The Global Trends of Total Factor Productivity

Evidence from the Nonparametric Malmquist Index Approach

by

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Abstract:

In this paper the Malmquist index of total factor productivity is applied to a sample of 87 countries observed over the period 1960-90. This index and the method needed to quantify it, the data envelopment analysis, has substantial advantages as compared to traditional growth accounting. Two of these advantages are that it does not rely on questionable equilibrium assumptions to merge multiple inputs into a single index and that the rate of total factor productivity growth can explicitly be decomposed into a measure of efficiency change and the rate of technological progress. Results are reported both in the form of growth rates and measures of relative productivity levels. In each case related labour productivity measures are calculated and the differences to the total factor productivity measures are analysed. Among the topics covered are the productivity slowdown, the Asian Miracle and the bimodality of the distribution of relative producitivity levels.

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1. Introduction

Since the emergence of endogenous growth theory (see Barro and Sala-i-Martin (1995) and Aghion and Howitt (1998) for booklength surveys) there has also been a renewed interest in empirical studies of real GDP growth rates and levels which is now manifest in the survey of Temple (1999) and the recent handbook article of Durlauf and Quah (1999). This has been enabled by the widespread availability of better and more complete data sets such as the Penn World Table that has complete time series of aggregate national accounts data for more than one hundert countries over the period 1960 to 1990 (see Summers and Heston (1991) for a description).

Empirical growth research over the last ten years has followed at least three distinct avenues. First, the most voluminous strand of literature runs linear regressions to explain the growth rate of real GDP per capita by a huge amount of different growth driving factors and simultaneously tries to estimate the rate of convergence of countries to their steady-state positions. Second, several studies supply new estimates of total factor productivity growth rates on an economy-wide level as a measure of technological progress. A third main approach of empirical growth investigates the dynamics of the whole distribution of real GDP per capita or per worker.

The present paper is related to the second and third avenues of empirical growth research. With respect to the second avenue we calculate total factor productivity growth rates not by traditional growth accounting but by a combination of two methods: the Malmquist index and nonparametric productivity measurement. Färe et al. (1994) have pioneered this approach for a limited sample of 17 OECD countries. This approach relies on much less stringent assumptions than growth accounting and the Malmquist index has the tremendous advantage of being decomposable in two factors that represent the change in productive efficiency and the rate of technological progress, respectively. Special attention is devoted to the different ways of aggregating inputs that growth accounting and the method used here employ. In addition to the presentation of rates of change we construct measures of relative productivity levels. There, the third avenue of empirical growth research comes into play in that the dynamics of the distributions of the various level measures are visualized by kernel density estimators.

The remainder of the paper is structured as follows. The following section discusses the Malmquist index and its empirical implementation by the data envelopment analysis. Section 3 describes the data and the sample of countries for which in section 4 the results for productivity change and in section 5 the results for the relative measures of productivity levels are presented. Section 6 concludes.

2. Nonparametric Productivity Measurement

Instead of growth accounting in this paper we use the Malmquist index to measure total factor productivity growth. Since there are very complete and assessible accounts of the Malmquist index and the related data envelopment analysis available elsewhere (see e.g. Charnes et al. 1994, Coelli et al. 1998, Färe/Grosskopf/Lovell 1994, Färe/Grosskopf/Roos 1998, Grosskopf 1993), the focus of the methodological discussion in this section is on one of the most important differences between the Malmquist index and the traditional growth accounting approach: how to chose the weights for the multifactor input index.

The Malmquist index of total factor productivity growth is stated as follows

$$M_h^{t+1}(\mathbf{x}_h^t, \mathbf{y}_h^t, \mathbf{x}_h^{t+1}, \mathbf{y}_h^{t+1}) = \left[\frac{D_h^t(\mathbf{x}_h^{t+1}, \mathbf{y}_h^{t+1})}{D_h^t(\mathbf{x}_h^t, \mathbf{y}_h^t)} \frac{D_h^{t+1}(\mathbf{x}_h^{t+1}, \mathbf{y}_h^{t+1})}{D_h^{t+1}(\mathbf{x}_h^t, \mathbf{y}_h^t)} \right]^{1/2}, \tag{2.1}$$

where the two inputs (capital K and labour L) of country h in period t are contained in the input vector $\mathbf{x}_h^t = (K_{ht}, L_{ht})'$ and the respective output (economy-wide output Y) is abbreviated as $\mathbf{y}_h^t = (Y_{ht})'$.[1] This Malmquist index is the geometric mean of two ratios of distance functions of the type

$$D_h^p(\mathbf{x}_h^q, \mathbf{y}_h^q) = (\sup\{\phi : (\mathbf{x}_h^q, \phi\mathbf{y}_h^q) \in S(p)\})^{-1}; \; p, q = t, t+1, \tag{2.2}$$

which give the reciprocal of the maximum augmentation of the output in period q (holding inputs constant) needed to reach a boundary point of the technology set

$$S(p) = \{(\mathbf{x}_h^p, \mathbf{y}_h^p) : \mathbf{x}_h^p > 0 \text{ can produce } \mathbf{y}_h^p > 0, \forall\, h = 1, ..., n\} \tag{2.3}$$

[1] Note that the Malmquist index is perfectly able to deal with any desired number of inputs and outputs.

in period p (conditions that the technology has to satisfy are given e.g. in Banker/Charnes/Cooper 1984). Constructed in this way, the Malmquist index indicates positive (negative) total factor productivity growth between the periods t and t+1 if it is larger (smaller) than 1.

One of the most fortunate features of this form of the Malmquist index is that it is decomposable into two factors which can be given a very illuminating economic interpretation:

$$M_h^{t+1}(\mathbf{x}_h^t, \mathbf{y}_h^t, \mathbf{x}_h^{t+1}, \mathbf{y}_h^{t+1}) = \underbrace{\frac{D_h^{t+1}(\mathbf{x}_h^{t+1}, \mathbf{y}_h^{t+1})}{D_h^t(\mathbf{x}_h^t, \mathbf{y}_h^t)}}_{EF_h^{t+1}} \underbrace{\left[\frac{D_h^t(\mathbf{x}_h^{t+1}, \mathbf{y}_h^{t+1})}{D_h^{t+1}(\mathbf{x}_h^{t+1}, \mathbf{y}_h^{t+1})} \frac{D_h^t(\mathbf{x}_h^t, \mathbf{y}_h^t)}{D_h^{t+1}(\mathbf{x}_h^t, \mathbf{y}_h^t)}\right]^{1/2}}_{TP_h^{t+1}} . \tag{2.4}$$

The first factor, EF, is interpreted as the change of productive efficiency between periods t and t+1, whereas the second factor, TP, is interpreted as the rate of technological change (see Färe et al. (1994) for more on this and a graphical illustration of a simple example). Improvements (deteriorations) of the factors between periods t and t+1 are again expressed by values larger (smaller) than 1.

