JOURNAL
OF EUROPEAN ECONOMY
Vol. 4 (№ 4). Decemder 2005
Publication of Ternopil State Economic University

Macroeconomics

Somesh K. MATHUR

ECONOMIC GROWTH: A DATA ENVELOPMENT ANALYSIS

Abstract

We estimate technical efficiency levels for 29 countries including some selected South Asian, East Asian and EU countries by means of data envelopment analysis. Luxembourg has an efficiency score of one (most efficient) in all the years analyzed. The Netherlands also have an efficiency score of one in 1966, 1971, 1976, and 1981. Japan, UK, Belgium, Ireland, Indonesia, Spain, and Germany have an efficiency score of one in at least one of the years from 1966 to 2000. In the year 2000 though, mean efficiency levels (excluding life expectancy as input) of South Asian countries are higher than those of the European countries (EU15 + Norway) and East Asian countries. In 1966–2000, Japan has the highest average efficiency followed by Hong Kong in the East Asian region.

We also decompose labour productivity growth into components attributable to technological changes (shifts in the overall production frontier), technological catch-up or efficiency changes (movement to or off the frontier), capital accumulation (movement along the frontier), and human capital accumulation (proxied by life expectancy). The overall production frontier is constructed using deterministic methods requiring neither specification of functional form for the technology nor any assumption about market structure or absence of market imperfections. Growth accounting results tend to convey that labour productivity changes over 1966–2000 were induced mostly by efficiency changes (technological catch-up) in the case of East Asian and South Asian countries, and by

Mathur Somesh K., Senior Lecturer, Department of Economics of Jamia Millia Islamia, New Delhi, India.

The article is based on the PhD thesis «Perspectives of Economic Growth in Selected South Asian and East Asian Countries» submitted to International Trade Division of Jamia National University, New Delhi, 2005.

technical changes in the case of the European countries (EU+ Norway). We also use Kernel densities to analyze the evolution of cross-country labour productivity distribution for the 29 countries included in our sample. There seem to be other factors, such as trade openness, government quality, populations' growth rate, savings rate, corruption perception indices, rule-of-law index, social capital and trust variables, formal and informal rules governing the society not included in this growth accounting exercise, which may be primarily responsible for the existence of bi-modal labour productivity distribution for the countries in the sample. However, this growth accounting exercise does find that there is convergence in the statistical terms of efficiency changes and human capital accumulation across the countries of the EU and South and East Asia.

Key words:

capital accumulation, counterfactual distributions, cross-country labour productivity distribution, data envelopment analysis, efficiency change, growth accounting, human capital accumulation, kernel smoothing, technical efficiency, technological change

