Productivity of Nations: a stochastic frontier approach to TFP decomposition

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Abstract

This paper tackles the problem of aggregate TFP measurement using stochastic frontier analysis (SFA). Data from Penn World Table 6.1 are used to estimate a world production frontier for a sample of 75 countries over a long period (1950-2000) taking advantage of the model offered by Battese & Coelli (1992). We also apply the decomposition of TFP suggested by Bauer (1990) and Kumbhakar (2000) to a smaller sample of 36 countries over the period 1970-2000 in order to evaluate the effects of changes in efficiency (technical and allocative), scale effects and technical change. This allows us to analyze the role of productivity and its components in economic growth of developed and developing nations in addition to the importance of factor accumulation. Although not much explored in the study of economic growth, frontier techniques seem to be of particular interest for that purpose since the separation of efficiency effects and technical change has a direct interpretation in terms of the catch-up debate.

The estimated technical efficiency scores reveal the efficiency of nations in the production of non tradable goods since the GDP series used is PPP-adjusted. We also provide a second set of efficiency scores corrected in order to reveal efficiency in the production of tradable goods and rank them. When compared to the rankings of productivity indexes offered by non-frontier studies of Hall & Jones (1996) and Islam (1995) our ranking shows a somewhat more intuitive order of countries. Rankings of the technical change and scale effects components of TFP change are also very intuitive. We also show that productivity is responsible for virtually all the differences of performance between developed and developing countries in terms of rates of growth of income per worker. More important, we find that changes in allocative efficiency play an important role in explaining differences in the productivity of developed and developing nations, even larger than the one played by the technology gap.

Key-words: *Total factor productivity, stochastic frontiers, technical change, technical efficiency, allocative efficiency, scale efficiency, convergence*

JEL Codes: C23; O47

1. Introduction

This paper uses an alternative way of measuring total factor productivity based on the analysis of stochastic frontiers. The great advantage of this approach is the possibility that it offers of decomposing productivity change into parts that can have a straightforward and simple economic interpretation. The stochastic frontier model used assumes the existence of technical inefficiency which evolves following a particular behavior. These assumptions allow one to split productivity changes into two parts. The first is the change in technical efficiency, which measures the movement of an economy towards the production frontier; the second is technical progress, which measures shifts of the frontier over time.

When applied to a flexible technology (e.g.: translog) – this technique further allows one to evaluate the presence of scale efficiency. The Bauer-Kumbhakar decomposition is then applied to a sample of 36 countries from 1970 to 2000, allowing the additional measurement of changes in allocative efficiency. The relative magnitude of this last component (allocative efficiency), together with technical change, seem to explain a large portion of the differences in economic growth between developed and developing countries.

In the next section we present the hypothesis behind the stochastic frontier estimation and the TFP decomposition. Section 3 presents the data and the sample of countries used in the estimation. Section 4 presents the estimates of the world stochastic production frontier and discusses the technical efficiency scores in comparison to the productivity indexes suggested by Islam (1995) and Hall & Jones (1996). It also discusses estimates for technical progress and returns to scale. In section 5, we use the estimates of the previous section in order to decompose TFP change from 1965 to 2000. The role of technical progress and allocative efficiency change in economic growth of both developed and developing nations is highlighted in section 6. At last, we discuss the contribution of these new results for the recent debate about the sources of economic growth and the nature and role of TFP components.

2. The stochastic frontier and TFP decomposition

The model used is basically that developed in the literature on technical efficiency and productivity, more specifically in the "statistical" and "parametric" branches of this literature, and is known as *Stochastic Frontier Analysis* (SFA). of the focus of SFA is to obtain an estimator for one of the components of TFP, the degree of technical efficiency Technical efficiency is estimated in addition to technical change which in its turn is captured (as usually) by a time trend and interactions of the regressors with time. The model used here is essentially that developed (independently) by Aigner, Lovell & Schmidt (1977) and by Meeusen & van den Broeck (1977). Their formulation was extended by Pitt & Lee (1981) and Schmidt & Sickles (1984) for the panel data case. Since then a number of enhancements have been suggested, such as that of Battese & Coelli (1992), in which the technical inefficiency is modeled so as to be time variant.

The general stochastic production frontier model is described by the equations below, where **y** is the vector for the quantities produced by the various countries, **x** is the vector for production factors used and β is the vector for the parameters defining the production technology.

$$y = f(t, x, \beta) \cdot \exp(v) \cdot \exp(-u) \text{ , } u \geq 0 \tag{1}$$

The **v** and **u** terms (vectors) represent different error components. The first refers to the random part of the error, while the second represents technical inefficiency, i.e., the part that is a downward deviation from the production frontier (which can be inferred by the negative sign and the restriction $u \geq 0$). Thus, $f(t, x, \beta) \cdot \exp(v)$ represents the frontier of stochastic production and **v** has a symmetrical distribution to capture the random effects of measuring errors and exogenous shocks that cause the position of the deterministic nucleus of the frontier, $f(t, x, \beta)$, to vary from country to country. The technical inefficiency is captured by the error component $\exp(-u)$. For each country i and each time period t, we have:

$$y_{it} = f(t, x_{it}, \beta) \cdot \exp(v_{it}) \cdot \exp(-u_{it}) \text{ ; } \quad i = 1,\ldots,N \text{ , } t = 1,\ldots,T \tag{2}$$

Once it is assumed that $v \sim \text{iid } N(0,\sigma^2)$; $u \sim NT(\mu,\sigma_u^2)$ i.e., u has a normal-truncated distribution (with a nonnull average μ)[1]; the two error components are independent of each other and x is supposed exogenous, the model can be estimated by maximum-likelihood techniques. Given these conditions, the traditional asymptotic properties of the MV estimators hold. In addition, we take the technical inefficiency component as time-variant, according to parametrization formulated by Battese & Coelli (1992)[2]:

$$u_{it} = \exp[-\eta(t-T)] \cdot u_i \,,\; u_{it} \geq 0 \;\text{ e }\; i = 1,\ldots,N \;\text{ e }\; t \in \tau(i) \tag{3}$$

In the above expression, $\tau(i)$ represents the T_i periods of time for which we have available observations for the i-nth country, among the available T periods in the panel (i.e., $\tau(i)$ may contain all periods in the panel or only a subset of periods). The sign of η dictates the behaviour of technical inefficiency over time. When η is not significantly different from zero, we have technical inefficiency that does not vary in time, also called persistent inefficiency. This specification of the behavioral pattern of inefficiency is somewhat inflexible, as the model's architects themselves admit, for, according to the formulation, technical inefficiency must grow at decreasing rates (η>0), or decrease at increasing rates (η<0). Moreover, the estimated value for η is the same for all countries in the sample, which means to say that the pattern of inefficiency rise or reduction is the same for all countries.

Assuming a translog technology with two production factors, namelly capital (K) and labor (L), the model can be expressed in the following way:

$$\begin{aligned} \ln y_{it} = {} & \beta_0 + \beta_t.t + \beta_K \ln K_{it} + \beta_L \ln L_{it} + \frac{1}{2}\cdot\beta_{tt}.t^2 + \frac{1}{2}\beta_{KK}(\ln K_{it})^2 + \frac{1}{2}\beta_{LL}(\ln L_{it})^2 + \\ & + \frac{1}{2}\beta_{KL}(\ln K_{it})\cdot(\ln L_{it}) + \beta_{Kt}[(\ln K_{it})\cdot t] + \beta_{Lt}[(\ln L_{it})\cdot t] + v_{it} - u_{it} \end{aligned} \tag{4}$$

The output elasticities with respect to K and L can be obtained from (4), working out the derivatives. Due to the use of a translog technology these elasticities are country and time specific. The technical progress measure is also specific for each country and period of time and can be obtained by time differentiation of (4).

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[1] The restriction of a half-normal distribution μ=0 can be tested.

[2] Other parameterizations of u are offered by Kumbhakar (1990), Cornwell, Schmidt & Sickles (1990), Lee & Schmidt (1993).

Bauer (1990) and Kumbhakar (2000) suggested a quite ingenious, yet simple, type of productivity decomposition which goes beyond the division of productivity changes into a catch-up effect and a technical innovation effect. Such framework also accounts for scale of production effects and inefficient allocation of productive factors. To perform this decomposition, first of all we must estimate the model depicted by (3) and (4). Once this model is estimated, it is possible to "compose" the rate of total factor productivity change from the results. The components of productivity can be identified from algebraic manipulations from the expression that denotes the deterministic part of the production frontier combined with the usual expression for the the productivity change Divisia index:

$$g_{PTF} = \frac{\dot{y}}{y} - s_K \frac{\dot{K}}{K} - s_L \frac{\dot{L}}{L}$$

From the deterministic part of (2) we have:

$$\frac{\dot{y}}{y} = \frac{\partial \ln f(t, K, L, \beta)}{\partial t} + \varepsilon_K \frac{\dot{K}}{K} + \varepsilon_L \frac{\dot{L}}{L} - \frac{\partial u}{\partial t}$$

In the expressions above and those that follow, the terms s_K and s_L represent the shares of capital and labor in income; ε_K and ε_L are output elasticities, with $RTS = \varepsilon_K + \varepsilon_L$, RTS denoting the returns to scale; g_K and g_L are the growth rates of K and L, respectively.

$$\lambda_K = \frac{\varepsilon_K}{RTS}, \quad \lambda_L = \frac{\varepsilon_L}{RTS} .$$

Substituting this result in the expression for the Divisia index, and after some algebraic manipulations we have:

$$g_{PTF} = PT - \dot{u} + (RTS - 1) \cdot [\lambda_K \cdot g_K + \lambda_L \cdot g_L] + [(\lambda_K - s_K) \cdot g_K + (\lambda_L - s_L) \cdot g_L] \quad (5)$$

That is, the rate of change in total factor productivity, g_{PTF}, can be split into four elements:

(i) the technical progress, measured by $TP = \frac{\partial \ln f(t, K, L, \beta)}{\partial t}$;

(ii) the change in technical efficiency, denoted by $-\dot{u}$;

(iii) the change in the scale of production, given by $(RTS - 1) \cdot [\lambda_K \cdot g_K + \lambda_L \cdot g_L]$; and

(iv) the change in allocative efficiency, measured by $[(\lambda_K - s_K) \cdot g_K + (\lambda_L - s_L) \cdot g_L]$.