To apply this theoretical device to real data for intputs and output a method for the quantification of the various distance functions (2.2) is needed. These calculations are usually performed by solving the linear programming problems of the data envelopment analysis (DEA) (here stated in the socalled output-oriented envelopment form under the assumption of constant returns to scale) for country h[2]

$$\begin{aligned} &\max_{\phi,\lambda} \ \phi_h \\ &\text{s.t.} \quad \phi_h Y_{hq} - \sum_{i=1}^{n} \lambda_i Y_{ip} \leq 0 \\ &\qquad\qquad\qquad \sum_{i=1}^{n} \lambda_i K_{ip} \leq K_{hq} \\ &\qquad\qquad\qquad \sum_{i=1}^{n} \lambda_i L_{ip} \leq L_{hq} \\ &\qquad\qquad\qquad \lambda_1, \ldots, \lambda_n \geq 0 \end{aligned} \tag{2.5}$$

and then setting $D_h^p(\mathbf{x}_h^q, \mathbf{y}_h^q) = \phi_h^{-1}$ for all $(p, q) \in \{(t,t), (t,t+1), (t+1,t), (t+1,t+1)\}$.

In this procedure the input-output combination each country in period q is compared with a piece-wise linear frontier production function that consists of the input-output combinations of

[2] See the first chapters of Charnes et al. (1994) or chapter 6 of Coelli et al. (1998) for comprehensive overviews of the various DEA models.

the most productive countries in period p. ϕ_h is increased as long as the first constraint is not violated and shows how much the output of country h in period q (holding capital and labour constant) can be increased in order to reach a virtual point on the frontier function constructed from the input-output combinations of all countries in period p. Thus each country in period q is compared to a virtual point on the frontier function that is constructed by a λ-weigthed linear combination of the inputs and ouputs of all countries in period p.

To see the differences of the Malmquist-DEA approach to traditional growth accounting with respect to the weighting of the inputs, we shift to the dual of the above program, that is, the output-oriented productivity form (also called multiplier form) of the DEA

$$\begin{array}{lllllll} \min\limits_{\mu_1,\nu_1,\nu_2} & \nu_1 K_{hq} & + \; \nu_2 L_{hq} & & & & \\ \text{s.t.} & \nu_1 K_{1p} & + \; \nu_2 L_{1p} & - \; \mu_1 Y_{1p} & \geq & 0 \\ & \vdots & \vdots & \vdots & & \vdots \\ & \nu_1 K_{np} & + \; \nu_2 L_{np} & - \; \mu_1 Y_{np} & \geq & 0 \\ & & & \mu_1 Y_{hq} & = & 1 \\ & \nu_1 \;\;, & \nu_2 \;\;, & \mu_1 & \geq & 0 \end{array} \tag{2.6}$$

which has been derived by Charnes/Cooper/Rhodes (1978) from the following fractional programming problem:

$$\begin{array}{lll} \min\limits_{u_1,v_1,v_2} & \dfrac{v_1 K_{hq} + v_2 L_{hq}}{u_1 Y_{hq}} & \\ \text{s.t.} & \dfrac{v_1 K_{1p} + v_2 L_{1p}}{u_1 Y_{1p}} & \geq \; 1 \\ & \vdots & \;\;\vdots \\ & \dfrac{v_1 K_{np} + v_2 L_{np}}{u_1 Y_{np}} & \geq \; 1 \\ & v_1 \;,\; v_2 \;,\; u_1 & \geq \; 0 \end{array} \tag{2.7}$$

The crucial trick employed here is to transform the fractional programming problem into a well-behaved linear programming problem by the application of the socalled Charnes-Cooper transformation (Charnes/Cooper 1962). In the present case this consists of substituting $\nu_1 = v_1/(u_1 Y_{hq})$, $\nu_2 = v_2/(u_1 Y_{hq})$, $\mu_1 = u_1/(u_1 Y_{hq})$ and the normalization $\mu_1 Y_{hq} = 1$ into the fractional programming problem (2.7) and then rearranging to obtain the the output oriented productivity form (2.6) of the DEA.

Now we are prepared to turn to the essential point to be made in this discussion. Therefore we ignore the distinction between the periods p and q and simply fix p = q. The fractional programming problem is based on the minimization of the ratio of an input index to an output index and simultaneously satisfying some consistency requirements to prevent the solution from being trivial. This procedure is equivalent to calculating 1/A = F(K,L)/Y if we start from a typical neoclassical production function Y = AF(K,L) with Hicks-neutral technological progress. Thus, in using the output-oriented productivity form of the DEA we quantify something that is proportional to 1/A so that by the distance function (2.2) we quantify something proportional to A and the Malmquist index gives the change of A between the periods t and t+1.

In contrast to that, growth accounting in its basic formulation attempts to perform the same task by a direct manipulation of the production function Y = AF(K,L) and results in the familiar relation

$$\frac{\dot{A}}{A} = \frac{\dot{Y}}{Y} - \alpha\frac{\dot{K}}{K} - (1-\alpha)\frac{\dot{L}}{L} \tag{2.8}$$

for the growth rate of A, labelled as the Solow residual according to Solows famous article in 1957 (Solow 1957). In growth accounting, the growth rates of the inputs are aggregated by their respective partial production elasticities which are quantified by their respective shares in total factor remuneration, α for capital and $1-\alpha$ for labour, thereby invoking the assumptions of perfectly competitive factor markets and constant returns to scale.

Equipped with these facts the difference between the Malmquist-DEA procedure and growth accounting becomes apparent. In growth accounting factor price information is needed to aggregate the inputs. To obtain the equivalence of the factor shares and the partial production elasticities strong equilibrium requirements have to be satisfied. Factor prices must equal marginal products, and this is satisfied only if factor markets are competitive, cleared and external effects and distortions originating e.g. from taxation are absent. In constrast to that, no factor price information at all is needed to quantify the Malmquist index by the DEA. Here the aggregation weights ν_1 and ν_2 for the inputs are obtained as an integral part of the optimization procedure. From the productivity form of the DEA (2.6) it is evident that the objective is to find a supporting hyperplane through the origin for period p

$$\mu_1 Y_p - \nu_1 K_p - \nu_2 L_p = 0 \quad (2.9)$$

that minimizes the vertical distance[3] from the hyperplane to the country being analyzed. The ratios of the input weights correspond to the gradient of the frontier facet that serves as the point of comparison for the country under investigation. From (2.9) we can easily find the marginal rate of technical substitution as $-\frac{dL_p}{dK_p} = \frac{\nu_1}{\nu_2}$. Thus, the aggregation weights give estimates of the marginal rate of technical substitution that characterizes the mixture of production processes that determine the supporting hyperplane and therefore estimate the inverse of the ratio of marginal productivities of the two input factors.