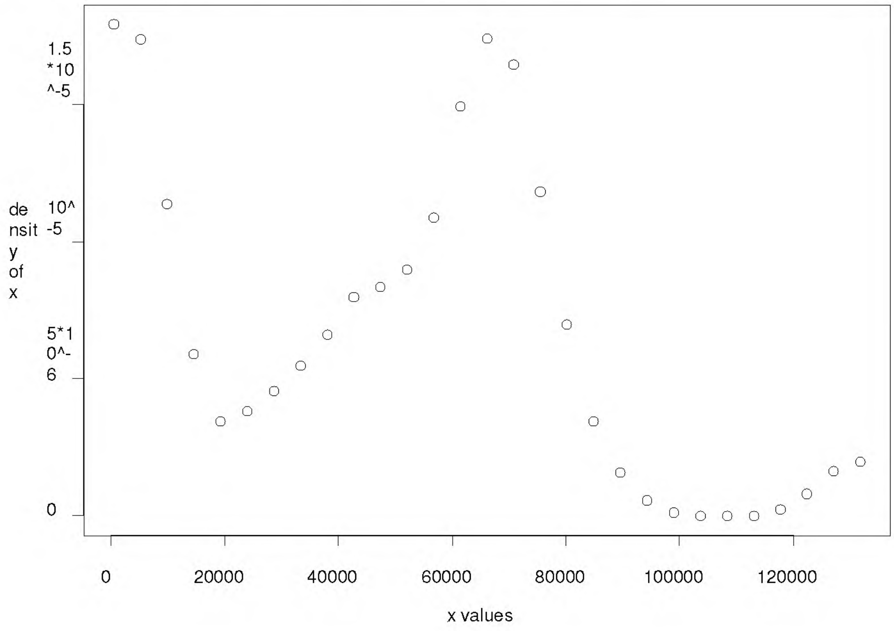
I. Introduction

Very much in the spirit of Quah's (1993, 1996b, 1997) suggested approach (also adopted by Galor [1996] and Jones [1997]), we analyze the evolution of the entire distribution of four growth factors: technological change, technological catch-up, capital accumulation, and human capital accumulation[1]. We analyze the contribution of these four components to growth of the countries' labour productivity and to shift in the countries' distribution of labour productivity over time. Data envelopment analysis has been used to estimate the best production frontier for some of the Developed (EU Nations), Developing (South Asians) and Newly Industrialized Countries (East Asian nations) included in our study. A country's production frontier is constructed using deterministic methods requiring neither specification of functional form for the technology nor any assumption about market structure or absence of market imperfections. Technological catch-up signifies movement towards the frontier; technical change is movement off the frontier; capital accumulation is movement along the frontier; and human capital accumulation implies changes in the efficiency of labour.

[1] This approach to Growth Accounting is not dependent on particular assumptions about technology, market structure, technological change, and other aspects of the growth process.

Figure 1.

Distribution of Output per Worker, 2000 (Bi-modal)



Quah has clearly brought out that analyses based on standard regression methods focusing on first moments of distribution can not adequately address the convergence issue. These arguments are supported by the empirical analyses of Quah and others, posing a robust stylized fact about the international growth pattern that begs for explanation. The output-per-worker distribution plots for 29 countries, consisting of 5 South Asian, 8 East Asian and 15 EU countries + Norway (see country names in Table 1 of Appendix), appear in Figure 1 (year 2000) and 2 (year 1966). (The data and the kernel-based distribution smoothing method are described in the Methodology section). During this 34-year period, the distribution of labour productivity changed from tri-modal distribution in 1966 to bi-modal distribution in 2000 with a higher mean (see data on output per worker in columns 2 and 3 of Table 3)[2]. This transformation means that,

[2] Two-Sample Kolmogorov-Smirnov Test (non-parametric test) is used to test whether two sets of observations could reasonably have come from the same distribution. This test assumes that the samples are random samples, the two samples are mutually independent, and the data are measured on at least an ordinal scale. In addition, the test gives exact results only if the underlying distributions are continuous. Data: *x*: output per worker in 1966, and *y*: output per worker in 2000 *ks* = 0.5172, *p*-value = 0.0007 alterna-

whereas in 1966, there were countries in the lower-, middle-income and upper-income groups, in 2000 the world became divided, as a stylized fact, into two categories: the rich and the poor. It seems that almost all the East Asian economies have joined the elite «rich group». According to Quah (1996a, b, 1997), this is a «two-club» or «twin-peak» convergence – a phenomenon that renders suspect analyses based on the first moment (or even higher moments) of this distribution. Our analysis aims to explain this bipolarization of the output-per-worker distribution, as well as its growth pattern, in terms of tri-partite and quadric-partite decomposition described below. As such, it builds upon Quah's insights about the need to examine the «dynamics of the entire cross-section distribution» (Quah, 1997, p. 29). In this study, we will further identify the policies which may reduce differential levels of per-capita income levels and growth rates of regions, and work out the reasons for the existence of bi-modal distribution of per capita income across countries. Additionally, the concept of labour productivity is related to the concept of efficiency, that is, the amount by which outputs can be increased without requiring extra inputs. We will also work out the 'efficiency levels' of the countries included in our sample by using the linear programming method of data envelopment analysis.

The main variables used in this study are GDP at constant 1995 US $, capital (constant 1995 US $), labour, life expectancy in years (proxy for human capital), and labour productivity (GDP divided by labour force) prevailing in the countries/ regions under consideration.

