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Research Article

Productivity of Nations: A Stochastic Frontier Approach to TFP Decomposition

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This paper tackles the problem of aggregate TFP measurement using stochastic frontier analysis. We estimate a world production frontier for a sample of 75 countries over a long period. The "Bauer-Kumbhakar" decomposition of TFP is applied to a smaller sample in order to evaluate the effects of changes in efficiency (technical and allocative), scale effects, and technical change. Estimated technical efficiency scores are compared to productivity indexes offered by nonfrontier studies. We conclude that differences in productivity are responsible for virtually all the differences of growth performance between developed and developing nations and that a large part of this is due to allocative efficiency.

1. Introduction

This paper uses an alternative way of measuring total factor productivity based on stochastic frontier analysis (SFA). The great advantage of SFA is the possibility that it offers of decomposing productivity change into parts that have straightforward economic interpretation.

Previous studies have attempted to evaluate the efficiency and productivity growth of nations in the context of the so-called technical inefficiency literature, most of which using data envelopment analysis (DEA) techniques for a sample of OECD countries (e.g., Färe et al. [1]). Deliktas and Balcilar [2, 3] have used SFA but in the context of a somewhat restricted time period of analysis (1991–2000) which permits a more comprehensive sample of countries (130-country frontier). However, they do not analyze or provide results about efficiency levels or rates of change of efficiency (or any other component of TFP change) for the great majority of such countries, focusing their analysis only on 25 transition countries. They do not study the role of allocative efficiency either.

The main contribution of our paper is to show that a suitable decomposition of TFP can be applied to a fairly large sample of heterogeneous countries for an extensive period of time in order to evaluate not just the roles of technical progress and technical efficiency change, but also scale and allocative efficiency change as determinants of long-term growth. We are not aware at this time of any other SFA study that has produced quantitative results showing that allocative efficiency plays an important role in the economic growth of nations.

The stochastic frontier model used in this article assumes the existence of technical inefficiency which evolves following a particular behavior. This allows one to split productivity changes into (i) the change in technical efficiency, which measures the movement of an economy towards (or away from) the production frontier, and (ii) 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 (Bauer [4], Kumbhakar [5]) may then be applied, allowing the additional measurement of changes in allocative efficiency. Our results show that this last component, together with technical change, explains a large portion of the differences in economic growth between developed and developing countries.

In the next section, we present the hypotheses behind the stochastic frontier estimation and TFP decomposition. Section 3 presents the estimates of the world stochastic production frontier and discusses the technical efficiency scores obtained comparing them to productivity indexes suggested by Islam [6] and Hall and Jones [7]. Technical progress and returns to scale estimates are also discussed. In Section 4, we use the estimates of the previous section in order to decompose TFP change from 1965 up to 2000. The role of technical progress and allocative efficiency change in economic growth of both developed and developing nations is highlighted in Section 5. At last, in Section 6, we discuss the contribution of these results for the recent debate about the sources of economic growth and the nature and role of TFP components.

2. SFA and TFP Decomposition

The approach adopted in this paper is that developed in the literature on technical efficiency and productivity, more specifically in the "statistical" and "parametric" branches of this literature, which is known as *Stochastic Frontier Analysis* (SFA). 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 usual) by a time trend and interactions of the regressors with time. The model used here is essentially that developed (independently) by Aigner et al. [8] and by Meeusen and van den Broeck [9]. Their formulation was extended by Pitt and Lee [10] and Schmidt and Sickles [11] for the panel data case. Since these two last mentioned studies, a number of enhancements have been suggested, such as that of Battese and Coelli [12], in which the technical inefficiency is modeled so as to be time variant. A thorough compilation of this literature is found in Kumbhakar and Lovell [13].

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

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

The $\mathbf{v}$ and $\mathbf{u}$ terms (vectors) represent different error components. The first one refers to the random part of the error, while the second 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 stochastic frontier of production and $\mathbf{v}$ 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 level of technical efficiency (TE), that is, the ratio of observed output to potential output (given by the frontier) is captured by the component $\exp(-u)$ (note that $\mathrm{TE}_{it} = y_{it}/\exp(x_{it}\beta) = \exp(x_{it}\beta - u_{it})/\exp(x_{it}\beta) = \exp(-u_{it})$ and, therefore, $0 < \mathrm{TE} < 1$). For each country i and each time period t, we have

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

Once it is assumed that $v \sim iid\, N(0, \sigma^2)$; $u \sim \mathrm{NT}(\mu, \sigma_u^2)$, that is, u has a normal-truncated distribution (with a nonnull average μ) the two error components are independent of each other and x is supposed exogenous, the model can be estimated by maximum-likelihood (ML) techniques and the restriction of a half-normal distribution ($\mu = 0$) can be tested. Given these conditions, the traditional asymptotic properties of the ML estimators hold. In addition, we take the technical inefficiency component as time-variant, as suggested by Battese and Coelli [12]:

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

Other parameterizations of $\mathbf{u}$ are possible but we will not pursue them here (see, e.g., Kumbhakar [14], Cornwell et al. [15], Lee and Schmidt [16]).

In expression (3), $\tau(i)$ 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 behavior of technical inefficiency over time. When η is not significantly different from zero, technical inefficiency does not vary in time (persistent inefficiency). This specification of the behavioral pattern of inefficiency is somewhat inflexible, as the model's architects themselves admit. According to the formulation, technical inefficiency must; grow at decreasing rates ($\eta > 0$) or decrease at increasing rates ($\eta < 0$). Moreover, the estimated value for η is the same for all countries in the sample, which means that the pattern of inefficiency rise or reduction is the same for all countries. Despite these limitations, we believe the model can still bring very interesting insights into the patterns of economic growth of nations.