We can then study the impact of each of the components of TFP. If the technology is immutable, it does not contribute in any way to productivity gains. The same happens with technical inefficiency. If it does not vary in time, it also does not have any impact on the rate of variation of productivity.

The contribution of economies of scale depends both on technology as well as on factor accumulation. If there are constant returns to scale, then RTS = 1, which cancels out the third component of the productivity variation. Otherwise, if RTS ≠ 1, part of the productivity change is explained by changes in the scale of production. In the case of increasing returns to scale (RTS > 1) and an increase in the amount of productive factors we have a higher rate of productivity growth. If the amounts of production factors diminish, then we would have a reduction in the rate of productivity change. An inverse analogous reasoning can be made for decreasing returns and reduction (increase) in the amount of productive factors.

Since $\lambda_K + \lambda_L = 1$, the distances $(\lambda_K - s_K)$ and $(\lambda_L - s_L)$ are symmetric and have opposite signs. Therefore, a factor reallocation that, say, increases the intensity of labor and reduces that of capital will necessarily bring a change in allocative efficiency. Only when there are no inefficiencies or scale effects is the measure of productivity change identical to technical progress.

3. Data and sample

The database for this study consists of a non-balanced panel for aggregated output and production factors (K and L) of a sample of countries that includes both wealthy as well as poor nations. These data were basically obtained from Penn World Tables (PWT), version 6.1, for years 1950 to 2000. Below we detail the definitions of each series used in the econometric estimations We also describe the procedures used in selecting the countries and the time periods that actually comprise the econometric estimations.

The output variable is GDP measured at constant prices (1996 US$), with purchasing power parity (PPP) adjustment. It is obtained by taking the *real GDP per capita chain series (RGDPPCH)* from PWT 6.1 and multiplying it by total population for each country.

With respect to labor we use a proxy, the population of equivalent adults (*peqa*), obtained from PWT. The concept derives from population data: based on data for the total population, an average is computed that attributes a weight of 1 to people older than 15 and 0.5 to people aged up to 15 (*pop*>15 * 1 + *pop*<=15*0.5). These data are obtained indirectly from the PWT 6.1, by performing calculations using three variables: real GDP per capita chain series (*rgdpch*) was divided by real GDP per equivalent adult (*rgdpeqa*) and then multiplied by the population (*pop*):

$$L = \frac{\text{rgdpch}}{\text{rgdpeqa}} \cdot \text{pop} = \frac{\text{PIB}}{\text{pop}} \cdot \frac{\text{peqa}}{\text{PIB}} \cdot \text{pop}$$

Another possibility would be to use data pertaining to the labor force. These can be obtained through a transformation similar to the one described above, using the variable *real GDP per worker* (*rgdpwok*). Detailed analysis of the two series per country suggests that the peqa series is more reliable, which was the motivation of our choice.

The perpetual inventory method was used to compute a series for the stock of capital of each nation in the sample[3]. This method uses an initial capital stock estimate (computed from investment data), the supposition of a stable rate of growth for a given period, and additional suppositions regarding the depreciation rate. The measure of the initial capital stock is quite sensitive to the problems of measurement error regarding the flow of investment (and also the growth of GDP).

The investment series used in computing the capital stock was obtained from multiplying the GDP, in constant 1996 local currency, by the "current" investment rate, and then converting this result to US$ using the 1996 exchange rate. GDP in 1996 local currency units was obtained by simply adding up all the components available in the *nafinalpwt* spreadsheet of the PWT. The current investment rate was obtained dividing the value of investment in current local currency by the current GDP. The exchange rate used is obtained from the series *XRAT*, found in the *nafinalpwt* spreadsheet of the PWT 6.1.

The initial capital stock is computed using the investment series. To do so, we took as the reference year, the year following that of the start of the investment series. We then used the perpetual inventory method to build up the remainder of the series. This procedure allowed each country to have its own capital stock series beginning in the first year for which we have available data for aggregated investment.

[3] PWT 6.1 does not provide a series for the capital stock of the different countries. Na documentação do banco de dados PWT 6.1 uma série de variáveis aparecem como "ainda não disponíveis", dentre elas a variável *Kapw – capital stock per worker* e algumas subdivisões do estoque de capital (e.g. *residential construction; non residential construction; transport equipment*).

The capital stock series used in this study was not adjusted for purchasing power parity disparities. More specifically it is taken in constant 1996 US$. This reflects the perception that investment decisions are taken considering relative domestic prices. Cohen & Soto (2003) also notice this and argue that PPP adjustment imposes on poorer countries relative prices that are different from those of the market, and an apparently high marginal productivity of capital. The price of investment goods has been decreasing over time in relation to the price of other products, a trend that has become more evident with the growing production of the information technology and communications industries. The quality of the products in these two industries has undoubtedly been improving, with prices continually dropping and capital use continually increasing. The consequence of this is that the importance of factor accumulation in the explanation of economic growth is increasing, making the part relative to productivity smaller. Once the capital stock values undergo PPP adjustment, these effects are exacerbated.

Factor shares s_K and s_L were basically obtained from two databases: (i) the *Annual National Accounts*, which brings information from 1970 to 2000 for 30 OECD members; and (ii) United Nation's *System of National Accounts* (SNA68). For OECD nations belonging to the sample in this study, we have used only this organization's database (it is homogeneous and contains more information than the SNA, some of them estimations, though). Information pertaining to other nations, not OECD members, were obtained mostly from SNA68.

Data for some countries were not available in SNA68 (usually those pertaining to the first and the last years of the sample). For these countries we tried other sources. Among them we can name ECLAC (Economic Commission for Latin America and the Caribeean) for data pertaining to Bolivia (2000), Costa Rica[4] (2000), Trinidad & Tobago (2000) and Jamaica and Peru (1995 and 2000), and MIDEPLAN (Ministerio de Planificación y Cooperación) for Chile (1975 to 1985 and 2000) [5]. For Brazil, data used are from the local official statistical bureau (IBGE).

The selection of countries included in the sample followed some criteria. The first and obvious criterion was availability of homogeneous data for the period in question. Nations that had a reduced number of observations were excluded. A minimum number of 30 continuous observations per country was set. Therefore, of the 203 economies listed in the PWT 6.1, 86 coun-

[4] For Bolivia and Costa Rica the numbers for 2000 are actually those of 1999.

[5] For Chile, there was no available information for 1970 in any sources used. We used then the numbers for 1973, first year for which the national accounts of this country displays that information.

tries that did not have information on either the labor force, GDP, investment, or exchange rate for the last 30 years were excluded. This criterion essentially removed from the sample a number of countries created or split in the last 20 to 30 years.

Previously socialist economies, such as People's Republic of China, Hungary, Romania and Poland, or those nations that are protectorates of others, such as Puerto Rico and Taiwan[6], were also excluded. The group of 86 excluded nations also includes those with a very small population – less than 500 thousand inhabitants in 2000. For this reason countries like Barbados, Cape Verde, Equatorial Guinea, Luxembourg and Seychelles Islands were also left out. The only exception to this last rule was Iceland, a country with available information dating back to 1950 and whose quality of data included this nation as a representative of small-population countries in this study.

Of the remaining 112 economies, another 13 were excluded because of lapses in the historical series caused by wars, civil wars or split-ups. In these cases, the estimation of capital stock using the perpetual inventory processes can clearly not be applied. The countries rejected due to this criterion were the following: Angola, Ethiopia, Bangladesh, Guinea, Comoros, Haiti, Burundi, Central African Republic, Madagascar, Mozambique, Sierra Leone, Papua New Guinea and Zaire (presently Congo). Eighteen other nations were excluded because of having highly volatile GDP per capita and investment rate figures, which causes excessively high deviations in the capital stock estimations (namely, Algeria, Benin, Botswana, Burkina Faso, Cameron, Congo Republic, Ivory Costa, Fiji Islands, Mauritius Islands, Gambia, Guinea Bissau, Guyana, Mali, Mauritania, Namibia, Niger, Tanzania and Togo).

Note that all countries included in this last group are poor, most of them from Africa. A question could be raised here, arguing that this decision would create a biased analysis through selection. We argue that this is not a problem in this study, because the purpose here is to describe a quite flexible production frontier (*translog*): in this case, output elasticities with respect to the productive factors can vary among countries and in time, which renders flexibility to the adjustments. In the event we undertook an analysis using the Cobb-Douglas technology, elasticities would be constant and would express sample averages subject to selection bias. In this analysis, quite to the contrary, the selection should favor precise estimations, because the ex-

[6] Hong Kong was kept in the sample, though .

[8] See Table A, from *Data Appendix for a Space-Time System of National Accounts: Penn World Table 6.1 (PWT 6.1)* p. 13 – available at http://pwt.econ.upenn.edu/ .

cluded economies (due to unreliable data) generally have a low “grade” in the ranking brought by the PWT in regard to data quality.[8]

This leaves us with 75 countries with data spanning from 1950 to 2000. The observations were taken for 11 different time periods, every 5 years, starting in 1950 and finishing in 2000. This type of procedure is rather common in the economic growth literature and is justified by the interest of studying long-term effects, and this can be perfectly addressed by more spaced time observations. Forbes (2000), to give one example, makes estimations with data gathered every five years and justifies this saying that yearly data contain short-term disturbances. Before proceeding to the estimations, the data were carefully reviewed, on a country per country basis. Special care was taken with the series for capital stock. It is known that estimations for initial capital stock can present problems that render capital stock data for the first years of the series less reliable. We must remember that the initial capital stock calculations presume a stable behavior for the economic growth rate (steady state), an assumption not very realistic. In the event the growth rate for the initial period is too low (much lower than that of steady state), the initial capital stock tends to be overestimated, and consequently these data appear to be reduced in the initial periods. The opposite can occur when the rate is high. Based on scatter plots (capital x GDP) we noticed the presence of observations for some countries that could suggest inadequate estimations of initial capital stock. This was the case of the following countries: Argentina, Australia, Denmark, Iceland, the Netherlands, New Zealand and Syria. Therefore, the first two (or three) observations of the series pertaining these countries were eliminated.