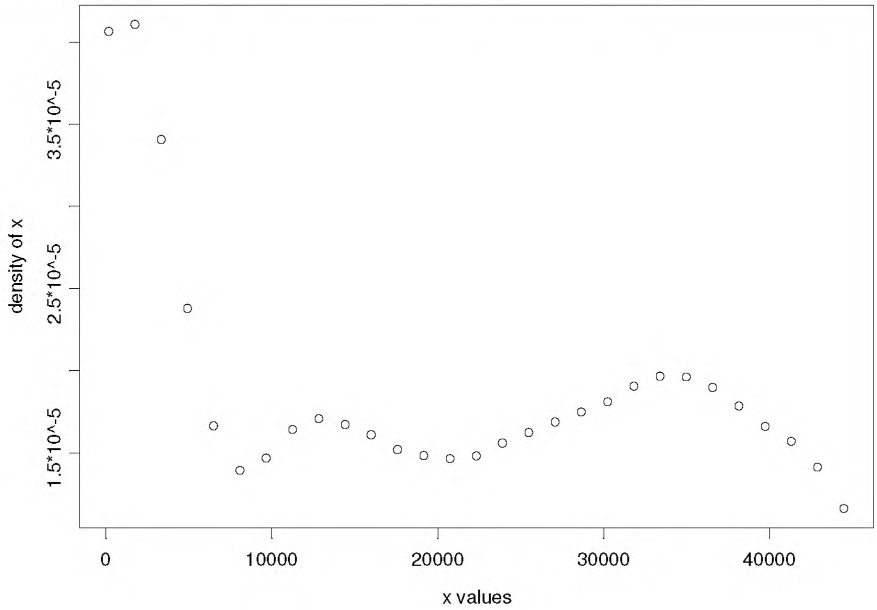
The paper is organized as follows. Section II reviews literature on data envelopment analysis and growth accounting without the need for specification of the functional form for technology, for the assumption that technological change is neutral, or for the assumptions about market structure or the absence of market imperfections. Section III determines the objectives of the study, Section IV states the hypotheses. Methodology is explained in Section V. Section VI describes the variables used in the study and efficiency analysis and gives an account of the data sources. Section VII discusses the results for the efficiency levels and changes and growth accounting of the countries studied. Section VIII discusses the counterfactual probability distribution and contrasts it with the labour productivity distribution of 1966. Section IX concludes. References and Appendix (available on demand) are at the end.

---

tive hypothesis: cdf of x: output per worker in 1966 does not equal the *cdf* of *y*: out put per worker in 2000 for at least one sample point. We conclude from the test that two sample probability distributions of output per worker in 1966 and 2000 are indeed different statistically.

Figure 2.

Distribution of Output per Worker, 1966 (Tri-modal)



II. Literature Review: Data Envelopment Analysis and Growth Accounting

We used DEA framework to estimate efficiency indices for the countries in the sample.

II.1. Data Envelopment Analysis (DEA)

DEA is a mathematical programming approach to estimating relative technical efficiency (TE) of production activities. The term DEA was originally proposed by Charnes et al. (1978). The Charnes' et al. (1978) work extended the Farrell's (1957) multiple-input, single output measures of TE to multiple-output, multiple-input technology. The DEA technique permits an assessment of the performance or TE of an existing technology relative to an ideal, «best-practice», or frontier technology (Coelli et al. 1998). The frontier or best-practice technology is a reference technology or production frontier that depicts the most technically efficient combination of inputs and outputs (i. e., maximum output at given technology and input levels, or minimum input levels at given output levels). Frontier technology is formed as a non-parametric, piece-wise, linear combination of the observed «best-practice» activities. Data points are enveloped with linear segments, and TE scores are calculated relative to frontier technology.

II.2. Growth Accounting

The results of total factor productivity estimation differ due to different assumptions about production functions and limited data on productivity of capital and labour and quality of workers. The studies of Kumar and Russell (2002) and Henderson and Russell (2003) are exceptions.