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

$$\begin{aligned} \ln y_{it} = {} & \beta_0 + \beta_t \cdot t + \beta_K \ln K_{it} + \beta_L \ln L_{it} + 0.5 \cdot \beta_{tt} \cdot t^2 \\ & + 0.5 \cdot \beta_{KK} (\ln \mathrm{K}_{it})^2 + 0.5 \cdot \beta_{LL} (\ln L_{it})^2 \\ & + 0.5 \cdot \beta_{KL} (\ln K_{it}) \cdot (\ln L_{it}) + \beta_{Kt} [(\ln K_{it}) \cdot t] \\ & + \beta_{Lt} [(\ln L_{it}) \cdot t] + v_{it} - u_{it}. \end{aligned} \tag{4}$$

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 partial differentiation of the deterministic part of (4) with respect to time.

Bauer [4] and Kumbhakar [5] suggested a quite ingenious, yet simple, type of productivity decomposition which goes beyond the division of productivity changes into a catchup effect and a technical innovation effect. Such framework also accounts for scale effects and inefficient allocation of productive factors. To perform this decomposition, we must first estimate the model depicted by (3) and (4). Then, it is possible to "compose" the rate of total factor productivity change from the results. In the expressions that follow, dots over variables indicate time derivatives, g_{TFP} denotes the rate of TFP growth, s_K and s_L are the shares of capital and labor in aggregate income, and ε_K and ε_L are output elasticities with respect to the factors of production.

The components of productivity change can be identified from algebraic manipulations from the deterministic part of the production frontier depicted in (2) combined with the usual expression for the productivity change Divisia index:

$$g_{\mathrm{TFP}} = \frac{\dot{y}}{y} - s_K \frac{\dot{K}}{K} - s_L \frac{\dot{L}}{L}. \tag{5}$$

From the deterministic part of (2), we have

$$\frac{\dot{y}}{y} = \frac{\partial \mathrm{lnf}(t, K, L, \beta)}{\partial t} + \varepsilon_K \frac{\dot{K}}{K} + \varepsilon_L \frac{\dot{L}}{L} - \frac{\partial u}{\partial t}. \tag{6}$$

In the expressions that follow, RTS denotes returns to scale with RTS $= \varepsilon_K + \varepsilon_L$, g_K is the growth rate of capital ($\dot{K}/K$) and g_L is the growth rate of labor ($\dot{L}/L$); $\lambda_K = \varepsilon_K/\mathrm{RTS}$ and $\lambda_L = \varepsilon_L/\mathrm{RTS}$ are defined as normalized shares of capital and labor in income. Combining (5) and (6), we have

$$\begin{aligned} g_{\mathrm{TFP}} &= \mathrm{TP} - \dot{u} + (\mathrm{RTS} - 1) \cdot [\lambda_K \cdot g_K + \lambda_L \cdot g_L] \\ &\quad + [(\lambda_K - s_K) \cdot g_K + (\lambda_L - s_L) \cdot g_L]. \end{aligned} \tag{7}$$

That is, total factor productivity growth can be split into four elements:

(i) technical progress, measured by TP $= \partial \ln f(t, K, L, B)/\partial t$;

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

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

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

We can now study the impact of each of the components of TFP. If the technology is immutable, it does not contribute 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 change of productivity.

The contribution of economies of scale depends both on technology as well as on factor accumulation. The presence of constant returns to scale (RTS = 1) cancels out the third component on the right of (7). 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 $(\lambda_K - \mathrm{s}_K)$ and $(\lambda_L - \mathrm{s}_L)$ 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. Estimation of the World Stochastic Frontier (1950–2000)

The model estimation was conducted using statistics software STATA, which includes among its preprogrammed models that of Battese and Coelli [12]. The database for this study consists of a nonbalanced 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. Data for factor shares were obtained from the *System of National Accounts* 1968 (SNA68, United Nations [17]) and from the *Annual National Accounts* of OECD (OECD [18]). Since the construction of a database that proved useful for conducting aggregate productivity analysis using SFA techniques seems to be an important contribution of this study, we choose not to just briefly describe the data and sample here, but to do it more extensively in Appendix A.

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 such restrictions are valid or not. These statistics are presented in Appendix B. As a general result of these tests, we can say that the statistics favor the (complete) translog functional form.

Results for the translog specification are presented in Table 1. All parameters are significant at 5%, except for the capital elasticity of output, 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 a half-normal distribution). The estimated value of η is positive, which means that technical efficiency grows at decreasing rates (catchup).

β_{KL} 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 nonneutral part of technical progress offsets these effects. The signs of β_{Kt} and β_{Lt} indicate, respectively, that the nonneutral part of technical progress goes hand in hand with capital accumulation (positive sign of β_{Kt}), and inversely with labor supply (negative sign of β_{Lt}), that is, technical progress is laborsaving and is more intense in countries where capital is abundant.

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 does indeed seem odd, two aspects must be kept in mind: (i) these results are "conditional" on the capital-labor ratio;

Table 1: Time-variant inefficiency model (Battese and coelli [12]).

Number of observations = 746 Number of countries = 75					Observations per country: minimum = 3 Average = 9.9, maximum = 11	
Log likelihood = 272.07096					Wald χ^2 (8) = 14,540.41 Prob > χ^2 = 0.0000	
$\ln y$	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_L	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_{LL}	0.0572	0.0216	2.6500	0.0080	0.0150	0.0995
β_{KL}	−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_{Lt}	−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
ilgtγ	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

(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 (Farrel [19]), a country such as Nicaragua is closer to the frontier, yet it is placed at the "edge" of the unit isoquant closest to labor axis (lots of labor, scarce capital), 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 aspect or caveat means that the productivity rank reflects the efficiency in producing nontradables. When the value of technical efficiency is converted by the PPP factor, we have production efficiency evaluated at tradables' prices. This adjusted TE ranking is displayed next to the first one in Table 2 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. The numbers refer to the last subperiod in our sample (1995–2000).