A similar problem occurred for some countries when scatter plots of production and population of equivalent adults were analyzed. Ireland, Greece and Cyprus experienced, at different moments, considerable reductions in their population of equivalent adults, presenting a behavior not compatible with the premise of factors diminishing returns. For the first two nations, this happened at the beginning of the series, a fact that could indicate problems with different sources for population data (up to 1960 the PWT’s population data come from the *United Nations Development Centre* and after this year they come from the World Bank). Consequently, we decided to exclude the first two observations of the series for Ireland (1950 and 1955) and the first (1955) for Greece.

4. Estimation of the world stochastic frontier (1950-2000)

The model estimation was conducted using the STATA 8 software, which includes among its pre-programmed models that of Battese & Coelli (1992). Initially, a number of alternative specifications were tested, imposing different restrictions on the parameters of the translog technology. Likelihood ratios tests allow us to check if the restrictions are valid or not. These statistics are presented in Appendix I.

Parameters presented in Table 1 are all significant at 5%, except the capital elasticity, which is significant at 6.5%. The mean inefficiency, μ, is significantly different from zero at 1%, showing that the normal truncated distribution is an appropriate assumption (if it were not significant, we would fall back to the case of half-normal distribution). The estimated value of η is positive, which means that technical efficiency grows at decreasing rates (catch-up).

β_{kn} is negative, revealing the possibility of substitution between the production factors. The β_t and β_{tt} coefficients indicate that the neutral part of technical progress has negative effects on production and in order to achieve (positive) technical progress, it is necessary that the non-neutral part of technical progress offsets these effects. The signs of β_{kt} and β_{nt} indicate, respectively, that the non-neutral part of the technical progress goes hand in hand with the capital accumulation (positive sign of β_{kt}), and inversely with labor supply (negative sign of β_{nt}), i.e., technical progress is labor-saving and is more intense in countries where capital is abundant.

Table 1 Time-variant inefficiency model

No. of observations = 746					Observations per country: min	= 3
No. of countries = 75					Average	= 9.9
					Maximum	= 11
Log likelihood = 272.07096						Wald $\chi2(8)$= 14,540.41
						Prob > $\chi2$ = 0.0000

lny	Coefficients	Standard error	z	P>z	Confidence interval 95% lower	upper
β_t	-0.1198	0.0455	-2.6300	0.0080	-0.2089	-0.0307
β_k	0.2457	0.1330	1.8500	0.0650	-0.0149	0.5064
β_n	0.3767	0.1883	2.0000	0.0450	0.0077	0.7458
β_{tt}	-0.0075	0.0015	-5.1300	0.0000	-0.0103	-0.0046
β_{kk}	0.0275	0.0111	2.4900	0.0130	0.0058	0.0492
β_{nn}	0.0572	0.0216	2.6500	0.0080	0.0150	0.0995
β_{kn}	-0.0605	0.0272	-2.2200	0.0260	-0.1138	-0.0072
β_{kt}	0.0106	0.0023	4.6100	0.0000	0.0061	0.0152
β_{nt}	-0.0063	0.0030	-2.1100	0.0350	-0.0121	-0.0004
β_0	8.8115	1.8366	4.8000	0.0000	5.2119	12.4111
μ	0.2074	0.0626	3.3100	0.0010	0.0846	0.3302
η	0.0652	0.0116	5.5900	0.0000	0.0423	0.0880
$\ln \sigma^2$	-2.7946	0.2291	-12.2000	0.0000	-3.2437	-2.3456
ilgt γ	0.6735	0.3514	1.9200	0.0550	-0.0153	1.3623
σ^2	0.0611	0.0140			0.0390	0.0958
γ	0.6623	0.0786			0.4962	0.7961
σ_u^2	0.0405	0.0140			0.0131	0.0679
σ_v^2	0.0206	0.0011			0.0184	0.0229

Inspection of the results for returns to scale, technical change, and technical efficiency reveals that these are economically meaningful. Table 2 shows country ranks for RTS, TE, and TP. The technical efficiency ranking must be viewed with caution. Although the presence of countries like Nicaragua, Venezuela and El Salvador in the first positions of the ranking does indeed seem odd, two aspects must be kept in mind: (i) these results are "conditional" on the capital-labor ratio; and (ii) the estimations took place using PPP adjusted figures for GDP. In other words, the first aspect mentioned means that, in a traditional Farrel diagram, a country such as Nicaragua is closer to the frontier, yet it is placed at the "edge" of the unit isoquant closest to the axis of the labor factor, at the same time that a country like Norway would be further from the frontier, but on the opposite edge of the isoquant (abundant capital, scarce labor).

The second caveat means that the ordering of productivity reflects the efficiency in non-tradables goods and services. When the value of technical efficiency is converted by the PPP factor, we have production efficiency at prices of tradable goods. This adjusted TE ranking is displayed next to the first one and shows a distinct ordering, in which developed countries are positioned at the top, led by the United States. These adjusted scores would better translate international competitiveness of countries.