Kumar and Russel (2002) use frontier methods to analyze international macroeconomic convergence. In particular, they decompose labour-productivity growth of 57 industrial, newly industrialized, and developing countries into components attributable to (1) technological change (shifts in the world's production frontier), (2) technological catch-up (movements towards or away from the frontier) and (3) capital accumulation (movement along the frontier). These calculations amount to standard growth accounting with a twist–without the need for specification of a functional form for the technology, assumption of neutral technological change, or assumptions about market structure or absence of market imperfections. Indeed, market imperfections, as well as technical inefficiencies, are possible reasons for countries to fall below the world-wide production frontier. Taking a cue from the Quah's critique spelled out in the introduction of this study, Kumar and Russel (2002) go on analyzing the evolution of the entire distribution of these three growth factors.

Although the analysis of Kumar and Russel is quite simple, it yields somewhat striking results:

(1) While there is substantial evidence of technological catch-up (movements towards production frontier), with the degree of catch-up directly related to initial distance from the frontier, this factor apparently has not contributed to convergence since the degree of catch-up appears not to be related to initial productivity.

(2) Technological change is decidedly non-neutral, with no improvement – even some implosion – at very low capital/labour ratios, modest expansion at relatively low capital/labour ratios, and rapid expansion at high capital/labour ratios.

(3) Both growth and bi-modal polarization are driven primarily by capital deepening.

Henderson and Russell (2003) introduce human capital into the Kumar and Russell's (2002) growth accounting analysis of international macroeconomic convergence. They amend the KR methodology by adopting the Diewert (1980) approach to dynamic frontier analysis, thus precluding the implosion of universal production frontier over time and (a) changes in the mean and (b) mean-preserving shifts in the distribution of productivity. Their principal conclusions were the following:

- More than a half of the increase in mean productivity ascribed by KR to physical capital accumulation was, in fact, the result of human capital accumulation.
- In contradiction to KR's conclusion that capital accumulation also accounts for the shift in distribution, primarily from uni-modal to bi-modal, their analysis indicates that efficiency changes produce a qualitative shift from uni-modal to bi-modal, whereas accumulation of physical and human capital produces an increased worldwide dispersion of productivity.
- There is evidence of technological progress in the developed nations only.

In this study, we also undertake growth accounting with a twist – without the need for specification of a functional form for the technology, assumption of neutral technological change, or assumptions about market structure or absence of market imperfections. We use the sample of 29 developing, newly industrialized and developed nations. The objective is to reconfirm whether Kumar and Russel's (2002) and Henderson and Russel's (2003) results indeed hold for the sample of countries included in our study.

III. Objectives of the Study

The objectives of this study are the following:

- To determine technical efficiency index for each of the 29 sampled countries and examine the impact of some of its determinants on the efficiency levels over the 5-year period from 1966 to 2000.
- To undertake growth accounting in order to decompose labour productivity growth into components attributable to technological changes (shifts in overall production frontier), technological catch-up or efficiency changes (movement to or off the frontier), capital accumulation (movement along the frontier), and human capital accumulation.

- To identify the reasons for the existence of the prevailing bi-modal labour productivity distribution by specifically analyzing the evolution of cross-country distribution over time for the 29 countries in the sample (that includes some South Asian, East Asian and EU15 countries + Norway).

IV. The Hypothesis

1. South Asian and East Asian countries are presently more 'efficient' than the developed nations included in the sample.

2. To test whether technological change, technological catch up, capital accumulation and human capital accumulation are primarily responsible for differential growth in labour productivity, as well as for the existence of bi-modal labour productivity distribution, across the countries and regions included in our sample.