The two procedures also differ in their respective data requirements. Whereas the Malmquist-DEA procedure needs only quantity data for inputs and output, these data are needed for a panel of several countries observed over several years. On the other hand, growth accounting can be performed for a single country in isolation but needs information regarding the shares of the inputs in total factor remuneration. Since in the international growth context, in which this study is performed, quantity data are easily available for a broad panel of countries via the Penn World Table, whereas information on factor shares is much more scarce and probably less reliable than quantity data, the Malmquist-DEA procedure is the natural choice. In addition to that, we are able to exploit the further benefits of this procedure: the evaluation of the productivity of each country against the benchmark of the best countries with approximately the same input mix, the ability to disentangle efficiency change from technological progress which are not separable in growth accounting, and the fact that virtually no assumptions (besides some weak consistency restrictions on the technology set) regarding the form of the production function, which is permitted to be different for each country and year, have to be introduced.

3. Data

The data needed for the implementation for the above described Malmquist-DEA procedure are taken from the Penn World Table 5.6 (Summers/Heston 1991) for the period 1960-90 and the 87 countries listed in table 1 below. As output variable we use real GDP in 1985 international prices, capital input is calculated from investment data by the perpetual inventory method

[3] In the case of the model with two inputs and one output this interpretation is exact in a diagram with the output on the ordinate. For more than one output the radial distance in output direction is considered.

(see Krüger/Cantner/Hanusch (2000) for a more detailed description) and labour input is quantified by the number of workers.

Table 1
Country Sample

OECD	Latin America	Sub-Saharan Africa	North Africa/ Middle East	Asia
Australia (AUS)	Argentina (ARG)	Cameroon (CMR)	Egypt (EGY)	Bangladesh (BGD)
Austria (AUT)	Bolivia (BOL)	Centr. A. Rep. (CAF)	Iran (IRN)	China (CHN)
Belgium (BEL)	Brazil (BRA)	Chad (TCD)	Israel (ISR)	Hong Kong (HKG)
Canada (CAN)	Chile (CHL)	Gabon (GAB)	Jordan (JOR)	India (IND)
Denmark (DNK)	Colombia (COL)	Gambia (GMB)	Morocco (MAR)	Indonesia (IDN)
Finland (FIN)	Costa Rica (CRI)	Ghana (GHA)	Syria (SYR)	Korea Rep. (KOR)
France (FRA)	Dominic. Rep. (DOM)	Guinea (GIN)	Tunisia (TUN)	Malaysia (MYS)
Germany (DEU)	Ecuador (ECU)	Kenya (KEN)		Pakistan (PAK)
Greece (GRC)	El Salvador (SLV)	Lesotho (LSO)		Philippines (PHL)
Iceland (ISL)	Guatemala (GTM)	Madagascar (MDG)		Singapore (SGP)
Ireland (IRL)	Guyana (GUY)	Malawi (MWI)		Sri Lanka (LKA)
Italy (ITA)	Honduras (HND)	Mali (MLI)		Taiwan (OAN)
Japan (JPN)	Jamaica (JAM)	Mauritius (MUS)		Thailand (THA)
Luxembourg (LUX)	Mexico (MEX)	Mozambique (MOZ)		
Netherlands (NLD)	Nicaragua (NIC)	Namibia (NAM)		
Norway (NOR)	Panama (PAN)	Nigeria (NGA)		
New Zealand (NZL)	Paraguay (PRY)	Senegal (SEN)		
Portugal (PRT)	Peru (PER)	Seychelles (SYC)		
Spain (ESP)	Uruguay (URY)	South Africa (ZAF)		
Sweden (SWE)	Venezuela (VEN)	Togo (TGO)		
Switzerland (CHE)		Uganda (UGA)		
Turkey (TUR)		Zambia (ZMB)		
U.K. (GBR)		Zimbabwe (ZWE)		
U.S.A. (USA)				

Note: World Bank country codes in parentheses.

With this sample at hand we can solve all the linear programs needed to quantify the Malmquist index and its decomposition (2.4). This results in M_h^t, EF_h^t and TP_h^t for the periods t = 1961,...,1990 and countries h = 1,...,87. In the subsequent two sections we look at the differences between the country groups defined in the columns of table 1 in terms of average rates of productivity change and in terms of average relative productivity levels. Additionally, we compare all results from the total factor productivity calculations via the Malmquist index with two measures of labour productivity: real GDP per capita (GDPP) and real GDP per worker (GDPW). The labour productivity measures are based on the data series RGDPCH and RGDPW from the Penn World Table in the notation of Summers and Heston (1991).

4. Productivity Change

Average percentage growth rates between two points in time, t_1 and $t_2 > t_1$, are calculated according to the formulas (4.1) to (4.5) for each country h = 1,...,87. The three first (ΔM, ΔEF and ΔTP) are based on the Malmquist index whereas ΔGDPP and ΔGDPW represent the changes of real GDP per capita and real GDP per worker, respectively:

$$\Delta M_h = \left(\left[\prod_{t=t_1+1}^{t_2} M_h^t \right]^{1/(t_2-t_1)} - 1 \right) \cdot 100 \tag{4.1}$$

$$\Delta EF_h = \left(\left[\prod_{t=t_1+1}^{t_2} EF_h^t \right]^{1/(t_2-t_1)} - 1 \right) \cdot 100 \tag{4.2}$$

$$\Delta TP_h = \left(\left[\prod_{t=t_1+1}^{t_2} TP_h^t \right]^{1/(t_2-t_1)} - 1 \right) \cdot 100 \tag{4.3}$$

$$\Delta GDPP_h = \left(\left[\frac{RGDPCH_h^{t_2}}{RGDPCH_h^{t_1}} \right]^{1/(t_2-t_1)} - 1 \right) \cdot 100 \tag{4.4}$$

$$\Delta GDPW_h = \left(\left[\frac{RGDPW_h^{t_2}}{RGDPW_h^{t_1}} \right]^{1/(t_2-t_1)} - 1 \right) \cdot 100\ . \tag{4.5}$$