Table 2. Technical efficiency, returns to scale and technical progress, 2000

Rank	Techinical Effciency (US$, PPP)		Techinical Effciency (US$)		Hall & Jones (1996) Ranking		Islam (1995) Ranking		Returns to scale Ranking		Technical progress Ranking	
1	NIC	0,975	USA	0,955	SYR	1,256	HKG	1,537	IND	1,148	JPN	0,79%
2	VEN	0,974	JPN	0,899	JOR	1,181	CAN	1,041	IDN	1,108	USA	0,44%
3	CAN	0,971	CHE	0,872	MEX	1,143	USA	1,000	USA	1,107	GER	0,27%
4	SLV	0,970	GBR	0,820	ITA	1,093	NOR	0,861	PAK	1,101	FRA	-0,11%
5	MEX	0,968	ISR	0,811	HKG	1,090	BEL	0,787	BRA	1,098	CHE	-0,31%
6	TUR	0,958	SWE	0,778	FRA	1,029	ESP	0,787	JPN	1,087	ITA	-0,34%
7	USA	0,955	CAN	0,770	BRA	1,002	FRA	0,787	MEX	1,085	GBR	-0,55%
8	ZAF	0,939	HKG	0,763	USA	1,000	JPN	0,787	PHL	1,081	NLD	-0,66%
9	CHL	0,932	DNK	0,761	CAN	0,987	DNK	0,748	EGY	1,078	AUS	-0,72%
10	IRN	0,929	NOR	0,740	ESP	0,983	GBR	0,712	TUR	1,077	AUT	-0,76%
11	GTM	0,928	ISL	0,740	PRT	0,980	NLD	0,712	IRN	1,076	CAN	-0,76%
12	TTO	0,924	SYR	0,723	GBR	0,962	SWE	0,712	THA	1,075	ESP	-0,79%
13	HKG	0,890	FIN	0,722	AUT	0,958	AUT	0,677	GER	1,075	NOR	-0,79%
14	TUN	0,883	IRL	0,717	BEL	0,948	GER	0,677	GBR	1,071	SWE	-0,82%
15	CRI	0,882	FRA	0,685	NLD	0,926	CHE	0,619	ITA	1,070	DNK	-0,83%
16	ISR	0,877	BEL	0,682	SWE	0,911	ISR	0,619	FRA	1,070	BEL	-0,89%
17	ZWE	0,867	VEN	0,672	GER	0,900	TTO	0,619	KOR	1,066	KOR	-1,13%
18	ECU	0,865	NLD	0,665	AUS	0,898	AUS	0,589	ZAF	1,066	FIN	-1,14%
19	LKA	0,858	AUT	0,656	CHE	0,873	ITA	0,589	COL	1,064	HKG	-1,28%
20	MYS	0,851	GER	0,643	VEN	0,873	NZL	0,589	ESP	1,062	NZL	-1,55%
21	COL	0,849	ITA	0,631	ISR	0,840	VEN	0,533	KEN	1,061	GRC	-1,61%
22	PRY	0,848	CRI	0,625	TTO	0,834	FIN	0,507	ARG	1,060	BRA	-1,62%
23	GBR	0,833	IRN	0,615	GTM	0,825	MEX	0,487	MAR	1,059	ARG	-1,68%
24	EGY	0,832	MEX	0,588	COL	0,800	SYR	0,463	NPL	1,056	PRT	-1,69%
25	URY	0,831	AUS	0,587	FIN	0,800	BRA	0,419	UGA	1,056	ISR	-1,83%
26	SEN	0,829	ESP	0,583	NOR	0,780	CRI	0,383	CAN	1,055	IRL	-1,89%
27	JOR	0,816	GRC	0,558	DNK	0,778	GRC	0,383	PER	1,053	MEX	-2,00%
28	PHL	0,816	JAM	0,558	IRL	0,770	IRL	0,383	VEN	1,051	MYS	-2,38%
29	GRC	0,809	ARG	0,511	TUN	0,762	KOR	0,383	GHA	1,051	ISL	-2,39%
30	NPL	0,800	URY	0,486	NZL	0,754	MYS	0,383	MYS	1,050	THA	-2,42%
31	PAN	0,796	PRT	0,480	TUR	0,751	URY	0,383	LKA	1,049	ZAF	-2,62%
32	ESP	0,790	NZL	0,466	JPN	0,744	ZAF	0,383	AUS	1,042	TUR	-2,64%
33	AUS	0,788	KOR	0,448	GRC	0,742	PRT	0,347	SYR	1,041	VEN	-2,69%
34	ARG	0,778	SLV	0,443	CRI	0,736	PER	0,330	CHL	1,041	CHL	-2,80%
35	PER	0,776	CHL	0,416	ARG	0,730	PRY	0,330	ZWE	1,039	IRN	-2,80%
36	ITA	0,776	PAN	0,415	URY	0,696	GTM	0,314	ECU	1,038	PER	-2,92%
37	IRL	0,774	TTO	0,404	KOR	0,664	MAR	0,314	NLD	1,038	COL	-2,95%
38	PRT	0,773	TUR	0,386	DOM	0,651	NIC	0,301	GTM	1,037	SYR	-3,01%
39	MAR	0,772	GAB	0,371	ZAF	0,645	COL	0,287	MWI	1,036	IDN	-3,16%
40	DOM	0,768	GTM	0,358	EGY	0,595	PAN	0,287	RWA	1,032	GAB	-3,21%
41	BEL	0,764	MYS	0,348	MAR	0,576	TUN	0,273	SEN	1,032	URY	-3,29%
42	FRA	0,755	ZAF	0,345	PER	0,565	TUR	0,273	TUN	1,030	PHL	-3,36%
43	FIN	0,752	BRA	0,339	MYS	0,560	ARG	0,259	TCD	1,030	IND	-3,51%
44	IDN	0,752	PER	0,337	SLV	0,557	JOR	0,259	GRC	1,029	TUN	-3,52%
45	BRA	0,750	JOR	0,325	PRY	0,541	SLV	0,247	PRT	1,029	EGY	-3,58%
46	HND	0,745	DOM	0,319	PAK	0,527	THA	0,247	BOL	1,028	TTO	-3,62%
47	BOL	0,744	HND	0,318	CHL	0,522	ECU	0,237	DOM	1,028	PAN	-3,71%
48	SWE	0,742	EGY	0,286	THA	0,513	CHL	0,225	BEL	1,028	MAR	-3,71%
49	NLD	0,738	COL	0,281	ECU	0,504	DOM	0,214	SWE	1,023	CRI	-3,73%
50	CHE	0,738	BOL	0,252	LKA	0,481	PAK	0,194	HND	1,022	JAM	-3,80%
51	RWA	0,737	TUN	0,252	BOL	0,469	PHL	0,186	AUT	1,021	ECU	-3,95%
52	PAK	0,734	ECU	0,250	PAN	0,463	BOL	0,169	SLV	1,020	DOM	-4,02%
53	TCD	0,722	PRY	0,242	HND	0,449	JAM	0,169	HKG	1,018	PRY	-4,10%
54	GAB	0,720	NIC	0,237	NIC	0,443	EGY	0,153	CHE	1,017	JOR	-4,25%
55	DNK	0,713	SEN	0,226	JAM	0,410	LKA	0,153	NIC	1,017	SLV	-4,29%
56	LSO	0,708	LSO	0,210	PHL	0,389	HND	0,126	PRY	1,016	GTM	-4,39%
57	NZL	0,703	MAR	0,209	IND	0,344	NPL	0,120	ISR	1,015	LKA	-4,48%
58	AUT	0,700	PHL	0,203	SEN	0,316	SEN	0,110	JOR	1,014	PAK	-4,53%
60	KOR	0,692	LKA	0,188	ZWE	0,275	UGA	0,104	DNK	1,010	BOL	-4,58%
61	JAM	0,678	ZWE	0,185	NPL	0,244	ZWE	0,104	FIN	1,010	HND	-4,90%
62	GER	0,677	THA	0,176	RWA	0,242	IND	0,071	CRI	1,006	ZWE	-4,90%
63	NOR	0,659	KEN	0,161	KEN	0,237	KEN	0,071	NOR	1,006	LSO	-5,19%
64	ISL	0,654	RWA	0,159	GHA	0,215	RWA	0,065	IRL	1,004	NIC	-5,24%
65	IND	0,640	UGA	0,158	UGA	0,162	MWI	0,058	URY	1,004	KEN	-5,32%
66	GHA	0,637	PAK	0,146	TCD	0,151	GHA	0,053	NZL	1,003	GHA	-5,49%
67	UGA	0,635	TCD	0,138	MWI	0,130	TCD	0,042	PAN	1,000	SEN	-5,50%
68	SYR	0,632	IDN	0,136					JAM	0,998	NPL	-5,94%
69	JPN	0,621	GHA	0,119					LSO	0,994	MWI	-6,10%
70	KEN	0,611	NPL	0,118					TTO	0,981	UGA	-6,19%
71	THA	0,595	IND	0,109					GAB	0,975	RWA	-6,43%
72	MWI	0,502	MWI	0,102					ISL	0,939	TCD	-6,56%

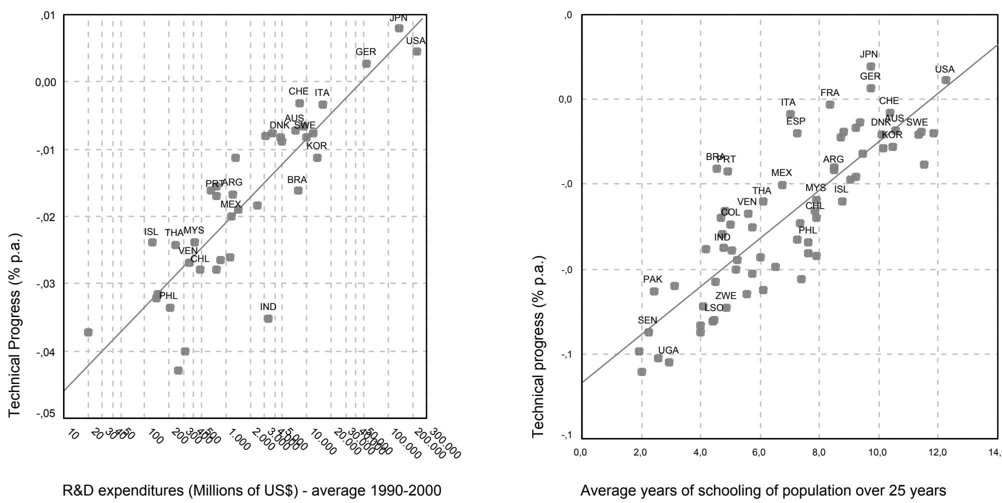
An interesting exercise is to compare our ranking to the productivity indices suggested by Islam (1995) and Hall & Jones (1996). The index of adjusted technical efficiency seems better suited for such comparisons, because it displays the efficiency in US$. This index is highly correlated[11] with those suggested by the above authors, with the advantage that this ordering seems to be more intuitive. The less productive nations remain practically unchanged at the bottom of the ranking, but the top of the productivity ranking no longer brings less developed nations, as in Hall & Jones (1996), for whom countries like Syria, Jordan, Mexico and Brazil are listed among the most productive economies, or as in Islam (1995), in which Hong Kong is considered the most productive nation – 53.7% more productive than the United States!

The results for RTS are very intuitive. The countries at the top of the ranking depict increasing returns to scale. These are large countries from the population and territorial perspective. The bottom positions in the ranking are occupied by basically very small (in size and population) countries. Another fact that comes to our attention is that Germany, Great-Britain, Italy and France, all of them European nations of very homogeneous characteristics, are placed next each other in the ranking.

The results for technical progress seem at first sight rather odd, with almost all of them being negative. Nonetheless, the ordering seems to match our intuition regarding the technological performance of the nations. At the top positions are Japan, United States, Germany and France. Among the countries at the bottom are the African nations, well-known for their lack of technological knowledge. A simple exercise of "casual empiricism" provides an interesting "test" of the existence of "economic intuition" behind the estimations of technical progress performed by the model. The idea is to evaluate if the measure of technical progress produced is related in any way to the effort to innovate carried out by countries in recent years. The scatter diagram for the technical progress measure and the natural logarithm of R&D expenses (average for 1990-2000) show us what seems to be, at least at first sight, a positive relation between these variables.

[11] The correlation coefficient between the adjusted technical efficiency index suggested here and the Hall & Jones (1996) index is 0.752, and the correlation index and the Islam (1995) index is 0.826, both significant at less than 1%. The correlation between the indices of the two studies named here is 0.740, also significant at less than 1%.

Graph 1. Expenditures in R&D, human capital and technical progress, 2000



Fonte: Table 2 and WDI 2002.

Another similar diagram, but relating the measure of technical progress with the average education level of the population shows another intuitive relation: countries with better educated population are also the ones with the highest levels of technical progress.

In addition to the analysis of production frontiers using data at five-year intervals, two other experiments were carried out to evaluate the relative performance of the model: (i) the estimation of the stochastic frontier model using annual data, and (ii) the estimation of traditional panel data models (fixed effects and random effects). Regarding the first experiment, it can be said that five-year interval data yield better results than annual ones, as expected. In spite of being valid on the whole, the annual model generates non-significant coefficients associated to time, capital stock and the labor force: p(z) = 16.7%, 19.0% and 24.5%, respectively. Moreover, the model’s total variance is larger, given the existence of short-term variability in output (0.077 as opposed to 0.061 in the model with five-year data). The average technical inefficiency, given by μ, is relatively high (0.249 compared to 0.207 in the five-year model), which leads this model to have higher variance of technical efficiency and lower of technical progress (which comes out negative for all countries after 1997). For this reason, the influence of μ in the total variance also rises, from 66.3% to 77%. If the estimation of the technical inefficiency were based on the Battese & Coelli (1995) model, maybe it would be possible to control the effect of these short-term variations.

The estimates produced by the fixed-effects and random-effects models in turn came out quite inferior to those of the stochastic frontier models. The Hausman test ($\chi^2 = 49{,}03$) favors the fixed effects model, although 4 out the 9 coefficients of the *translog* specification ended up being not significant at 10%. Furthermore, the results are not intuitive at all. Some countries have zero or negative labor elasticities, such as Iceland and South Korea, and the returns to scale vary greatly: the United States, to give an example, would have an estimated RTS of 1.26, whereas Iceland would be a mere 0.49. The estimations of technical progress likewise are not very reasonable: United States, Japan and Germany show large technical regress at the same time that Trinidad & Tobago, Lesotho and Jamaica have extraordinary technical progress. This result reinforces the idea that frontier models are better suited for the analysis of productivity in comparison with traditional econometric methods.