V. The Methodology

The level of efficiency for each country was established by applying Data Envelopment Analysis (DEA)[3] for the 5-year period of 1966-2000. Further, we decompose labour productivity into components: efficiency change, technological change, capital accumulation, and human capital accumulation. Technological change reflects shifts in the world's production frontier determined by the state-of-the-art, potentially transferable technology. Efficiency change reflects movements toward (or away from) the frontier as countries adopt the «best practice» technologies and reduce (or exacerbate) technical and allocative inefficiencies. Capital accumulation reflects movements along the frontier. The world's production frontier at each point of time is constructed using deterministic, non-parametric (mathematical programming) methods (that is, finding the smallest convex cone enveloping the data). Efficiency is measured as the (output-based) distance to frontier. These data-driven methods do not require specification of any particular functional form for the technology, nor do they require any assumption about market structure or absence of market imperfections. Market imperfections, as well as technical inefficiencies, are possible reasons for countries to fall below the world's production frontier. Changes in life expectancy are proxy for human capital accumulation. Introduction of human capital results in a quadri-partite decomposition of productivity growth.

[3] Our efficiency calculations were carried out using the Onfront software (demo version) available from Economic Measurement and Quality I Lund AB (Box 2134, S-220 Lund, Sweden (www.emq.se)).

V.1. Non-Parametric Construction of Technologies and Efficiency Measurement

Our approach to constructing the world's production frontier and the associated efficiency levels of individual economies (distances to frontier) was motivated in part by the first such efforts made by Fare, Grosskopf, Norris, and Zhang (1994b), and Charnes et. al (1978) followed by Kumar and Russell (2002) and Henderson and Russell (2003), which, in their turn, were based on the pioneering works of Farrell (1957) and Afriat (1972). We follow mainly Kumar and Russell (2002). The basic idea is to envelop the data in the «smallest» or «tightest-fitting» convex cone; the (upper) boundary of this set then represents the «best-practice» production frontier. Although this data-driven approach, implemented with standard mathematical programming algorithms, requires no specification of functional form, it does require an assumption about returns to scale of the technology (as well as free input and output disposability). Our technology contains four macroeconomics variables: aggregate output and three aggregate inputs – labour, physical capital, and human capital (proxied by life expectancy in years). Let $(Y_t^j,\ L_t^j,\ K_t^j,\ H_t^j)$ $t = 1, ..., T$, $j = -1, 1...J$ represent T observations on these four variables for each of J countries. In particular, we construct the constant-returns-to-scale, period-t technology using (in principle) all data up to that point in time:

$$\tau_t = \Big\{(Y, L, K, H) \in R_+^4 \Big| Y \le \sum_{\tau \le t} \sum_j z_\tau^j Y_\tau^j .$$

$$L \ge \sum_{\tau \le j} \sum_j z_\tau^j L_\tau^j \ \ K \ge \sum_{\tau \le j} \sum_j z_\tau^j K_\tau^j ,\ \ H \ge \sum_j z^j H,\ \ z^j \ge 0 \forall j \Big\} \qquad (1)$$

This technology is the Farrell cone; other assumptions about returns to scale would incorporate an additional constraint on the activity level, $t = 1, ..., T$, $j = 1, ..., J$ (see, e. g., Fare, Grosskopf, and Lovell (1994)).

In this construction, each observation is interpreted as a unit operation of the linear process. z_j represents the level of operation of that process, and every point in the technology set is a linear combination of the observed output/input vectors or the point dominated by the linear combination of the observed points. The constructed technology is a polyhedral cone, and isoquants are piecewise linear.

The Farrell (output-based) efficiency index for country j at time t is defined by

$$E\big(Y_t^j, L_t^j, K_t^j, H\big) = \min\big\{\lambda \mid \big(Y_t^j \mid \lambda, L_t^j, K_t^j, H\big) \in \tau_t\big\} \qquad (2)$$

This index is the inverse of the maximal proportional amount by which output Y_t^j can be expanded while remaining technologically feasible, given technology τ_t and input quantities L_t^j, K_t^j and H. It is less than or equal to 1 and takes the value of 1 if and only if the *jt* observation is on the period-*t* production frontier. In this case of scalar output, the output-based efficiency index is simply the ratio of actual output to potential output measured in actual input quantities, but in multiple-output technologies, the index is a radial measure of the (proportional) distance of actual output vector to production frontier.

In our simple case, we deal only with three macroeconomic variables: aggregate output and two aggregate inputs – labour and capital. Let (Y_t^j, L_t^j, K_t^j), $t = 1, \ldots, T$, $j = 1, \ldots J$ represent T observations on these three variables for each of the J countries.

