Ireland	0.90	0.57	1.48	1.47	2.94
Italy	0.63	0.38	1.43	1.01	2.44
Netherlands	−0.25	0.75	0.37	0.50	0.87
Norway	0.62	1.35	−0.02	1.97	1.94
Portugal	0.63	−0.28	2.80	0.36	3.16
Spain	−1.02	0.55	2.08	−0.47	1.61
Sweden	−0.52	1.34	0.08	0.82	0.90
Switzerland	−0.05	1.40	−0.07	1.36	1.28
Turkey	−0.65	−0.37	3.00	−1.02	1.98
UK	0.22	0.36	1.41	0.59	1.99
Australia	−0.30	1.46	−0.13	1.16	1.03
New Zealand	−1.31	0.83	0.34	−0.48	−0.14
Mean	−0.04	0.79	1.00	−0.75	−1.75

(1.33%) was much lower as a result of the reduced growth of the capital–labour ratio (0.45%).

The results of Table 3 also enable us to observe the imortance 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 labour productivity, which is illustrative of the bias remarked upon in nonfrontier approaches to the analysis of productivity.

IV. 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 analyse in detail the process of convergence in labour productivity experienced by the countries of the OECD during the period 1975–90. 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, 1996a, 1996b; among others). However, these studies do not consider the existence of inefficiency as one of the components of TFP.

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 labour productivity due to each of these factors has been greater in the countries with lower initial labour productivity, in which case this factor will have contributed to convergence; lower in the countries with lower initial labour 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.

We can estimate by means of ordinary least squares (OLS) the regression of the average growth of labour productivity and of each of its components, on the logarithm of the initial labour 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 labour 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:

$$\left(\frac{\mathrm{d}y_i}{T}\right) = c + b \cdot \log y_{i0} + u_i \tag{9}$$

$$\left(\frac{\mathrm{d}y_{Ei}}{T}\right) = c_E + b_E \cdot \log y_{i0} + u_{Ei} \tag{10}$$

$$\left(\frac{\mathrm{d}y_{TCi}}{T}\right) = c_{TC} + b_{TC} \cdot \log y_{i0} + u_{TCi} \tag{11}$$

$$\left(\frac{\mathrm{d}y_{TFPi}}{T}\right) = c_{TFP} + b_{TFP} \cdot \log y_{i0} + u_{TFPi} \tag{12}$$

$$\left(\frac{\mathrm{d}y_{Ii}}{T}\right) = c_I + b_I \cdot \log y_{i0} + u_{Ii} \tag{13}$$

where $\log y_{io}$, is the logarithm of the initial labour productivity level, is always the only repressor. The dependent variable is the annual rate of growth of labour productivity in Equation 9, the contribution to that growth of gains in efficiency (E) in Equation 10, the average contribution of technical progress (TC) in Equation 11, the average contribution of TFP growth in Equation 12, and the average contribution of the accumulation of inputs per worker in Equation 13. Furthermore, the following relationship is established among these parameters:

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

Table 4 offers the results for the period 1975–90. In column 1 we can observe convergence in the levels of labour productivity over the whole period. Its small magnitude (−0.89%) agree with the results habitually offered by the literature (see Barro and Sala-i-Martin, 1995). 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 analysed (−0.13%) is negligible and is not statistically significant. The effect of technical change is shown in column 3. The results indicate that technical change was a significant source of divergence; the countries with highest initial productivity experienced greater relative

Table 4. *Convergence in labour productivity and its sources*

	Sources of convergence			
(1) Total	(2) Efficiency	(3) Technical progress	(4) = (2) + (3) TFP	(5) Inputs per worker (K/L)
−0.0089 (−2.456)	−0.0013 (−0.385)	0.0118 (5.100)	0.0104 (2.211)	−0.0194 (−4.223)
[0.22]	[0.01]	[0.55]	[0.19]	[0.46]

Note: t-student in parentheses. R^2 in squared brackets. Column 1: Average annual rate of absolute convergence of labour productivity according to Equation 9. Columns 2–5: Contribution to convergence of each of the components of growth according to Equations 10–13.

technical progress. Thus, the effect over the period as a whole was +1.18%. 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.[14]

Column 4 shows the results corresponding to TFP. Given that the growth of TFP is the aggregation of the change in efficiency and of technical change, its contribution to convergence is equiavalent to the net effect of both. Consequently its cumulative effect in the period was divergent (+ 1.04%) 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.).

Finally, the effect of the accumulation of inputs per worker, which could be associated with the typical neoclassical mechanism of convergence, can be appreciated in column 5. This is a significant source of convergence (−1.94%). Thus, the accumulation of factors of production was greater in the countries with lower initial levels of labour productivity and as a result the latter has tended to converge in the OECD.

V. CONCLUSIONS

The studies that have analysed 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 labour producitivity convergence. Thus, studies such as that of Dowrick and Nguyen (1989) show that the process of technological catching-up has contributed to labour productivity convergence in the countries of the OECD.

The studies that have analysed the importance of technological convergence are generally based on the study of TFP, this being estimated by means of nonfrontier approches (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 analyse the importance of efficiency change (diffusion) and technical change (innovation) in the process of labour productivity convergence observed in the countries of the OECD, using for this purpose a frontier approach 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 countries, the USA and Canada.

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 labour productivity convergence in the period considered, since technical progress has always been greater in the richer countries.

Thus, the results obtained contradict those of other studies that show the greater gains in TFP by the poorer countries as favouring labour 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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[14] Taskin and Zaim (1997) obtain the same result.

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