An interesting exercise is to compare our ranking to the productivity indexes suggested by Islam [6] and Hall and Jones [7], which are traditional studies that do not use the frontier approach. Such indexes are also displayed in Table 2. The numbers of Hall and Jones [7] are obtained using a variation of the Solow residual calculation. They do a cross-sectional comparison with a base country, namely, USA, for year 1988 (USA = 1,000). The numbers from Islam [6] are obtained using a nonfrontier panel data approach, which also stipulates USA as a base of comparison (USA = 1,000). Islam's scores are averages for the period 1960–85. For a detailed explanation of the indexes calculated by these authors, we refer the reader to the original papers (Hall and Jones [7] Islam [6], and also to the survey provided by Islam [20], which compares the two of them.) Our main concern here, however, is not to analyze the absolute value of the indexes, but to compare how countries rank in each approach.

As for the argumentation above, our adjusted index of technical efficiency seems better suited for such comparisons, because it displays the efficiency scores in international US$. This index is highly correlated with those suggested by the authors mentioned above, with the advantage that the ranking 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 and Jones [7], for whom countries like Syria, Jordan, Mexico, and Brazil are listed among the most productive economies, or as in Islam [6], in which Hong Kong is considered the most productive nation: 53.7% more productive than the United States.

The results for RTS are also 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, GreatBritain, Italy, and France, all of them

Table 2: Rankings: technical efficiency, returns to scale, and technical progress.

Rank	Technical efficiency (US$, PPP)*		Technical efficiency (US$)*		Hall and Jones [7]		Islam [6]		Returns to scale*		Technical progress*	
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%

Table 2: Continued.

Rank	Technical efficiency (US$, PPP)*		Technical efficiency (US$)*		Hall and Jones [7]		Islam [6]		Returns to scale*		Technical progress*	
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%

Source: Islam [20], Table 11.3 page 485–488], and own estimations. Hall and Jones indexes depicted here are equal to exp (log A), in Table 9 of Hall and Jones (1996) [7].
(*) Annual average rates 1996–2000. Three countries were left out due to lack of information for this subperiod.

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. (Although most of the numbers for Technical progress (TP) in Table 2 are negative, they refer only to the last subperiod of our sample, that is, 1996–2000. TP presented a pattern in which it starts positive and then shows a decaying trend along the subperiods in the sample.) Nonetheless, the ordering seems to match our intuition regarding the technological performance of nations. At the top positions are Japan, United States, Germany, and France. Among the countries at the bottom are the African nations, wellknown 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. Figure 1(a) brings a scattered diagram for the technical progress measure and the natural logarithm of R&D expenses (average for 1990–2000) and shows us what seems to be, at least at first sight, a positive relation between these variables. Figure 1(b) plots the measure of technical progress against the average education level of the population revealing 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). The results are presented in Appendix C and suggest that frontier models may be better suited for the analysis of productivity in comparison with traditional econometric methods.

4. The Behavior of TFP and Its Components

With the results obtained in Section 3 for the 75-country sample, and the data on functional distribution of income (s_K and s_L), it is possible to decompose productivity change in the manner shown in Section 2. However, data for factors shares in income are not available for all these economies.