5. *TFP and its components (1970-2000)*

With the results of the estimation of the model, obtained in Section 3 for the 75 countries of the sample, and the data on functional income distribution (s_K and s_L), it is possible to decompose productivity change in the manner shown in section 1. However data for factors shares in income are not available for all these economies. We managed to collect data for only 36 of the 75 countries, and just from 1970 up to 2000. The "full" decomposition of TFP is then restrict to this group of 36 nations. Table 3 brings the results.

The exercise of ordering the countries according to the magnitude of the variation of the average productivity change along these 30 years shows some interesting results. All top positions (until the 21st in the ranking) are OECD countries. Among them, Japan's performance stands out, with an average productivity growth rate of 2.42% p.a. during this period. The next countries are Austria (1.77%), France (1.75%), Norway (1.53%), Switzerland (1.51%) and USA (1.49%). In the middle block we find some Latin American countries, such as Jamaica, Brazil, Peru, Venezuela and Bolivia, all of them with relatively low TFP growth rates. Brazil showed during this period an average rise in productivity of 0.39% per year. Among the other Latin American countries of the sample we see that Mexico, Costa Rica, and, surprisingly, Chile had reductions in productivity. Greece and Turkey are the only OECD members with negative productivity growth during this time.

Countries that provided the largest contribution of technical progress in the variation of productivity for the 1970-2000 period were Japan, the United States, France, Switzerland, Italy, United Kingdom, the Netherlands and Australia, in this order. Contributions for this group ranged from 0.56 to 0.30 percentage point per year, on average. As we can see, they are all developed countries that invest substantial amounts in R&D.

Table 3. Sources of economic growth 1970-2000 – average annual change in (%)

Country	Economic growth	Capital accumulation	Labor expansion	Productivity					Random shocks
				Change in TFP	Technical progress	Technical efficiency	Gains of scale	Allocative gains	
AUS	4.16	1.17	1.06	0.93	0.30	0.46	0.06	0.12	1.00
AUT	3.74	1.70	0.30	1.77	0.25	0.69	0.01	0.81	-0.03
BEL	3.29	1.60	0.31	1.40	0.23	0.52	0.03	0.61	-0.02
BOL	2.73	1.68	1.00	0.05	-0.55	0.57	0.00	0.02	0.00
BRA	5.59	4.51	1.13	0.39	0.01	0.55	0.41	-0.58	-0.44
CAN	4.14	1.87	1.10	0.98	0.26	0.06	0.12	0.54	0.19
CHE	2.03	1.31	0.52	1.51	0.40	0.59	-0.01	0.53	-1.30
CHL	4.98	3.88	0.87	-0.41	-0.30	0.13	0.11	-0.35	0.64
COL	4.93	3.73	1.05	-0.20	-0.30	0.31	0.20	-0.41	0.34
CRI	4.89	4.01	1.63	-0.32	-0.47	0.24	-0.12	0.03	-0.43
DNK	2.61	0.89	0.35	1.39	0.27	0.65	-0.01	0.47	-0.02
ESP	3.97	2.79	0.54	1.30	0.23	0.45	0.17	0.44	-0.66
FIN	3.65	1.76	0.37	1.45	0.18	0.55	-0.02	0.74	0.07
FRA	3.43	1.79	0.47	1.75	0.41	0.54	0.15	0.64	-0.57
GBR	2.73	0.99	0.27	1.33	0.32	0.35	0.10	0.55	0.13
GRC	3.67	4.37	0.30	-0.46	0.05	0.41	0.04	-0.95	-0.55
IRL	6.03	2.18	0.61	0.97	-0.05	0.49	-0.04	0.56	2.27
ISL	4.13	1.22	0.93	0.97	-0.09	0.82	-0.21	0.46	1.01
ITA	3.53	2.14	0.29	1.24	0.35	0.49	0.15	0.25	-0.14
JAM	1.80	2.06	0.86	0.41	-0.43	0.75	-0.08	0.18	-1.54
JOR	6.23	5.95	2.17	-0.83	-0.63	0.39	-0.14	-0.45	-1.06
JPN	5.26	3.54	0.58	2.42	0.56	0.92	0.34	0.57	-1.28
KEN	5.17	3.22	1.48	0.07	-0.79	0.95	0.16	-0.24	0.39
KOR	9.31	6.93	0.88	0.62	-0.03	0.71	0.40	-0.46	0.87
MEX	5.00	4.57	1.27	-0.18	-0.07	0.06	0.34	-0.51	-0.66
NLD	3.59	1.20	0.65	1.27	0.30	0.58	0.05	0.34	0.46
NOR	4.09	1.75	0.40	1.53	0.25	0.81	-0.03	0.50	0.41
NZL	2.39	0.47	0.77	0.76	0.15	0.68	-0.02	-0.05	0.39
PER	3.15	2.75	1.00	0.21	-0.20	0.49	0.10	-0.17	-0.81
PRT	4.71	3.09	0.39	1.20	-0.02	0.50	0.05	0.67	0.03
SWE	2.57	0.96	0.36	1.44	0.28	0.57	0.01	0.57	-0.20
THA	8.01	6.51	0.62	-0.73	-0.29	1.00	0.37	-1.79	1.60
TTO	3.62	2.65	0.83	-0.23	-0.41	0.15	-0.16	0.18	0.36
TUR	5.38	5.93	0.79	-1.33	-0.26	0.08	0.33	-1.48	-0.01
USA	3.97	1.70	0.84	1.49	0.52	0.09	0.28	0.59	-0.07
VEN	1.82	2.24	1.41	0.06	-0.10	0.05	0.08	0.04	-1.90

Among the 19 countries that presented positive contributions of technical progress, 18 are OECD members. Brazil is the only non-member of that organization that managed to have technical progress contributing for higher productivity, mainly in the 1965 to 1985 period. This trend matches that of three other Latin American countries that underwent a marked import substitution process, namely Mexico, Peru and Venezuela. The fall in the pace of technical progress of these countries coincides with the debt crisis and economic liberalization, periods during which the industrialization process slows down its pace.

An important aspect pertains to the interpretation of technical regress (negative technical progress) that appears in the results of this study[12]. First it should be pointed out that a frontier was not estimated for each country and therefore it is not a matter of saying that this or that country had "inward" shifts to their frontiers. The interpretation is quite difficult in light of the way that technical progress was achieved, by including a time trend in the model (and interactions of time with capital and labor). According to Arrow (1962), this procedure, which is rather common in the literature, is most of all a confession of ignorance. As discussed in Section 3, the underlying idea here is that countries closer to the frontier (and on the forefront of technical progress) are responsible for the actual shift in the world production frontier. One way of interpreting technical regress in less developed nations is that it may be the result of changes that end up halting the production of some high-technology products and encouraging the manufacturing of low-technology products. Since GDP is the aggregation of value added in a number of industries, this sliding performance could be the result of production shifting from some highly productive sectors to others, where productivity is lower.

All countries enjoyed rising technical efficiency, as shown in Table 4.3. That is a characteristic of the estimated model. The Battese & Coelli (1992) model imposes the restriction of a common η to all countries. In the global sample including the 75 countries, the estimated value for this parameter was positive, which resulted in a catch-up pattern for all countries: technical efficiency grows at decreasing rates. The countries that appeared closer to the frontier were: Thailand, Kenya, Japan, Iceland, Norway, Jamaica and South Korea. It is quite intuitive that Thailand, Japan and South Korea should appear at the top here, since they have made great effort to absorb technology. For the other countries, this conclusion does not seem to be so obvious. Nonetheless, Kenya, Iceland and Jamaica enjoyed very high rates of growth during some periods in the sample, which could suggest a movement towards the frontier whose cause could only be understood following a deeper investigation of the history of these economies (something beyond the scope of this study). Among countries with lesser gains of technical efficiency are the United States and

[12] Other authors also report this kind of result using frontier techniques - Rao & Coelli (1998), for example.