Starting with the productivity changes over the whole sample period 1960-90 in table 2 we observe first of all that the labour productivity measures ΔGDPP and ΔGDPW for Asia and especially the two subgroups 4Tiger[4] and 7NICs[5] show the highest growth rates in these countries. These growth rates are much higher than the labour productivity growth in the OECD countries[6] und in their subgroups consisting of the countries of the European Union[7] and the G7

4 These are the four Asian "Tiger" states Hong Kong, Korea, Singapore and Taiwan.

5 This subgroup consists of the four "Tiger" states and additionally Indonesia, Malaysia and Thailand.

6 Herein the 24 member countries of the OECD in 1990 are comprised.

7 Defined as the 15 member countries of the European Union after the enlargement in 1995.

countries[8]. The most modest labour productivity growth occured in Latin America and in Sub-Saharan Africa.

Table 2
Productivity Change 1960-1990

Country Group/ Subgroup	Productivity (ΔM)	Efficiency (ΔEF)	Technology (ΔTP)	Output/Capita (ΔGDPP)	Output/Worker (ΔGDPW)
OECD	1.305386	0.468462	0.834629	2.971185	2.645517
European Union	1.478495	0.588153	0.885757	3.084238	2.879754
G7	1.246043	0.342727	0.900622	3.080403	2.742905
Latin America	-0.128129	0.282944	-0.407329	1.129364	0.984906
Sub-Saharan Africa	-0.200031	-0.064690	-0.140855	0.840880	1.010867
North Afr/Middle East	0.168365	0.614017	-0.444321	2.782459	2.742970
Asia	0.532170	0.671945	-0.135323	3.917433	3.650528
4Tiger	0.315627	1.221936	-0.892967	6.628535	5.793700
7NICs	0.253514	0.870115	-0.607892	5.609777	5.016241
Mean	0.370836	0.326983	0.043396	2.110802	1.989634
Median	0.692478	0.240736	0.189200	2.136831	1.951032
Standard Deviation	1.484680	1.164491	0.899635	1.813453	1.690819
Skewness	-1.932167	-0.733886	-0.872314	0.222430	0.087028
Kurtosis	10.580355	4.810684	4.716414	3.472451	3.079682

Note: average percentage growth rates according to (4.1)-(4.5) with t_1=1960 and t_2=1990.

With respect to total factor productivity growth ΔM this pattern changes substantially. The Latin American and African countries are still an the bottom end of the range but the relative positions of the OECD countries and the Asian countries (together with their subgroups) reverse. Now the countries of the European Union and the G7 group are ranked top whereas the 4Tiger and 7NICs show much lower total factor productivity growth rates, especially when compared to their labour productivity growth rates. This remarkable reversal of the ranking of the OECD countries and the 4Tiger/7NICs subgroups shows the dependence of the ranking on taking account of the pace of capital accumulation in the Malmquist-based measure in contrast to the pure labour productivity measures (see Krüger/Cantner/Hanusch (2000) for a more extensive discussion of the differences between the G7 and the 4Tiger subgroups within the same

[8] Contains Canada, France, Germany, Italy, Japan, United Kingdom and the United States.

country sample and references to the literature on the total factor productivity dimension of the East Asian Miracle).

The decomposition of the Malmquist index into efficiency change and technological progress is given in the columns ΔEF and ΔTP, respectively. From there, it can be clearly seen that technological progress over the whole period 1960-90 occured only within the OECD countries, whereas all other country groups suffered from negative technological progress rates and therefore technological regress.[9] Improvements of efficiency can be recognized in all country groups except Sub-Saharan Africa. The 4Tiger/7NICs show an especially fast movement towards their respective frontier parts. This technological catch-up is more marked than in Asia on the whole and contrasts with the technological regress which is more marked in the 4Tiger/7NICs than in the mean of all Asian countries. Technological catch-up and technological regress together lead to positive total factor productivity growth in the 4Tiger/7NICs which is, however, lower than in the other Asian countries. For the OECD/EU/G7 countries efficiency improvements are likewise found. There the efficiency improvements account only for roughly a third of total factor productivity growth whereas the remaining two thirds are attributed to technological progress.

Below the results for the country groups table 2 contains some descriptive statistics. These point out that for the whole world labour productivity growth is much larger than total factor productivity growth but has also a larger standard deviation. From the skewness and kurtosis statistics we observe that the growth rate distributions are more in accord with the normal distribution in the case of the labour productivities than they are in the case of the total factor productivity measures. The distributions of the latter seem to be skewed to the left and show excess kurtosis.

If we now turn to a comparison of the productivity deveploments in two subperiods 1960-73 and 1973-90 in tables 3 and 4 we can detect some interesting differences. In the case of labour productivity there is a substantial attenuation of the growth rates after 1973. Only the Asian

[9] The result of technological regress in most parts of the world seems to be a bit puzzling at first glance. It can be made more sense of it if one takes into account that the Malmquist index captures only changes of the best-practice technology and with such a concept both forward and backward movements of parts of the frontier function are compatible.

countries have been able to uncouple from this development and continued to realize high growth rates. Regarding the total factor productivity measures there is also an attenuation during the second subperiod. Total factor productivity growth in the OECD/EU/G7 countries approximately halved, in Sub-Saharan Africa the negative trend of productivity growth has been intensified further and in Latin America as well as in North Africa/Middle East the positive total factor productivity growth in the first subperiod has changed sign after 1973. Only in Asia a negative productivity trend during the first subperiod has changed to a positive one in the second subperiod, whereby the difference in the 4Tiger/7NICs has been lower than in Asia on the whole.

Table 3
Productivity Change 1960-1973

Country Group/ Subgroup	Productivity (ΔM)	Efficiency (ΔEF)	Technology (ΔTP)	Output/Capita (ΔGDPP)	Output/Worker (ΔGDPW)
OECD	1.898990	0.044303	1.853739	4.202221	4.075331
European Union	2.084392	0.106309	1.975580	4.412724	4.521801
G7	1.892800	0.035765	1.856059	4.378199	4.205377
Latin America	0.937574	-0.422397	1.374537	2.766555	2.943100
Sub-Saharan Africa	-0.088441	-0.860624	0.764693	1.964582	2.326996
North Afr/Middle East	1.022585	0.202227	0.817462	4.321018	4.660216
Asia	-0.163078	-0.804134	0.650715	3.525622	3.533976
4Tiger	-0.095034	-0.487198	0.388325	7.301182	6.620311
7NICs	-0.229690	-0.768498	0.540286	5.752627	5.380681
Mean	0.773921	-0.416290	1.192528	3.189081	3.319012
Median	1.185608	-0.184457	1.433803	3.150672	3.244304
Standard Deviation	2.383375	1.894477	1.273559	2.141621	2.034206
Skewness	-1.921950	-0.234838	-2.510605	0.092613	0.061434
Kurtosis	12.180244	4.696742	15.792769	3.113971	2.821908

Note: average percentage growth rates according to (4.1)-(4.5) with t_1=1960 and t_2=1973.