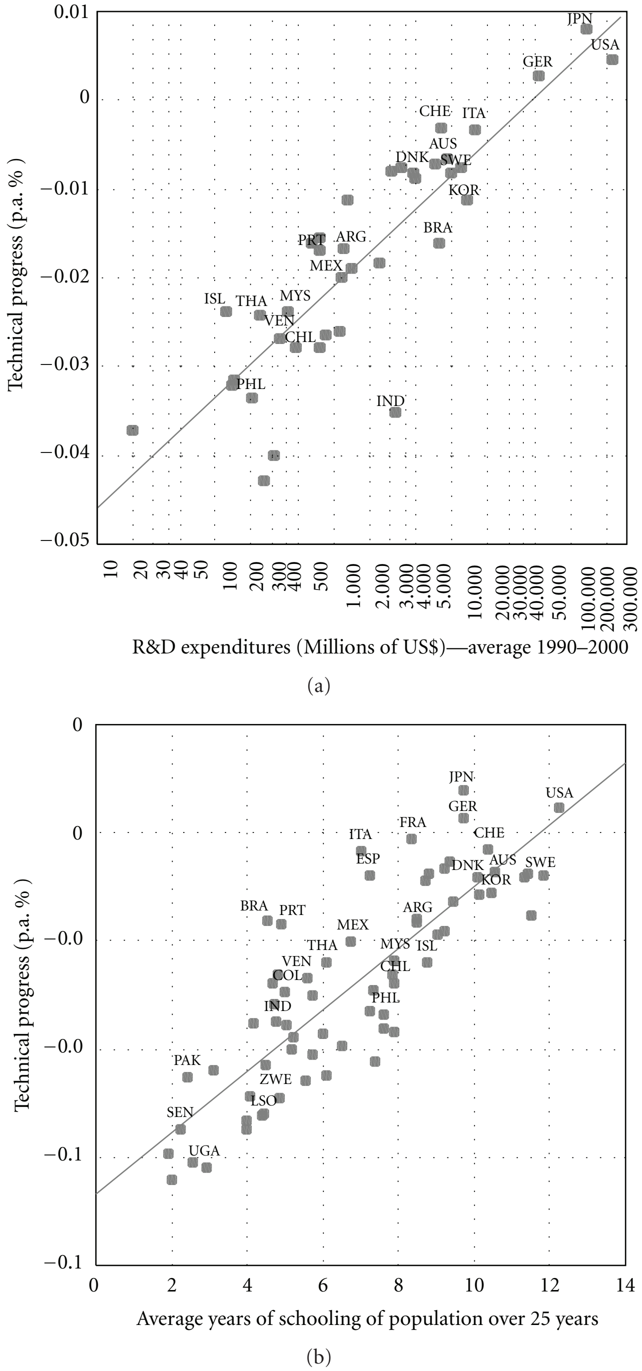

Figure 1: R&D Expenditures, human capital and technical progress. Sources: own estimations and World Development Indicators (World Bank) for R&D and Schooling. Technical progress rates are averages for 1996–2000.

We managed to collect data for only 36 of the 75 countries in the sample, and just from 1970 up to 2000. The full decomposition of TFP is then restricted to this group and period. Table 3 brings the results.

Examination of average productivity change numbers along the 30 years in question shows some interesting results. All top positions are occupied by OECD countries. Among them, Japan's performance stands out, with an averageannual productivity growth rate of 2.42%. The countries that follow 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 an average rise in productivity of 0.39% per year. Among the other Latin American countries in 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 for which technical progress (TP) showed the greatest impact on productivity growth were Japan, the United States, France, Switzerland, Italy, United Kingdom, The Netherlands, and Australia, in this order. Contributions of TP for this group of countries ranged from 0.56 to 0.30 percent per year, on average. As we can see, they are all developed nationsthat invest substantial amounts in R&D.

Among the 19 countries that presented positive contributions of technical progress, 18 are OECD members (see Table 3). As mentioned before, for many countries, the last subperiod (1996–2000) reveals negative technical progress (as shown in Table 2). Notwithstanding that, in Table 3, we depict positive average annual contributions of TP to growth for 19 countries (of the total 36). These numbers are averages calculated for the longer period 1970–2000.

Brazil is the only member of OECD 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 (other authors also report this kind of result using frontier techniques—Rao and Coelli [21] is an example). 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 [22], 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 circumstances or decisions 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

Table 3: Sources of economic growth 1970–2000: average annual % change.

Country	[1]Economic growth	[2]Capital accumulation	[2]Labor expansion	Productivity change					Random[3] shocks
				TFP	Technical progress	Technical efficiency	Scale effects	Allocative efficiency	
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

(1) Growth of GDP; (2) Growth rates adjusted by income shares; (3) Obtained as a residual.

highly productive sectors to others, where productivity is lower. To test this hypothesis is beyond the scope of this paper and would require an analysis disaggregated by sectors of activity (an interesting example of a disaggregate study is Kim and Han [23], which analyses several South Korean industries using the Bauer-Kumbhakar decomposition).

All countries enjoyed rising technical efficiency as shown by the positive numbers in Table 3. That is a characteristic of the estimated model. The Battese and Coelli [12] model imposes the restriction of a common η to all countries. In the sample including all 75 countries, the estimated value for this parameter was positive, which resulted in a catchup pattern for all countries: technical efficiency grows at decreasing rates. The countries that had the largest catchups 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 and educate their people. For the other countries, however, 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, revealing 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 low technical efficiency improvements are the United States and Canada which is reasonable, since both these nations are already close to the frontier. They are in fact pushing the frontier further.

It is plausible to suppose that countries with vast masses of population are those set to gain the most from scale effects. That is exactly the result obtained, with Brazil, South Korea, Thailand, Mexico, Japan, Turkey, and the USA showing large numbers for this component. All of them but Japan and the USA are usually referred to as "developing" nations and have surely experienced leaping growth during some subperiods of the sample, most of which based on factor accumulation. This accumulation also paved the way to productivity growth based on scale. It is 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 and 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 reflect either an approximation or a departure of the value of the estimated shares of income factors (λ_K and λ_L) from 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 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 the II National Development Plan was being implemented and government played an important role 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.

Figure 2 shows the evolution of total factor productivity change 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, that is, 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 1980s to the mid 1990s, this tendency reverses and begins to contribute to productivity growth, even if very little. After that period, the contribution turns negative again, but not as large as in the first five-year periods under study. Mexico also reduces the negative allocative effects as of the mid 1980s, but never enough to contribute to a rise in productivity. For those two countries, the improvement in allocative efficiency roughly coincides with market-oriented reforms. A significant relationship between such phenomena remains to be tested though. On the other hand, Figure 2 also shows that rich nations such as France, the United States, and Japan have persistent gains with allocative efficiency.

5. The Role of Technical Progress and Allocative Efficiency in Economic Growth

We will now take a closer look at the differences in economic growth patterns of developed and developing nations. Table 4 and Figure 3 bring results on the sources of growth for those two groups of countries. 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 displays annual averages for each five-year period and also for the whole thirty-year period.