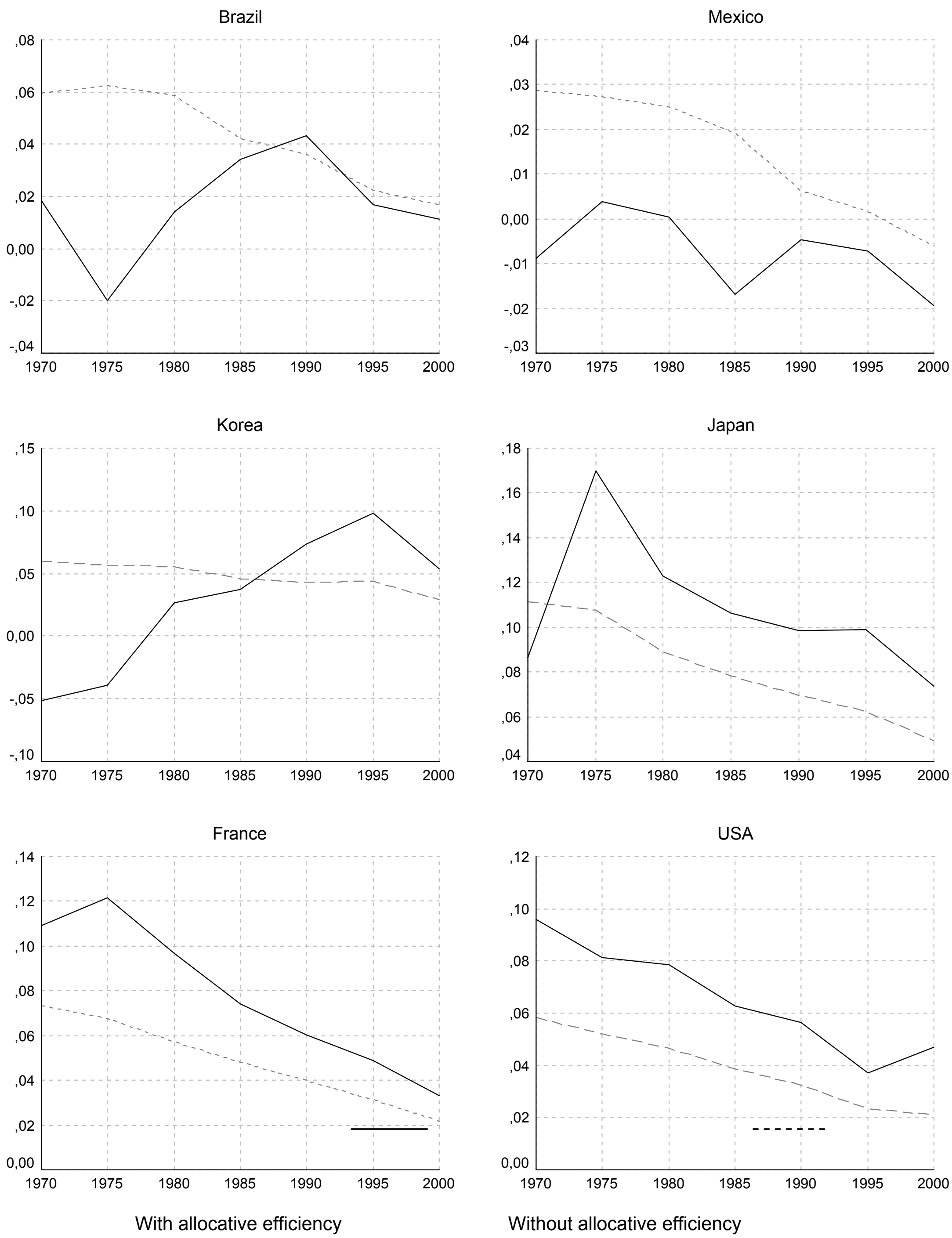
Canada which makes sense, since both these countries are already close to the frontier. They are in fact pushing the frontier further.

It is intuitive to conclude that countries with vast masses of population are those set to gain the most from scale effects. They are Brazil, South Korea, Thailand, Mexico and Japan. All of them but Japan are usually referred to as "developing" nations and have surely experienced leaping growth during at least some periods of the sample, based on a considerable accumulation of factors. It is also rather intuitive that countries with small population have gained less, or even lost productivity, as witnessed by the results of Ireland, Jamaica, Costa Rica, Jordan, Trinidad & Tobago and Iceland.

The estimated model produces scores that reflect the levels of technical efficiency of these nations, but not levels of allocative efficiency. The effects of allocative efficiency are only evaluated in dynamic terms, and in it reflect either an approximation or a departure of the value of the estimated shares of income factors (λ_K and λ_L) from the their competitive values (i.e., factor remuneration from its marginal products). As shown in Table 3, countries that had the largest allocative efficiency gains were Austria, Finland, Portugal, France, Belgium, the United States and Japan. At the other end are countries that lost out with the dynamics of factor allocation. Most of the Latin American countries fall within this group, as well as South Korea (until 1985) and Thailand. Some of OECD's poorest members are also among those countries that had poor performance in allocative efficiency terms, such as Greece and Turkey.

We see systematic gains with factor allocation in richer economies and losses (or very modest gains) in poorer ones. It is interesting to point out that the differences between these two groups of countries regarding changes in allocative efficiency are even more marked in the first three periods (five-year periods) of the sample. It is well known that both Brazil and Thailand decided on a strategy of "growth without adjustment" in response to the oil shock of 1973, with increasing debt during this time. In Brazil at this time the II National Development Plan, was being implemented and government played a heavy hand in resource allocation in the economy and was responsible for large infrastructure investments. The importance of government in resource allocation is also a characteristic of South Korea during the early years in the sample.

Graph 2. Total factor productivity, with and without allocative efficiency



The set of charts above shows the development of total factor productivity in six economies, calculated in two ways: (i) with allocative efficiency and (ii) without this component. The first aspect to be highlighted is the distinct patterns of behavior displayed by developed and developing nations. France, the United States and Japan present dynamic gains with resources allocation, and for them TFP computing allocative efficiency remains above the measure that excludes this component. The opposite happens in Brazil for most of the sample period and in all of it for Mexico. South Korea, on the other hand, has a distinct pattern, in which the curves cross each other, i.e., allocative efficiency inverts its impact, becoming a driver for productivity gains in that country.

For Brazil, TFP computed without allocative efficiency is, usually superior, showing the effects of "ill allocation" of production factors. From the mid 80s to the mid 90s, this effect reverses and begins to contribute to productivity growth, even if very little. After that period the contribution turns negative again, even if less impressive than in the first five-year periods under study. Mexico also reduces the negative allocative effects as of the mid 80s, but never enough to contribute to a rise in productivity. On the other hand, France, the United States and Japan have persistent gains with allocative efficiency.

6. *The role of technical progress and allocative efficiency in the economic growth of developed and developing nations (1970-2000)*

We will now take a closer look at the differences in economic growth patterns of developed and developing nations. Table 4 and Graph 3 bring data on GDP growth and the sources of growth for two groups of countries[13]. Table 4 displays annual averages (for each five-year period and for the whole 30 year period). For economic growth and each of its sources we computed the difference between the rate of change calculated for developed nations and that calculated for developing countries. The same was done for the productivity components.

[13] The group of developed nations consists of OECD member countries except Mexico, Greece and Turkey, which are in the developing nations group. This last group includes, in addition to the above three, all other countries in the sample (total of 36 countries).

Table 4. Sources of economic growth per group of countries and periods – % change

Variable	Countries**	Annual averages in the sub-periods*							Annual average	Accumulated
		1970	1975	1980	1985	1990	1995	2000		
GDP growth	Developed	5.33	3.92	3.44	2.30	3.62	2.04	3.57	4.04	228.22
	Developing	5.29	5.14	5.64	1.93	3.38	4.12	2.90	4.74	301.10
	Difference	0.03	-1.16	-2.08	0.37	0.23	-2.00	0.65	-0.67	-18.17
Capital accumulation	Developed	5.58	5.84	4.34	3.14	2.99	2.44	2.53	4.48	272.60
	Developing	6.54	6.72	6.59	5.04	3.85	4.13	3.59	6.09	489.67
	Difference	-0.90	-0.83	-2.11	-1.81	-0.82	-1.63	-1.02	-1.52	-36.81
Labor expansion	Developed	0.97	1.19	0.89	0.77	0.59	0.85	0.65	0.98	34.14
	Developing	2.95	2.82	2.81	2.68	2.41	2.15	1.91	2.96	139.92
	Difference	-1.93	-1.59	-1.87	-1.86	-1.78	-1.27	-1.24	-1.92	-44.09
Change in GDP per worker	Developed	4.32	2.70	2.53	1.52	3.01	1.17	2.91	3.03	144.68
	Developing	2.27	2.25	2.76	-0.73	0.95	1.92	0.98	1.73	67.18
	Difference	2.00	0.43	-0.22	2.27	2.04	-0.74	1.91	1.28	46.36
Change in capital per worker	Developed	4.57	4.59	3.42	2.35	2.39	1.57	1.87	3.46	177.76
	Developing	3.49	3.79	3.68	2.30	1.40	1.94	1.65	3.04	145.78
	Difference	1.05	0.77	-0.25	0.05	0.98	-0.36	0.22	0.41	13.02
Change in TFP	Developed	1.32	1.56	1.34	1.04	0.97	0.68	0.59	1.25	45.14
	Developing	0.07	-0.10	-0.23	-0.11	-0.16	-0.35	-0.37	-0.21	-6.11
	Difference	1.25	1.66	1.58	1.15	1.14	1.03	0.97	1.46	54.58
Technical progress	Developed	0.54	0.44	0.33	0.21	0.09	-0.04	-0.17	0.23	7.22
	Developing	0.04	-0.06	-0.16	-0.28	-0.41	-0.53	-0.66	-0.34	-9.76
	Difference	0.50	0.50	0.49	0.49	0.50	0.49	0.49	0.58	18.82
Change in technical efficiency	Developed	0.56	0.53	0.49	0.46	0.43	0.40	0.38	0.54	17.63
	Developing	0.43	0.40	0.37	0.35	0.33	0.31	0.29	0.41	13.13
	Difference	0.13	0.13	0.12	0.11	0.10	0.10	0.09	0.13	3.98
Change in efficiency of scale	Developed	0.05	0.06	0.06	0.06	0.07	0.07	0.07	0.07	2.25
	Developing	0.01	0.07	0.10	0.10	0.13	0.14	0.14	0.12	3.53
	Difference	0.04	0.00	-0.04	-0.04	-0.07	-0.07	-0.07	-0.04	-1.24
Change in allocative efficiency	Developed	0.17	0.52	0.45	0.30	0.38	0.24	0.31	0.39	12.50
	Developing	-0.40	-0.50	-0.54	-0.28	-0.21	-0.26	-0.14	-0.39	-10.99
	Difference	0.57	1.02	1.00	0.59	0.59	0.49	0.45	0.78	26.40