The Farrell efficiency index can be calculated by solving the following linear program for each observation:

$$\min_{\lambda, z^1, \ldots, z^j} \lambda \text{ subject to}$$

$$Y^j / \lambda \leq \sum_k z^k Y_t^k,$$

$$L^j \leq \sum_k z^k L_t^k,$$

$$K^j \leq \sum_k z^k K_t^k,$$

$$z^k \geq 0 \forall k.$$

The solution value of λ in this problem is the value of efficiency index for country j at time t.

V.2. Tri-partite Decomposition of the Factors Affecting Labour Productivity

We decompose the ratio of labour productivity in the current year to labour productivity in the base year into three components: efficiency change (catching up to the frontier), technical change (movement of frontier) and capital accumulation (movement along the frontier). Please, refer to Kumar and Russell's Paper (2002) for derivation.

$$\frac{y_c}{y_b} = \frac{e_c}{e_b} \left(\frac{\bar{y}_c(k_c)}{\bar{y}_b(k_c)} \times \frac{\bar{y}_c(k_b)}{\bar{y}_b(k_b)} \right)^{\frac{1}{2}} \times \left(\frac{\bar{y}_b(k_c)}{\bar{y}_b(k_b)} \times \frac{\bar{y}_c(k_c)}{\bar{y}_c(k_b)} \right)^{\frac{1}{2}}$$

$$=: EFF \times TECH \times KACCUM.$$

V.3. Quadri-partite Decomposition of the Factors Affecting Labour Productivity Conceptual Decomposition

Further, we can decompose the ratio of labour productivity in the current year to labour productivity in the base year into four components: efficiency change (catching up to the frontier), technical change (movement of the frontier), capital accumulation (movement along the frontier) and Human Capital Accumulation. Please, refer to Henderson and Russell's paper (2003) for derivation.

$$\frac{y_c}{y_b}=\frac{e_c}{e_b}\left(\frac{\tilde{y}_c(k_c)}{\tilde{y}_b(k_c)}\times\frac{\tilde{y}_c(k_b)}{\tilde{y}_b(k_b)}\right)^{\frac{1}{2}}\times\left(\frac{\tilde{y}_b(k_c)}{\tilde{y}_b(k_b)}\times\frac{\tilde{y}_c(k_c)}{\tilde{y}_c(k_b)}\right)^{\frac{1}{2}}\frac{H_c}{H_b}$$

$$=: EFF \times TECH \times KACC \times HACC.$$

V.4. Kernel Densities

We employ kernel-based density functions for estimating cross-country labour productivity distribution for various years. Density estimates are computed using the Rosenblatt-Parzen kernel density estimator. We use an optimal bandwidth parameter chosen as

$$h = 1{,}0592 * \sigma * N\text{^}(-.20),$$

where σ is the standard deviation of the data and N is the number of observations. Splus software was used to estimate Kernel smoothers.

VI. Description of Data and Variables

For technical efficiency and growth accounting exercise (labour productivity decomposition into four factors), we consider a sample of 29 countries (5 South Asian, 8 East Asian, 15 EU countries + Norway) over the period of 1966–2000 using the data from the World Development indicators on CDROM (various years). The included countries are identified in Table I of Appendix. For DEA, our measure of aggregate output is GDP calculated at constant 1995 US \$. Aggregate inputs used in the DEA model are capital stock, labour force and life expectancy (proxy for human capital). The capital stock for each country was calculated from gross capital formation (current US \$). The measurement method is as described in Chou (1993). Appropriate deflator was used to estimate capital stock at constant 1995 US \$.