We see that developing nations grew more than developed ones (18.2%). This happened because both capital accumulation and 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 considerably 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

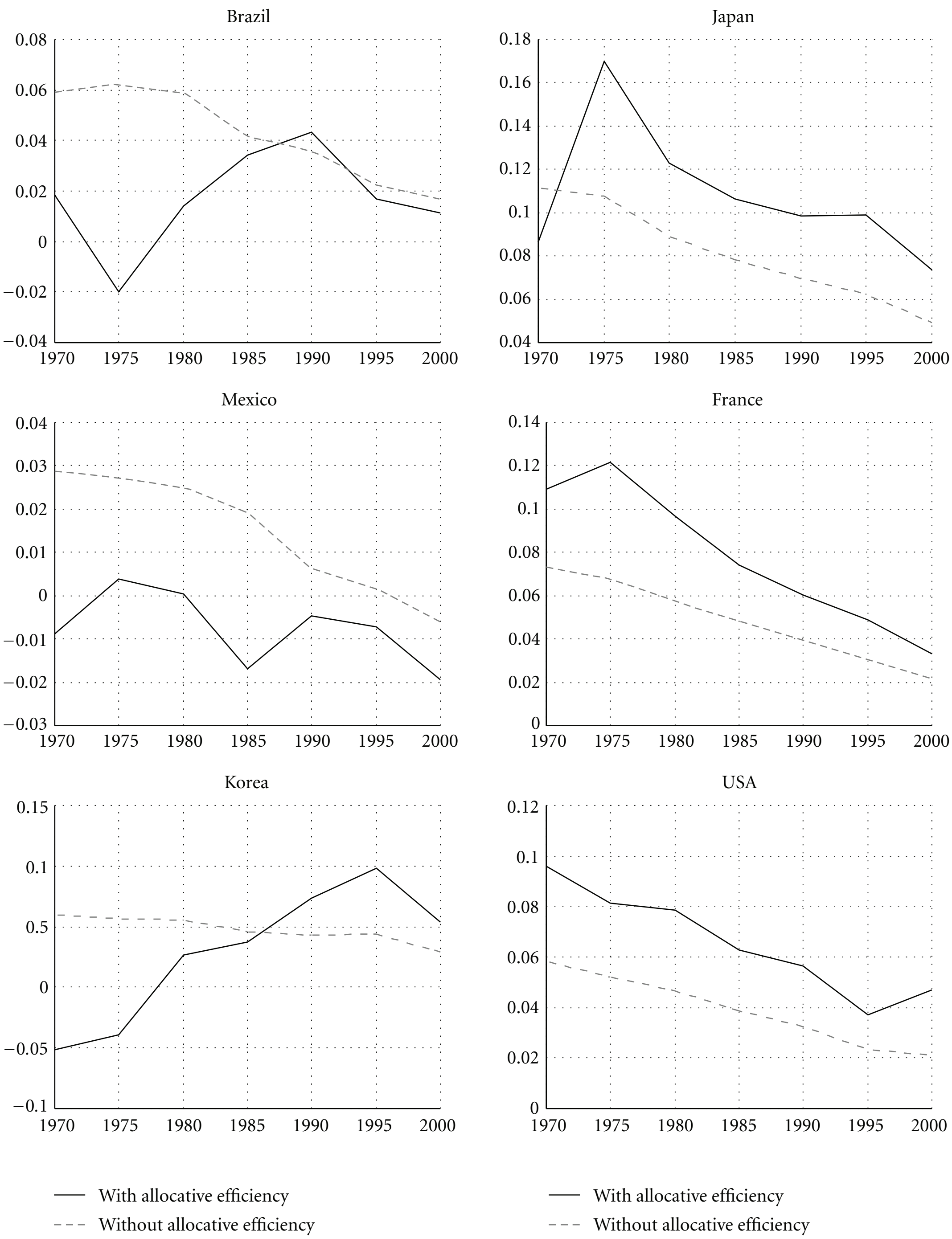

Figure 2: Total factor productivity change, with and without allocative efficiency.

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

Table 4: Sources of economic growth per group of countries and subperiods: % change.

Variable	Group of countries*	Annual averages in the sub-periods 1966–1970	1971–1975	1976–1980	1981–1985	1986–1990	1991–1995	1996–2000	Annual average	Accumulated
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 scale efficiency	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 values in this table were calculated by taking simple arithmetic averages over the countries comprising each group of the rates of change for each subperiod. The accumulated effects as well as the annual average numbers were computed by compounding (or discounting) rates. The relative factor prices and relative marginal productivity of each period used in our calculations refers to the last year of the 5-year interval; for example, the values of s_K, s_L, λ_K, and λ_L used to estimate the allocative efficiency changes between 1966 and 1970 refer to 1970.

divergence between the standards of living of the two groups. 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 and their motivation explored. The remarks made at end of Section 4 are speculations on this topic and relate these common aspects to policy.

The allocative nature of policy effects is captured in a rather informal way in Figure 4, where the measure of allocative efficiency estimated here is plotted against two indicators (that, hopefully, do reflect policy). One is the Governance Index developed by Kaufmann et al. [24] and the other is the degree of capital account openness, according to the measure suggested by Santana and Garcia [25]. As expected, the economies with better governance in 1998 enjoyed less distortions and consequently greater allocative gains between 1995 and 2000 as depicted in Figure 4(a). Figure 4(b) plots the allocative efficiency measure against the openness index mentioned (for 33 of the 36 economies) from 1970 to 2000. Here, we have five-year changes in these two measures, and we can see that reduction in barriers to capital flow seems to be associated with improvements in allocative efficiency.