Considering the components of the Malmquist index we can get further insight into the effects of this socalled productivity slowdown[10]. During the first subperiod technological progress

[10] The term productivity slowdown in general designates the decreasing growth rates of labour and total factor productivity after 1973 as a result of the two oil price shocks in the middle and the end of the 1970s (see e.g. Denison 1979, 1985, Jorgenson/Gollop/Fraumeni 1987 and Maddison 1987). A recent study of Ben-David

took place in all country groups. The largest rates of technological progress can be recognized in the OECD countries and the smallest (but still positive) ones in Asia. The signs of the efficiency change rates show that outside of the OECD the majority of countries was not able to keep up with the outward shifts of their respective reference segments of the frontier function. Within the OECD catch-up occured, whereas substantial negative efficiency changes took place in Latin America, Sub-Saharan Africa and Asia. These partially outweighted the contribution of technological progress to total factor productivity growth and lead to negative total factor productivity growth in some of the country groups.

Table 4
Productivity Change 1973-1990

Country Group/ Subgroup	Productivity (ΔM)	Efficiency (ΔEF)	Technology (ΔTP)	Output/Capita (ΔGDPP)	Output/Worker (ΔGDPW)
OECD	0.855338	0.795799	0.062920	2.043311	1.569205
European Union	1.019048	0.959862	0.061213	2.083416	1.645271
G7	0.755881	0.579876	0.176132	2.102740	1.641573
Latin America	-0.932232	0.830900	-1.743775	-0.098615	-0.480085
Sub-Saharan Africa	-0.255644	0.572516	-0.818737	0.011434	0.035933
North Afr/Middle East	-0.459650	0.952613	-1.397052	1.635836	1.313678
Asia	1.081481	1.829055	-0.730292	4.228971	3.749837
4Tiger	0.642422	2.553299	-1.859868	6.120632	5.169978
7NICs	0.631658	2.144444	-1.475726	5.507318	4.744871
Mean	0.078682	0.911851	-0.821489	1.307559	0.998038
Median	0.367754	0.976227	-0.699298	1.551285	1.073368
Standard Deviation	1.590955	1.478477	1.097864	2.261969	2.157371
Skewness	-0.767182	-0.975944	-0.149618	-0.161405	-0.145905
Kurtosis	4.221727	6.253901	1.676709	3.267357	3.112925

Note: average percentage growth rates according to (4.1)-(4.5) with t_1=1973 and t_2=1990.

A completely different pattern of efficiency change and technological progress emerges in the second subperiod. After the year 1973 only the OECD countries had a positive but very modest average rate of technological progress. In all other country groups negative rates of technological progress can be observed. The distances towards the frontier function have,

and Papell (1998) also clarifies the world wide dimension of the growth rate attenuation.

however, decreased in all country groups which is indicated by positive rates of efficiency change throughout. Efficiency improvements in Asia and even more marked in the 4Tiger/7NICs are more than twice as large as in the average of all country groups. Additionally, the efficiency improvements outweight the amount of technological regress in these countries and therefore result in a positive growth rate of total factor productivity on average. In contrast to Asia the efficiency increments in Latin America, Africa and Middle East remain lower (in absolute values) than the negative rates of technological progress and for that lead on balance to a decreasing rate of total factor productivity growth.

5. Productivity Levels

Besides the above analysed growth rates, differences in productivity levels also have some relevance for long-run macroeconomic research and policy questions. In a series of papers Hall and Jones (1996, 1997, 1999) have recently shifted the emphasis away from productivity change towards relative productivity levels which they deem to be the more reliable indicators of long-run economic performance. Following their arguments in this section we construct five measures of relative productivity levels corresponding to the rates of change in (4.1) to (4.5). To obtain our measures of relative productivity levels in 1990 we cumulate the productivity change for each single country $h = 1,...,87$, starting from the distance towards the frontier function in 1970:

$$\mathrm{MALM}_h = D_h^{1970}(\mathbf{x}_h^{1970}, \mathbf{y}_h^{1970}) \times \prod_{t=1971}^{1990} M_h^t \quad . \tag{5.1}$$

Related measures are constructed by cumulating solely the efficiency change or technology progress rates using the same starting point:[11]

$$\mathrm{EFF}_h = D_h^{1970}(\mathbf{x}_h^{1970}, \mathbf{y}_h^{1970}) \times \prod_{t=1971}^{1990} \mathrm{EF}_h^t \quad , \tag{5.2}$$

$$\mathrm{TECH}_h = D_h^{1970}(\mathbf{x}_h^{1970}, \mathbf{y}_h^{1970}) \times \prod_{t=1971}^{1990} \mathrm{TP}_h^t \quad . \tag{5.3}$$

[11] The choice of the year 1970 as the starting point for the subsequent cumulation of growth rates results on the one hand from the need to let pass ten years of capital accumulation to mitigate the influence of the initial capital stock estimates and on the other hand from the desire to have at least two decades of growth rate accumulation in order to have the chance of observing differences between the MALM, EFF and TECH measures.

For the purpose of comparison we also calculate two measures of relative labour productivity in 1990 using a sligthly modified procedure which is nevertheless consistent with the idea of the Malmquist-based level measures. We start with the levels of real GDP per capita (GDPP) and real GDP per worker (GDPW) in 1970 relative to the USA in 1970 as the country with the highest levels of GDPP and GDPW in that year and then again cumulate subsequent growth factors until 1990:

$$CGDPP_h = \frac{RGDPCH_h^{1970}}{RGDPCH_{USA}^{1970}} \times \prod_{t=1971}^{1990} \frac{RGDPCH_h^t}{RGDPCH_h^{t-1}} , \tag{5.4}$$

$$CGDPW_h = \frac{RGDPW_h^{1970}}{RGDPW_{USA}^{1970}} \times \prod_{t=1971}^{1990} \frac{RGDPW_h^t}{RGDPW_h^{t-1}} . \tag{5.5}$$

Table 5 summarizes the five measures of relative productivity levels in 1990 calculated according to the above described procedure for the country groups and subgroups defined in the preceding section.