VII. Discussion of the Results: Efficiency Levels and Changes, Technological Changes, Capital Accumulation and Human Capital Accumulation. Contribution of These Factors to Labour Productivity Changes (1966–2000)

VII.1. Empirical Results: Technological Catch-up (Efficiency Levels and Changes)

Table I and II list the efficiency levels for each of the 29 countries in 1966, 1971, 1976, 1981, 1986, 1991, 1996, and 2000. Efficiency indices are calculated from the input and output data for the 29 countries included in our study. The output and input data are given below in the Appendix Tables (available from the author). For comparison, we calculate these indices both with and without life expectancy (denoted, respectively, by LE and WLE in the tables). Human capital is proxied by life expectancy of countries in years 1966, 1971, 1976, 1981, 1986, 1991, 1996, 2000.

Luxembourg has an efficiency score of 1 in all the years with or without life expectancy (human capital). The Netherlands also have efficiency scores of 1 in 1966, 1971, 1976, and 1981. Japan, UK, Belgium, Ireland, Indonesia, Spain, and Germany have an efficiency score of 1 in at least one of the years from 1966 to 2000. In the year 2000 though, mean efficiency levels (without life expectancy as input) of South Asian countries is higher than those of the European countries (EU15 + Norway) and East Asian economies. Japan has the highest average efficiency followed by Hong Kong in the East Asian region in the period 1966–2000.

Bangladesh and India also have scores of 1 in at least one of the years from 1966 to 2000. It seems peculiar that these countries are on the frontier. The interpretation of this finding is that Bangladesh and India have low per-capita incomes because they seem to be relatively undercapitalized, but not because they use their relatively meager capital inputs inefficiently. Another (perhaps more plausible) interpretation is that the DEA method of constructing the best -practice frontier – a lower bound on the frontier under the assumption of constant returns – fails to identify the «true»-but-unknown frontier, especially at low capital-to-labour ratios[4].

---

[4] We should note that these mathematical programming methods take no account of measurement error, sampling error and other stochastic phenomena. Recent research (Leopold Simar, 1996; Alois Kneip et.al, 1998; Irene Gijbels, 1999; Simar, L. and Paul W. Wilson, 2000) has made substantial progress on the use of bootstrapping method to construct confidence intervals around efficiency index. In this study, however, we are more concerned about the statistical significance of changes in the distributions of efficiency indices and the components of tri-partite and quadri-partite decomposition of productivity changes.

Table 1.

Technical Efficiency Indices (1966–2000)

Country	WLE	LE	WLE	LE	WLE	LE	WLE	LE
	1966		1971		1976		1981	
Bangladesh	0.29	0.29	0.37	0.37	0.71	0.75	1	1
India	0.11	0.56	0.19	0.53	0.46	0.58	0.67	0.86
Nepal	0.53	0.53	0.56	0.56	1	1	0.97	0.97
Pakistan	0.12	0.12	0.22	0.22	0.5	0.5	0.84	0.84
Sri lanka	0.1	0.1	0.21	0.21	0.51	0.51	0.59	0.59
Belgium	0.77	0.82	0.8	0.89	0.88	0.95	0.9	0.91
Austria	0.67	0.72	0.74	0.81	0.8	0.87	0.84	0.87
Denmark	0.98	1	0.92	1	0.91	0.98	0.86	0.86
Finland.	0.59	0.62	0.6	0.65	0.65	0.71	0.71	0.75
France	0.72	0.84	0.75	0.94	0.79	0.9	0.83	0.86
Germany	0.91	1	0.75	0.96	0.79	0.9	0.83	0.83
Greece	0.33	0.36	0.4	0.43	0.45	0.49	0.59	0.59
Ireland	0.41	0.42	0.43	0.44	0.48	0.48	0.83	0.83
Italy	0.48	0.77	0.52	0.81	0.57	0.79	0.7	0.86
Luxembourg	1	1	1	1	1	1	1	1
Netherlands	1	1	1	1	1	1	1	1
Portugal	0.22	0.24	0.26	0.29	0.26	0.28	0.35	0.35
Spain	0.46	1	0.48	1	0.72	1	0.93	0.95
Sweden	0.82	0.86	0.77	0.86	0.78	0.85	0.76	0.78
UK	0.55	1	0.51	0.96	0.52	0.89	0.96	1
Norway	0.77	0.79	0.73	0.79	0.8	0.87	0.85	0.85
Malaysia	0.16	0.16	0.22	0.22	0.65	0.65	0.96	0.96
China	0.12	0.54	0.17	0.37	0.34	0.42	0.35	0.47
Indonesia	0.08	0.22	0.17	0.23	0.78	0.8	1	1
Japan	0.62	0.98	0.78	1	0.88	1	1	1
Philippines	0.08	0.18	0.11	0.16	0.38	0.38	0.69	0.69
Singapore	0.25	0.25	0.34	0.34	0.42	0.42	0.7	0.7
Thailand	0.13	0.15	0.17	0.17	0.53	0.53	0.78	0.78
Hong Kong	0.3	0.3	0.31	0.31	0.75	0.75	1	1
Mean	0.46	0.58	0.50	0.60	0.67	0.73	0.81	0.83
SA (5) Mean	0.23	0.32	0.31	0.67	0.64	0.67	0.81	0.85
EU15+ Norway Mean	0.66	0.78	0.67	0.81	0.71	0.81	0.81	0.83
EA (8) Mean	0.21	0.35	0.28	0.62	0.59	0.62	0.81	0.83