6. SFA and Recent Issues in the Economic Growth Literature

Two excerpts from contemporary remarks made by Robert Solow reveal that much remains to be clarified regarding

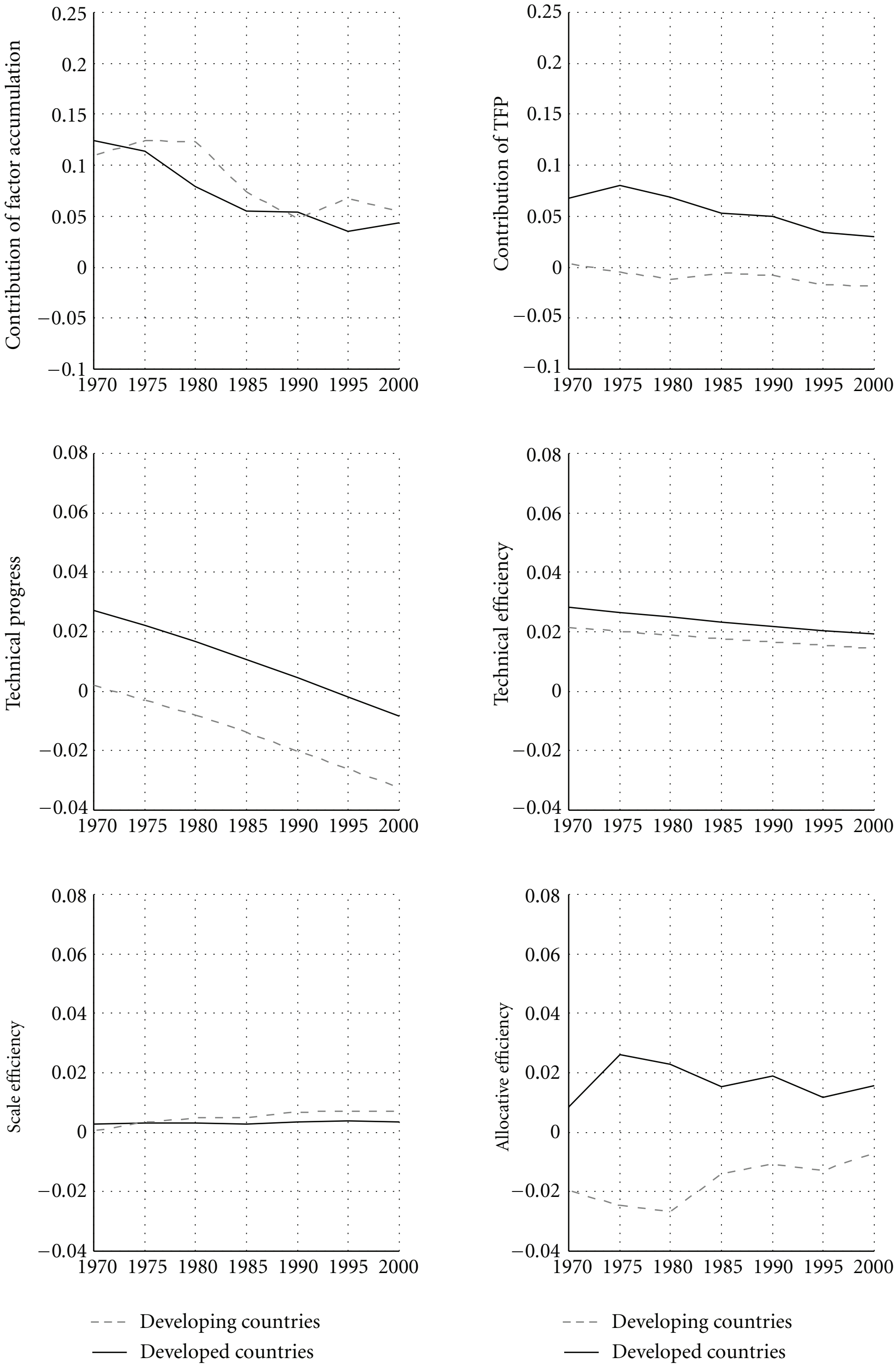

Figure 3: Sources of growth by group of countries (% changes).

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 do not 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,"*

Solow [26],

> *"...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 [27],

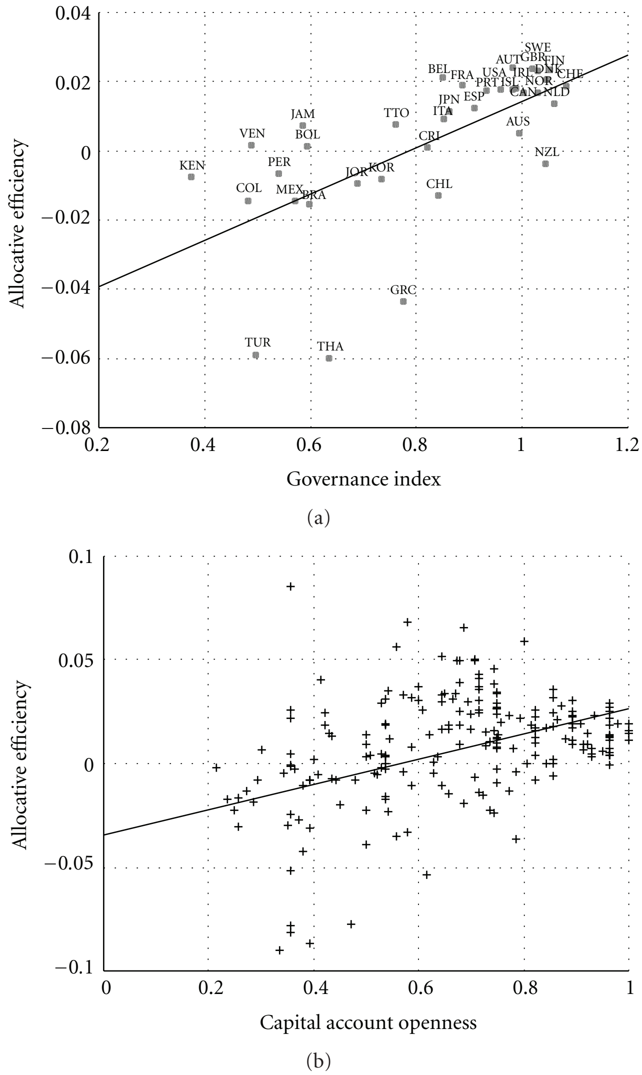

FIGURE 4: Governance, financial liberalization and allocative efficiency. Sources: Kaufmann et al. [24] for the governance index; Santana and Garcia [25] for openness index; and own estimations of allocative efficiency.