The measures for the country groups are again the arithmetic means of the country specific measures. The overall pattern of results shown in the table corresponds to the analysis of the rates of change and is also consistent with a priori expectations. Regarding MALM, the G7 countries have the highest, Sub-Saharan Africa the lowest productivity levels and Asia as well as Latin America are in between, thereby Asia outperforming Latin America.[12] Quite surprising is the average productivity for the North African/Middle East countries, especially when compared to Asia. This result is mainly due to the fact that this group consists of only seven countries in our sample and some of these are quite near to the frontier function in the starting year of the growth rate cumulation 1970. This general pattern continues to show up in the EFF column, but there with substantially higher efficiency levels in the four Asian "Tiger" states and the seven NICs. However, these two subgroups are ranked last if we merely take account of the cumulated growth rates of technological progress as done in the TECH column.

[12] Despite the very different concepts to calculate the total factor productivity levels, MALM has a correlation coefficient of 0.79 with the growth accounting based measure of Hall and Jones (1996).

Table 5
Relative Productivity Levels in 1990

Country Group/ Subgroup	Productivity (MALM)	Efficiency (EFF)	Technology (TECH)	Output/Capita (CGDPP)	Output/Worker (CGDPW)
OECD	0.874042	0.832468	0.754361	0.993356	0.896636
European Union	0.881912	0.849456	0.728141	0.951524	0.898164
G7	0.913341	0.866813	0.809739	1.140697	0.990233
Latin America	0.516569	0.653281	0.477421	0.233021	0.286937
Sub-Saharan Africa	0.477173	0.546604	0.436743	0.114429	0.110835
North Afr/Middle East	0.713287	0.866886	0.616949	0.291809	0.404195
Asia	0.605837	0.665171	0.479477	0.363188	0.331523
4Tiger	0.629310	0.820747	0.402614	0.796401	0.669776
7NICs	0.582266	0.724249	0.407155	0.572762	0.496690
Mean	0.633934	0.693473	0.554598	0.435597	0.424671
Median	0.614588	0.717944	0.492883	0.254571	0.299888
Standard Deviation	0.232243	0.205658	0.231323	0.412045	0.353524
Skewness	0.312673	-0.454496	0.593942	0.882498	0.697909
Kurtosis	2.395792	2.259240	2.406849	2.246963	2.122551

Note: cumulated growth rates according to (5.1)-(5.5).

With respect to the relative levels of the GDP per capita and per worker in the last two columns we find a much wider dispersion between the country groups. There is one large gap between the OECD and the Asian countries and two other gaps between Asia and Latin America and between Latin America and Sub-Saharan Africa which is again at the lower end of the scale. The finding that dispersion is much wider with respect to the labour productivity measures than it is with respect to the total factor productivity measures may to some extent be the result of inaccuracies in the procedure to estimate the capital stocks. But since Sub-Saharan African and Latin American countries use much less capital to produce their GDP it is not at all implausible. Therefore, due to less capital input usage the total factor productivity levels of these countries can be expected to be above their respective labour productivity levels.

To gain further insight regarding the relative productivity levels we now trace the evolution of the frequency distributions of these levels from the starting point in 1970 until 1990 in the form of three snapshots for the years 1970, 1980 and 1990. The main tool used to get a visual impression of the distribution of the relative productivity levels in a particular year is the method of kernel density estimation for unidimensional data (see Wand/Jones 1995, ch. 2). The data for the kernel density estimates are constructed as follows:

in 1970: distance towards the frontier function in 1970 in the case of MALM, EFF, TECH and for CGDPP, CGDPW labour productivity per capita or per worker respectively in relation to the USA in 1970 (that is the first factor in (5.1) to (5.5) without any subsequent cumulation of growth rates);

in 1980: relative productivity levels as defined in (5.1) to (5.5) with the modification that the cumulation of growth rates goes until 1980 instead of 1990;

in 1990: relative productivity levels exactly as given in (5.1) to (5.5).

In the following we apply the kernel density estimator with an Epanechnikov kernel function and a bandwidth parameter selected according to the rule of thumb proposed by Silverman (1986, pp. 47f.) to each of these data series.

Looking first at the kernel densities for the labour productivity measures CGDPP and CGDPW in figures 1 and 2 we observe a bimodal shape of the distribution in 1970 with a dominating mode in the range of low labour productivity and a second one at high labour productivity.[13]

[13] The range of the relative labour productivity measures is bounded in the interval $(0,\infty)$ for all years by construction. Despite of that the kernel density estimator calculates positive density values in the range of negative labour productivities. This phenomenon is caused by the socalled boundary bias problem of kernel density estimation (see Simonoff 1996, pp. 49f.). Methods to remedy for this problem would result in a higher mode in the range of low labour productivity but would not affect any of the conclusions drawn from figures 1 and 2. The density estimates for the productivity levels based on the Malmquist index in figures 3 to 5 are not affected by this bias problem.

Figure 1
Density Estimates for Labour Productivity per Capita (CGDPP)