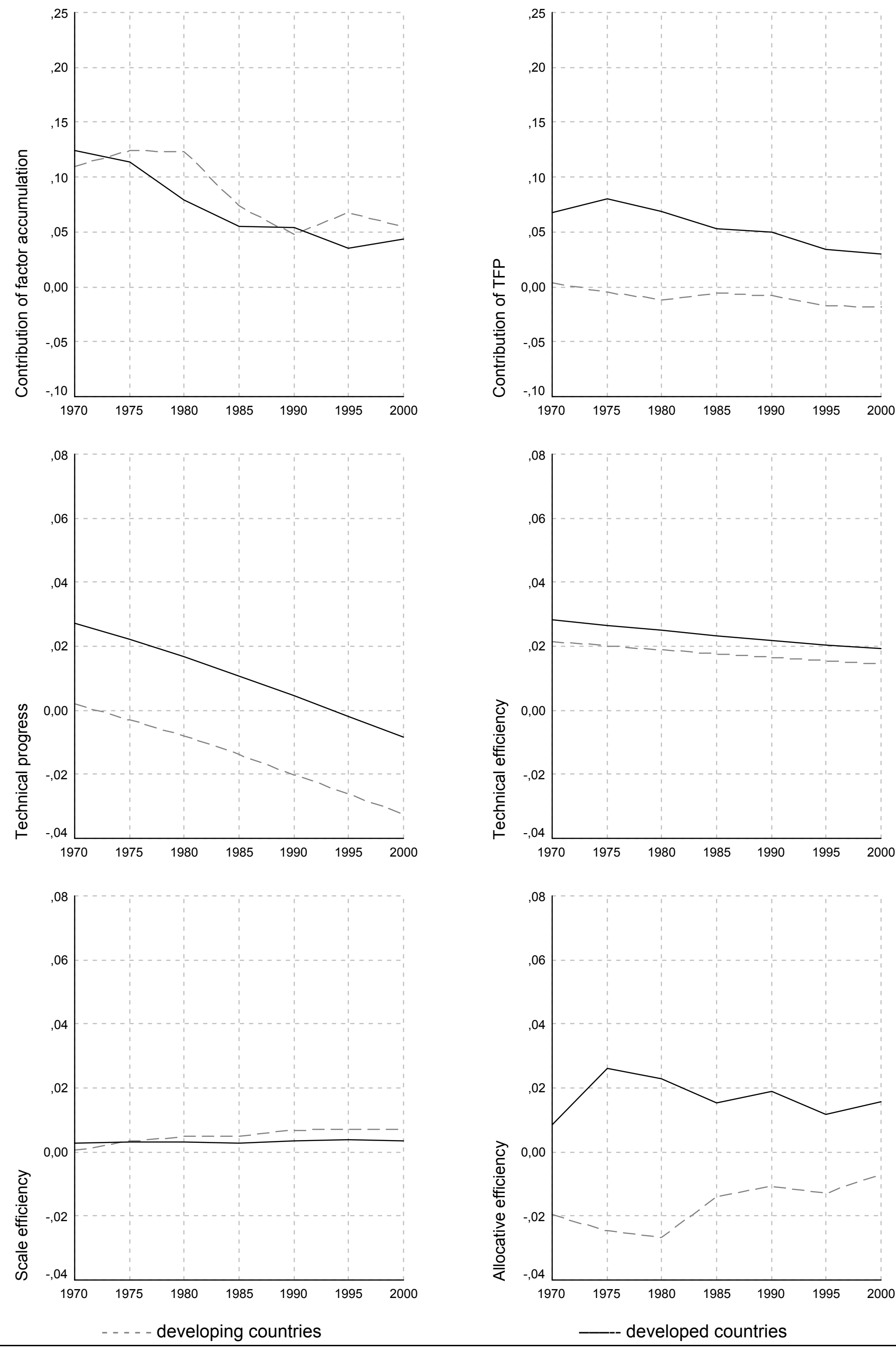
* The years represent the final point of each period, e.g., 1970 refers to the five-year period from 1966 to 1970, 1975 refers to the five-year period from 1971 to 1975, and so on. ** The values in this table were calculated by taking the simple average of the rates of change during the sub-periods for the countries comprising each group. The accumulated affect is computed by compounding the rates and discounting the differences (not linearly).

We see that developing nations grew more than developed ones (18.2%). This happened because both capital accumulation as well as labor expansion were larger in developing countries. However, the growth of GDP per worker was greater in developed countries, which can be attributed basically to two factors: (i) the difference between the growth rates of capital and labor was greater in developed nations, thus providing higher growth of capital per worker; (ii) the change in TFP in developed nations was considerable higher than in developing ones (yet it should be said that in the second group this change pushed down GDP's growth). The differences between the two groups in regard to growth of capital per worker are well below the differences in TFP growth. This suggests that productivity plays a role of great importance in the development of nations, better yet, that it might explain a significant part of the differences in GDP per capita growth between rich and poor countries.

If we take a look at the relative importance of the components of productivity, we see that developed nations have some advantages, even if minor, in regard to technical efficiency. On the other hand, we also see that this difference is in part offset by positive scale effects enjoyed by developing countries. Judging by the magnitude of the differences between the groups of countries regarding the pace of technical progress and the evolution of allocative efficiency, we are able to conclude that these two components explain most of the differences in productivity existing between the two groups. While developed nations enjoyed technical progress of 7.2% in the 30 years analyzed here, developing countries in fact suffered a 9.8% drop in that component, a gap that adds up to 18.8%. We also notice that rich countries accumulated sizable 12.5% in allocative efficiency improvement, at the same time that in poor countries this variable fell 11%. Here we have an accumulated difference of 26.4% in this component, which places this figure at the forefront in explaining the differences in productivity among the two groups of countries, and consequently the differences in the rates of output growth.

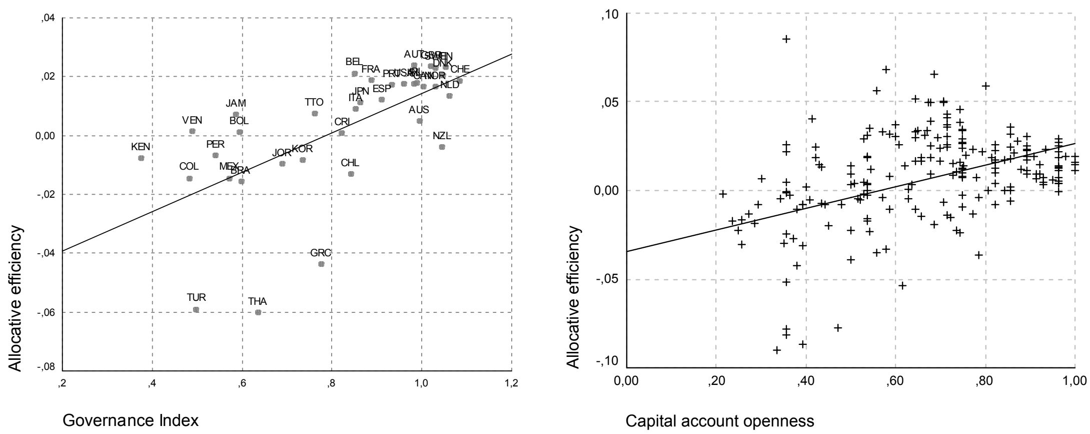
Lower rates of growth of output per worker in developing nations, in comparison with developed ones lead to divergence between the standards of living of the two groups of countries. In light of this, common aspects among countries having similar growth patterns, (and similar behavior for the difference between the two measures of TFP mentioned before – with and without allocative efficiency), should be sought. It might not be unreasonable to assume that the liberalization process witnessed in developing countries has helped improve resource allocation. Both Brazil and Mexico had a reduction in allocative inefficiency at the same time these economies underwent greater liberalization, as seen in Graph 2. Following this line of thinking, South Korea, a country that started the liberalization process earlier, inverted the allocative efficiency effect in the 80s, and maintained gains of productivity with this component of TFP since then.

Graph 3. Sources of growth per group of countries



Graph 4 reinforces this notion. It illustrates the relation between the governance index developed by Kaufmann, Kraay and Zoido-Lobatón (1999), and the average annual change in allocative efficiency for the 36 economies, from 1970 to 2000. As expected, the economies with better governance enjoyed less distortions and consequently greater allocative gains. The other graph shows the relation, for 33 of these 36 economies, from 1970 to 2000, between allocative efficiency and the degree of liberalization of financial flows, according to the measure suggested by Santana (2004). Also in this case, where we see five-year changes in these two measures, the elimination of distortions brought by barriers to the flow of capital seem to benefit the growth of allocative efficiency.

Graph 4 Governance, financial liberalization and allocative efficiency



Source: Kaufmann, Kraay and Zoido-Lobatón (1999), Santana (2004) and own data.

6. *Concluding remarks*

Two excerpts from contemporary remarks made by Robert Solow reveal that much remains to be clarified regarding the determinants of economic growth and their relative importance:

> "…Bits of experience and conversation have suggested to me that it may be a mistake to think of R&D as the only ultimate source of growth in total factor productivity. I don't doubt that it is the largest ultimate source. But there seems to be a lot of productivity improvement that originates in people and processes that are not usually connected with R&D. Some of it comes from the shop floor, from the ideas of experienced and observant production workers. This should probably be connected with Arrow's "learning by doing" or with the Japanese slogan about "continuous improvement." There is another

> part that seems to originate in management practices – in design, in the choice of product mixes, even in marketing. Notice that this is not just straightforward enhancement of productive efficiency. All this talk about value creation may be more than a buzzword; it may even be important. We need to understand much more about how these kinds of values get reflected in measured real output, and whether they can be usefully analyzed by our methods."
>
> Solow (2001a)

> "…the nontechnological sources of differences in TFP may be more important than the technological ones. Indeed they may control the technological ones, especially in developing countries."
>
> Solow (2001b)

The results presented in the previous sections readily provide information to clarify the apparent contradiction between these two statements. Even if restricted to a relatively small sample of countries, the results presented in Table 4 reveal that, in fact, for developed nations technical progress and technical efficiency changes are responsible for the larger part of TFP change accumulated in the last 30 years: of the 45.1 percentage points increase in TFP, 26.1 can be attributed to the joint effect of these two components (i.e., around 58% of all change). Yet for developing nations, for which TFP had a 6.1 percentage points decrease during the same period, the component that contributed the most to this result is allocative efficiency change, which reduced productivity in nearly 11 percentage points. Together, technical progress and changes in allocative efficiency contributed with a small accumulated growth of 2.1 percentage points. This technological performance is unsatisfactory in large part due to relatively small investments made by poor nations in R&D.