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 technical efficiency contributed with a small accumulated growth of 2.1 percentage points, an unsatisfactory performance which is at least in part due to relatively small investments in R&D made by poor nations.

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)—roughly about 60% of these differences. The pattern of technical progress is behind the other 40% of the gap. These facts suggest 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 inefficiency reduction, the results of this 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 first statement quoted above goes on to identify and briefly describe the nontechnological sources of productivity mentioned (see Solow [26], page. 8). The examples given by him 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 in his thinking, 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 and Levine [28] added fuel to the existing controversy among the scholars currently discussing the "sources of economic growth," on the relative importance of factor accumulation and productivity. The underlying objective of their work 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. The terminology neoclassical revival is due to Alwyn Young. It is used by Klenow and Rodríguez-Clare [29] to qualify a body of studies that tries to counter the new growth theory and is associated to the hypothesis that the differences among nations in levels and in per-capita income change are caused by differences in physical and human capital accumulation. Some examples of this line of work are Mankiw et al. [30], Young [31, 32] and Barro and Sala-i-Martin [33]. Easterly and Levine [28] 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 among the various countries in per-capita income levels and per-capita income growth rates. 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 the 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 and Rodríguez-Clare [29] 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, because 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 and Rodríguez-Clare [29] 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 studies closer to each other.

Regarding income per capita, the difference between rich and poor nations is the second stylized fact pointed out by Easterly and Levine [28]. According to them, 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 [34] argues, however, that institutional frameworks (such as tax structure, protectionism, lack of property rights,) may reduce the accumulation of physical and human capital. In line with the ideas suggested by Easterly and Levine [28], 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 list of Easterly and Levine [28] 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 output.

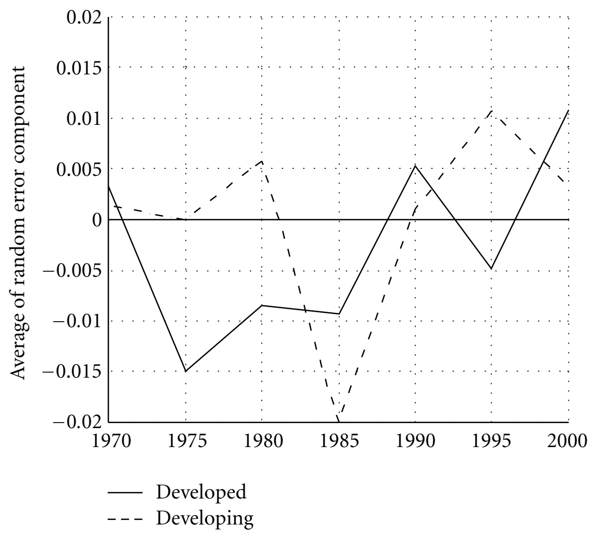

Figure 5: Average random error component by group of countries, 1970 to 2000.

Robert Solow (Solow [26]) argues 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 control for weather changes or pests. Demand fluctuations are another source of deviation of output from its balanced growth path. If we return to Figure 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. (In fact, it is even possible 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 obtained in our estimations reveals that the presumption of normal distribution with zero mean seems to suit the data well.) All the other TFP components have clear trends, with little fluctuation, except perhaps for allocative efficiency, which responds to policies.

In evaluating the random shocks obtained as a residual and depicted in Figure 5, one can easily provide an interpretation for their behavior in terms of demand fluctuations following unexpected events. We can associate, for instance, the downturn in the second half of the seventies to the oil crises of 1974 and 1979 and the long recession period of the eighties in developing countries to the debt crisis following the Mexican default in 1982.

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, that is, 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 and Levine [28] 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, intragroup 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. Although the estimated measure of scale effects for developing economies came up suggesting increasing returns to scale (for India, Indonesia, Brazil, and Mexico, to name a few), the magnitude of these effects is not up to the task of explaining the fourth stylized fact identified by Easterly and Levine [28].

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 size of the government, among other factors, are related to countries' growth rates and to TFP. This is consistent with our results since changes in government policy have fundamental impacts on allocative efficiency. We believe to have shown the great importance of allocative efficiency change in productivity change, and consequently in growth rate differences.

With a clear economic interpretation and the advantage of separating random shocks from the regular behavior of the economies, the stochastic frontier approach combined with flexible functional forms (for production frontiers) and the TFP decomposition described here seems to be a promising way of looking at aggregate productivity, one up to the task of providing a broad range of explanations in the field of economic growth.

Appendices

A. Data and Sample

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 used 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 (L), 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 (*pop*), an average is computed that attributes a weight of 1 to people older than 15 ($pop15^{+}$) and 0.5 to people aged up to 15 ($pop15^{-}$). That is, $pequa = (pop15^{+}) \times 1 + (pop15^{-}) \times 0.5$. 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*), that is, $L = (rgdpch/rgdpeqa) \cdot pop = (\text{GDP}/pop) \cdot (peqa/\text{GDP}) \cdot pop$.

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*). A country-by-country detailed analysis of the two series suggests that *peqa* 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. 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 its components, which are 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.

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 and Soto [35] 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 capital stock values undergo PPP adjustment, these effects are exacerbated.