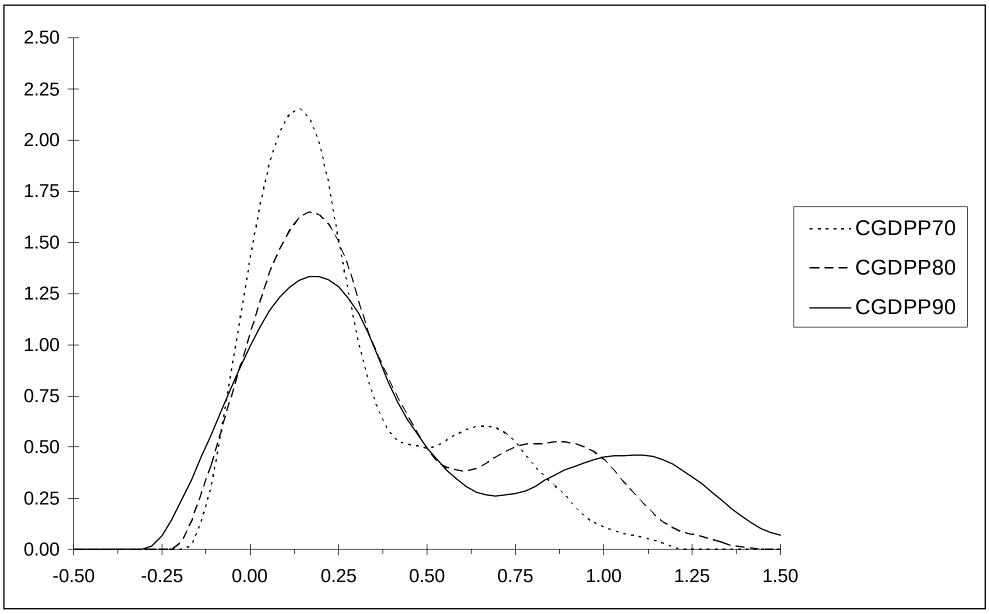
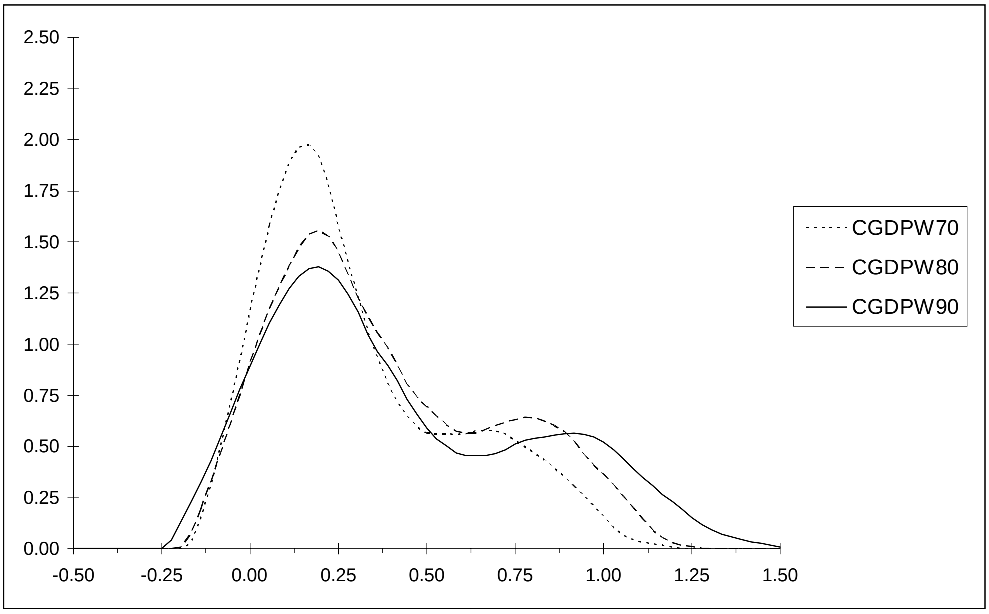


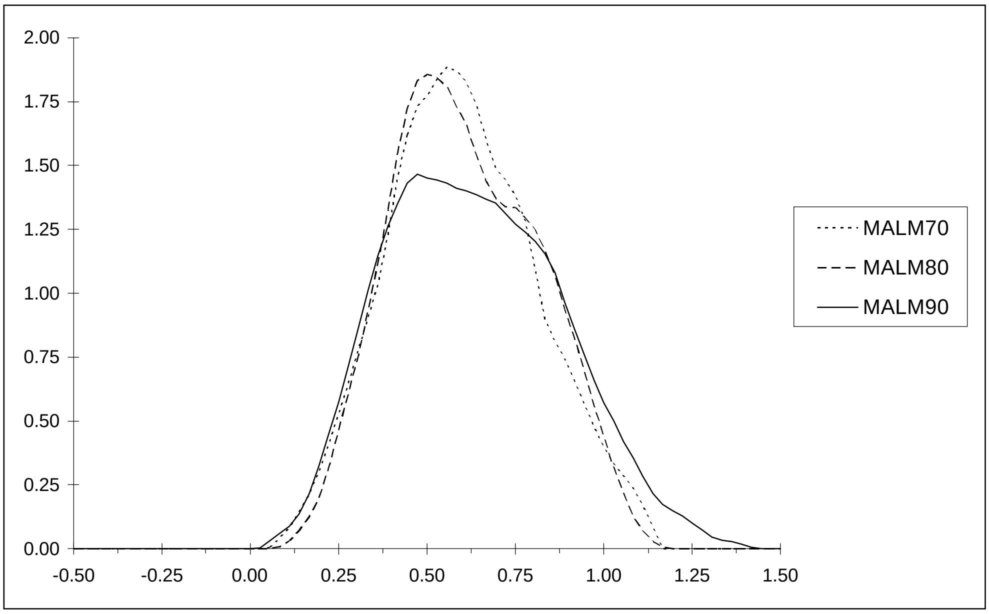
Figure 2
Density Estimates for Labour Productivity per Worker (CGDPW)



There are two important features to be highlighted in the evolution of these distributions from 1970 to 1990. First, the mode at low relative productivity levels dominates in 1970 but loses much probability mass until 1990. In contrast to that the mode at high relative productivity levels gains substantial probability mass during the same period. Second, the drifting apart movement of the two modes is solely due to the rightward movement of the mode at high relative productivity levels whereas the mode at low relative productivity levels shifts only very modestly to the right. Thus, on the one hand we observe a substantial fraction of countries that improve their labour productivity so that they catch up from the low to the high mode where average labour productivity improves faster than at the low mode. On the other hand the two modes get more and more separated with the consequence that catching-up will become increasingly difficult in future times if we suppose that such a transition is not a jump from the low to the high mode but is a gradual process that lasts for at least a decade. These results for the labour productivity measures are perfectly in accord with the related analyses of Bianchi (1997), Paap and van Dijk (1998) and Quah (1993a,b; 1996a,b; 1997).

Turning now to the total factor productivity measures based on the Malmquist index the picture is quite different. Figure 3 depicts the densities for MALM and shows that there is a single mode in 1970 and 1980 with only minor changes of the whole distribution during that decade. Until 1990, however, the mode flattens due to a gain in probability mass in the range of high productivity levels in a neighborhood of the productivity level 1.25.

Figure 3
Density Estimates for Relative Productivity Levels (MALM)



The causes of this pattern can be easily discerned if we look at the kernel density estimates obtained from the accumulation of only a single component of the Malmquist index as done in formulas (5.2) and (5.3) to calculate the EFF and TECH measures. These density estimates are depicted in figures 4 and 5.