The evidence presented here also seems to corroborate the second statement made by Solow. As argued in the previous section, allocative efficiency is, among the components of TFP, the one that most contributes to the gap between the two groups of nations (with respect to income per worker and TFP) - about 60% of these differences. The pattern of technical progress is behind the other 40% of the gap. These facts point out that economic policies that directly affect factor allocation are extremely relevant in explaining the differences in the growth performance between developed and developing countries.

Regarding the changes in productivity associated with technological diffusion and waste reduction, the results of the article allow us to identify the importance of the increase in technical efficiency estimated by the stochastic frontier model, which contributes both to the growth of developed nations as well as developing ones. This perception seems to be in part shared by Robert Solow. The examples given by Solow are typical of what the production frontier literature calls efficiency improvement, both technical and allocative. Since he does not consider the explicit possibility of inefficiency, Solow seems to consider these phenomena some sort of innovation, yet not related to R&D expenses (design, marketing, etc.). However, we clearly see that he feels that technical progress leveraged by R&D spending is not the only driver of productivity.

Recently, Easterly & Levine (2001) added fuel to the existing controversy among the scholars espousing the "sources of economic growth", on the relative importance of factor accumulation and productivity. The underlying objective of these authors is to demonstrate that, unlike what is preached by the "Neoclassical Revival", the focus of investigation of economic growth should be productivity and its determinants[14]. The authors list five stylized facts regarding economic growth to underpin their idea. Some of their findings are corroborated by the results of this study, but others are not.

The first stylized fact presented by these authors states that differences in TFP growth explain the differences in per-capita income and per-capita income growth rates among the various countries. Although factor accumulation may be important to trigger growth and be responsible for a sizable share of this growth in a number of countries, it is not able to explain the differences in level of income or in rates of income change among nations. In relation to this fact, it should be pointed out, first of all, that the great importance of capital accumulation in the countries' growth rate also appears in the results for the reduced 36-country sample. In fact, we find that 80% of the growth would be attributable to the accumulation of capital and labor, and only the 20% remaining would come from productivity gains. The results vary when we calculate separately the average for the group of 24 developed countries (factor accumulation is lower, close to 63% of the growth) and for the group of 12 developing nations (contribution to productivity is negative and therefore the factor accumulation is behind all the economic growth).

If our reference is output per worker, the importance of capital accumulation remains high. With some additional calculations based on the numbers listed in Table 4, we conclude that on average 62.1% of the GDP growth is due to capital accumulation. Klenow & Rodriguez-Clare (1997) reach a similar result for a sample of 98 countries: on average 70% of economic growth is the result of physical and human capital accumulation. The comparison is obviously limited, be-

[14] Klenow & Rodriguez-Clare (1997) use this terminology created by Alwyn Young to qualify a body of studies that tries to counter the New Growth Theory and is associated to the hypothesis that the differences in levels and in per-capita income variation among nations are caused by differences in physical and human capital accumulation. Some examples of this line of work are Mankiw, Romer & Weil (1992), Young (1994, 1995) and Barro & Sala-i-Martin (1995).

cause human capital is not considered in this study and because the samples are different. Nonetheless, the reduced sample used in this article contains 24 of the 30 OECD members, while the sample used by Klenow & Rodriguez-Clare (1997) contains all of them. Consequently, we can conclude that most of the nations that differentiate the two samples are developing economies, which generally have a higher share of capital in income. Thus, the inclusion of these countries would tend to raise the participation of factors in the growth of GDP per worker (above 62.1%), bringing the results of the two samples closer to each other.

Regarding income per capita, the difference between rich and poor nations is the second stylized fact pointed out by Easterly & Levine (2001). According to these authors, this phenomenon is not very consistent with the analytical apparatus that emphasizes factor accumulation with diminishing returns and lack of economies of scale. It would be more appropriate to emphasize productivity growth based on technology and increasing returns. Klenow (2001) argues however that institutional or political institutions (such as tax structure, protectionism, lack of property rights, etc.) may reduce the accumulation of physical and human capital. In line with the ideas suggested by Easterly & Levine (2001), the results of this article reject an interpretation based on factor accumulation for this discrepancy.

The divergence between developed and developing nations was one of the results found using the empirical model applied in this study. Moreover, it is clear that the differences in the rates of productivity change are behind all the differences in the rates of growth of GDP per worker (the accumulation of factors contributed towards reducing such differences). Note that this result was obtained within the traditional framework of an aggregated production function with diminishing returns. It was not necessary to incorporate in the analysis a new sector (a knowledge production sector presenting increasing returns).

The third stylized factor in the Easterly & Levine (2001) list suggests that the accumulation of factors is persistent, at the same time that economic growth is not. Considering that changes in the rate of growth depend both on changes in factor accumulation as well as on changes in productivity, the validity of this stylized fact implies that TFP cannot be persistent. A consequence of this is that productivity measures would necessarily have a volatile behavior. This could be avoided if production data to be explained reflected the potential, rather than the actual product.

Robert Solow (Solow, 2001a) says that growth theory is a theory of the evolution of potential product. This is justified by the fact that the countries' growth paths do not resemble at all the concept of steady state. In economies where agriculture has a considerable weight, sudden weather changes or pests can bias the traditional TFP measure. Consequently, either we work with potential output as a dependent variable or we add explanatory variables that controls for weather changes or pests. Demand fluctuations are another source of deviation of output from its balanced growth path. If we return to Graph 3 and examine the evolution of productivity change, we see that it has an absolutely "serene" behavior. Here probably lies the greatest contribution of the approach combining stochastic production frontier estimation and the Bauer-Kumbhakar decomposition: it allows us to separate the effects of random shocks from the other TFP components. All the other TFP components have a clear trend, with little fluctuation, except perhaps for allocative efficiency, which responds to policies.

The specification of the stochastic frontier model with two error components, each with one type of probability distribution, allows us to estimate the component of technical inefficiency and to evaluate the magnitude of the random component, as a residual. In fact, it is possible even to evaluate if the assumptions of a normal truncated distribution for the technical efficiency component and of normal distribution with zero mean for the random component describe well the behavior of the observed data. The analysis of the residuals shows that the presumption of normal distribution with zero mean seems to suit the data well.

The fourth stylized fact points out that production factors tend to flow towards the same direction and as a consequence economic activity is quite concentrated. This is valid not only among countries but also within them (regions, states and cities). If there were no productivity differences, the trend would be exactly the opposite, i.e., that of an even distribution of factors among the various countries, because of the presence of decreasing returns. Differences in policies could explain factor accumulation (regulation, tax structure, legal systems, public education, etc.). However, usually these policies have a nationwide scope and would not be helpful in explaining concentration within the nations. Easterly & Levine (2001) do not provide a single explanation for this phenomenon and argue that such stylized fact is consistent with existing explanations in terms of poverty traps, intra-group factors or geographical externalities, and is also consistent with explanations based on differences of productivity caused by technological differences.

The results of this article have shown that developing nations accumulate production factors at a much faster pace than that of developed nations and for this reason also grow faster. The model used presents a measure of scale effects for the sample countries that is intuitive but not fully consistent with the notion of concentration of economic activity, because there are a number of developing economies that presented increasing returns to scale (India, Indonesia, Brazil and Mexico, to name a few). However the magnitude of the scale effects estimated is not up to the task of explaining the fourth stylized fact identified by Easterly & Levine (2001).

The fifth and last stylized fact states that policies implemented by nations have a relevant impact on long-term growth rates of these nations. The authors try to show that variables related to policy decisions of nationwide scope, such as education, degree of trade and financial liberalization, and the size of the government, among other factors are related to countries' growth rates and to TFP. Changes in government policy have a fundamental impact on allocative efficiency. As seen, the results presented in this study show the great importance of allocative efficiency change in productivity change, and consequently in growth rate variations of these countries.

To sum up, the results show that the use of production frontiers, with flexible specification and TFP decomposition, seem to be quite promising for the study of aggregate productivity. With a clear economic interpretation and the advantage of separating random shocks from the regular behavior of the economies, the approach using stochastic frontiers seems to be up to the task of providing a broad range of explanations on economic growth.

Appendix

The likelihood ratio statistic is given by $\lambda = -2[\hat{L}_R - \hat{L}_{NR}]$, where $\hat{L}_R$ e $\hat{L}_{NR}$ are, respectively, the estimated log-likelihood of the described model and of the non-restrict model. The table below summarizes the tests performed. The null hypothesis under question is always that the model identified in the matrix column is nested in the model of the matrix line. The LR statistic has a χ^2 (DF) type distribution, where DF shows the difference in the degrees of freedom among the various models. If the value expressed in the cell of the statistics matrix is greater than the critical value, then the null hypothesis cannot be rejected, otherwise it can be rejected.

Table A.1 Likelihood ratio tests

Model	Full translog	Harrod Neutral	Solow Neutral	Hicks Neutral	TL w/o technical progress	Cobb - Douglas	Cobb – Douglas W/o technical progress
Full translog	--	19.69 $\chi^2(1)$	4.55 $\chi^2(1)$	19.71 $\chi^2(2)$	33.43 $\chi^2(4)$	110.01 $\chi^2(6)$	152.21 $\chi^2(7)$
Harrod Neutral	--	--	NC	0.01 $\chi^2(1)$	13.74 $\chi^2(3)$	90.32 $\chi^2(5)$	132.51 $\chi^2(6)$
Solow Neutral	--	--	--	15.15 $\chi^2(1)$	28.88 $\chi^2(3)$	105.46 $\chi^2(5)$	147.65 $\chi^2(6)$
Hicks Neutral	--	--	--	--	13.72 $\chi^2(2)$	90.31 $\chi^2(4)$	132.50 $\chi^2(5)$
TL w/o technical progress	--	--	--	--	--	NC	118.78 $\chi^2(3)$
Cobb – Douglas PT	--	--	--	--	--	--	42.20 $\chi^2(1)$
Cobb –Douglas w/o PT	--	--	--	--	--	--	--

Note: NC = not comparable; TL= translog; Cobb-Douglas PT = with time trend; Cobb-Douglas w/o PT = without time trend.

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