Factor shares s_K and s_L were basically obtained from two databases: (i) Annual National Accounts from OECD, which brings information from 1970 to 2000 for 30 members of that organization; and (ii) the *System of National Accounts* 1968 (SNA68) from the United Nations. 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 estimates, though). Information pertaining to non-OECD countries were obtained mostly from SNA68.

Data for some countries were not available in SNA68 (usually those relative to the first and the last years of the sample). For these countries, we tried other sources. Among them, we can name the Economic Commission for Latin America and the Caribbean (ECLAC) for data pertaining to Bolivia (2000), Costa Rica (2000), Trinidad and Tobago (2000), Jamaica and Peru (1995 and 2000), and MIDEPLAN (Ministerio de Planificación y Cooperación) for data of Chile (1975 to 1985 and 2000). For Bolivia and Costa Rica the numbers for 2000 are actually those of 1999 (the closest available). 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 display that information. For Brazil, data used are from the local official statistical bureau, Instituto Brasileiro de Geografia e Estatística (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 of 30 continuous observations per country was set. Therefore, of the 203 economies listed in the PWT 6.1, 86 countries 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 (Hong Kong was kept in the sample, though), were also excluded. The group of 86 excluded nations also comprises 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 "good quality" information dating back to 1950.

Of the remaining 112 economies, other 13 were excluded because of lapses in the historical series caused by wars, civil wars, or splitups. In these cases, the estimation of capital stock using the perpetual inventory method 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 Congo (formerly Zaire). 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, Cameroon, Congo, Cote D'Ivoire, Fiji, Mauritius, 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, 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, the selection should actually favor more precise estimations, as the excluded economies generally have a low "grade" in the ranking provided by the PWT in regard to data quality (see Heston et al. [36], Table A, p. 13).

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, which can be better addressed by more spaced time observations. Forbes [37], 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 less reliable capital stock numbers for the first years of the series. 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 the numbers appear to be too small 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

Table 5: Likelihood ratio tests.

Model	Full Translog All $\beta s \neq 0$	Harrod Neutral	Solow Neutral	Hicks Neutral	Translog without TP	Cobb-Douglas with TP
Harrod Neutral	19.69	—	—	—	—	—
$\beta_{Kt} = 0$	χ^2 (1)					
Solow Neutral	4.55	NC	—	—	—	—
$\beta_{Lt} = 0$	χ^2 (1)					
Hicks Neutral	19.71	0.01	15.15	—	—	—
$\beta_{Kt} = \beta_{Lt} = 0$	χ^2 (2)	χ^2 (1)	χ^2 (1)			
Translog without TP	33.43	13.74	28.88	13.72	—	—
$\beta_t = \beta_{tt} = \beta_{Kt} = \beta_{Lt} = 0$	χ^2 (4)	χ^2 (3)	χ^2 (3)	χ^2 (2)		
Cobb-Douglas with TP	110.01	90.32	105.46	90.31	NC	—
$\beta_{tt} = \beta_{Kt} = \beta_{Lt} = \beta_{KL} = \beta_{KK} = \beta_{LL} = 0$	χ^2 (6)	χ^2 (5)	χ^2 (5)	χ^2 (4)		
Cobb-Douglas without TP	152.21	132.51	147.65	132.50	118.78	42.20
$\beta_t = \beta_{tt} = \beta_{Kt} = \beta_{Lt} = \beta_{KL} = \beta_{KK} = \beta_{LL} = 0$	χ^2 (7)	χ^2 (6)	χ^2 (6)	χ^2 (5)	χ^2 (3)	χ^2 (1)

NC = not comparable; TP = technical progress.

two (or three) observations of the series pertaining to 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.

B. Likelihood Ratio (LR) Tests

The likelihood ratio statistic is given by $\lambda = -2[\hat{L}_R - \hat{L}_{\mathrm{NR}}]$, where $\hat{L}_R$ and $\hat{L}_{\mathrm{NR}}$ are, respectively, the estimated log-likelihood of the described model and of the nonrestrict model. Table 5 summarizes the tests performed. The null hypothesis under question is always that the model identified in the matrix line is nested in the model of the matrix column. The λ statistic has a χ^2 (DF) distribution, where DF is the difference in the degrees of freedom between the models. If the value expressed in the cell of the matrix below is greater than the critical value, then the null hypothesis cannot be rejected, otherwise, it can be rejected. For example, testing if the Harrod Neutral model is nested in the Full Translog Model is the same as testing the restriction $\mathrm{H}_0 : \beta_{Kt} = 0$ in this last specification. Since the test statistic for the comparison between the restricted and unrestricted model is $\lambda = -2[262{,}224 - 272{,}071] = 19{,}69$ and the critical value at 1% is 6,64, we reject H_0 (which in turn means that we cannot reject the hypothesis that the Harrod Neutral model is nested in the Full Translog model).

C. Alternative Estimations

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). The results are presented below.

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 nonsignificant coefficients associated with time, capital stock, and the labor force: $p(\mathrm{z})$ = 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 explains the higher variance of technical efficiency and lower of technical progress (that turns 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 technical inefficiency was based on the Battese and Coelli [38] model, it might have been possible to control the effect of these short-term variations. There is also the possibility to follow the approach suggested by Cuesta [39], a task we intend to pursue in another enterprise.

The estimates produced by the traditional panel data fixedeffects and randomeffects models turned up 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 returns to scale vary a lot: 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 do not seem very reasonable: United States, Japan, and Germany show large technical regress at the same time that Trinidad and Tobago, Lesotho, and Jamaica have extraordinary technical progress. These resultssuggest that frontier models may be better suited for the analysis of productivity in comparison with traditional econometric methods.

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