Figure 4
Density Estimates for Relative Efficiency Levels (EFF)

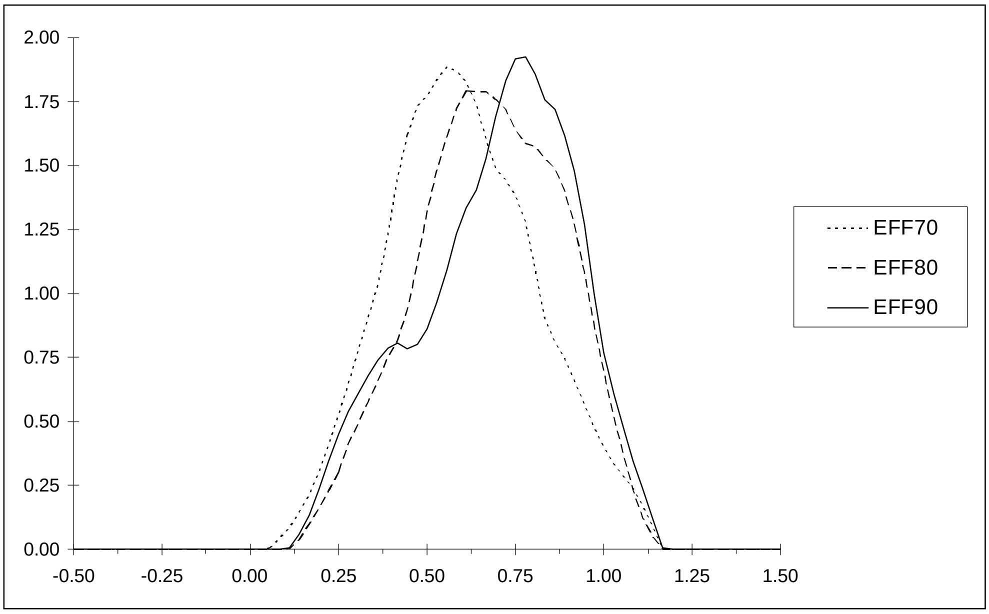
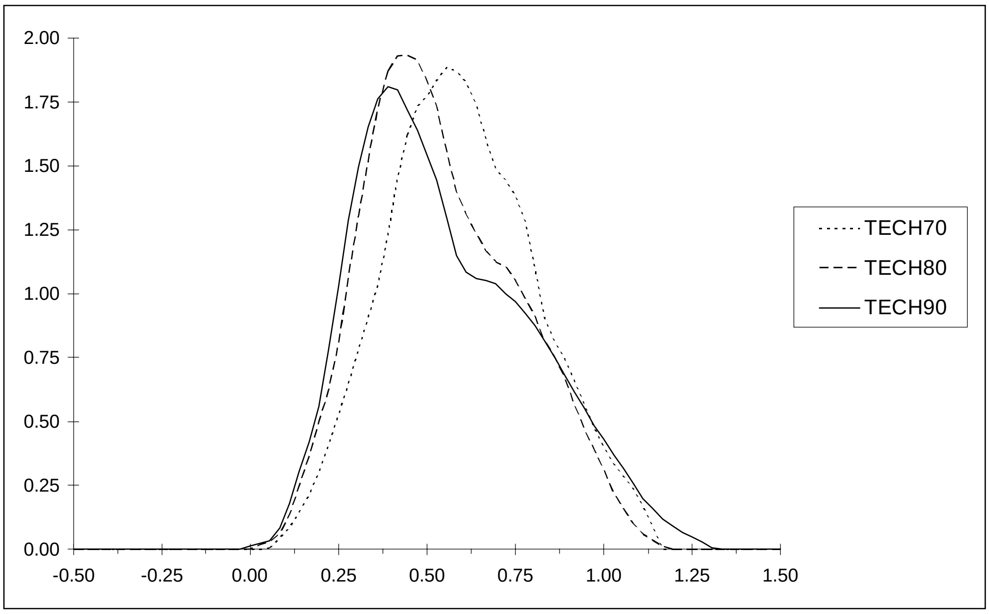


Figure 5
Density Estimates for Relative Technology Levels (TECH)



We observe that both are basically unimodal in 1970 and 1980 and that both show a weak tendency towards the formation of a second mode until 1990, more pronounced in the case of EFF than for TECH. The overall evolution of the densities of EFF and TECH seems to be a mirror image of each other. The mode of the density of EFF shifts to the right whereas the mode of the density of TECH shifts to the left. Thus we have an increasing number of countries with a higher EFF level but a lower TECH level. If these patterns of change persist into the future we will see a further flattening of the mode of MALM and if the modes of EFF and TECH move sufficiently far apart and/or if the rudiment of a second mode evolves towards a full bimodal distribution we will inevitably also get a bimodal density shape for MALM as we already can observe for the labour productivity measures during the period 1970 to 1990.

6. Conclusion

To conclude, we now summarize the main lessons to be learned from the analysis performed in this paper. First, regarding productivity change during the period 1960-90 we have seen that capital has a large impact on the ranking of the country groups. The ranking of the OECD countries and the newly industrializing Asian countries is very different with respect to labour productivity growth and total factor productivity growth. Technological progress over the whole period 1960-90, to the extent to which it can be measured by the Malmquist index, occurs only in the OECD countries and therefore in the range of relatively high capital intensity. With the exception of Sub-Saharan Africa catching-up in the form of efficiency improvements can be observed in all country groups.

Second, the comparison of the subperiods 1960-73 and 1973-90 reveals the world wide impact of the productivity slowdown. Both total factor productivity and labour productivity measures decrease in most of the country groups with the exception of Asia in terms of total factor productivity after 1973. Especially the fact that the technological progress rates are affected by the slowdown shows that all parts of the frontier function regress or stagnate after 1973. On the positive side, we have considerable amounts of efficiency improvement and therefore catching-up in all country groups after 1973, whereas falling behind movements were prevalent before 1973.

Third, the constructed measures of relative productivity levels give a plausible ranking for the differences between the country groups. Kernel density estimates show a twin-peaked structure in the case of the labour productivity levels which is deemed to be a new stylized fact of economic growth by Durlauf and Quah (1999) and has recently been modelled using a knowledge based simulation approach originating from innovation economics by Pyka, Krüger and Cantner (1999). The total factor productivity measures, however, are not bimodally distributed, but there is a certain chance of observing the emergence of a bimodal distribution shape in future times if the development patterns of the years 1970 to 1990 continue. This means that with respect to both labour productivity and total factor productivity catching-up may become increasingly difficult in the future with the consequence of having more countries caught in a development trap with little prospect of ever reaching high levels of technology and wealth.

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