Note: Technical Efficiency is calculated using Onfront Software. Higher values mean higher technical efficiency, while the value of 1 means that the country is moving along the best production frontier. Efficiency Indices are calculated using input and output data. While the inputs are labour force, capital stock (constant 1995 US$) and life expectancy (in years), output is GDP at constant 1995 US$. LE denotes life expectancy included in efficiency measurement. WLE denotes efficiency measurement without life expectancy.

Table 2.

Technical Efficiency Indices (1966–2000): Continued

Country	WLE	LE	WLE	LE	WLE	LE	WLE	LE	Mean Effi-ciency WLE 1966-2000	Mean Effi-ciency LE 1966-2000
	1986		1991		1996		2000			
Bangladesh	1	1	1	1	0,96	0,96	0,91	0,91	0,78	0,78
India	0.74	0.89	0.54	0.58	0.62	0.76	0.66	0.76	0.49	0.69
Nepal	0.92	0.92	0.8	0.8	0.69	0.69	0.73	0.73	0.77	0.77
Pakistan	0.84	0.86	0.77	0.79	0.8	0.85	0.73	0.74	0.60	0.61
Sri Lanka	0.68	0.68	0.63	0.63	0.69	0.69	0.69	0.69	0.51	0.51
Belgium	0.81	0.86	0.73	0.96	0.75	1	0.68	0.93	0.79	0.91
Austria	0.77	0.86	0.75	0.96	0.74	0.97	0.63	0.87	0.74	0.86
Denmark	0.81	0.87	0.73	0.92	0.79	0.99	0.71	0.91	0.83	0.94
Finland	0.69	0.77	0.64	0.8	0.59	0.77	0.61	0.8	0.63	0.73
France	0.76	0.82	0.68	0.92	0.7	0.98	0.63	0.9	0.73	0.89
Germany	0.76	0.81	0.7	0.94	0.7	1	0.59	0.86	0.75	0.91
Greece	0.53	0.56	0.64	0.68	0.68	0.78	0.57	0.63	0.52	0.56
Ireland	0.89	0.93	0.91	0.95	1	1	1	1	0.74	0.75
Italy	0.81	0.93	0.86	1	0.71	0.93	0.61	0.83	0.65	0.86
Luxembourg	1	1	1	1	1	1	1	1	1	1
Netherlands	0.95	1	0.83	1	0.81	1	0.72	0.97	0.91	0.99
Portugal	0.4	0.43	0.58	0.6	0.61	0.7	0.51	0.56	0.39	0.43
Spain	0.9	0.98	0.97	1	0.75	0.92	0.61	0.78	0.72	0.95
Sweden	0.69	0.74	0.7	0.86	0.65	0.82	0.62	0.81	0.72	0.82
UK	0.87	0.99	0.9	1	0.8	1	0.86	1	0.74	0.98
Norway	0.82	0.87	0.67	0.77	0.65	0.89	0.67	0.89	0.74	0.84
Malaysia	0.67	0.7	0.65	0.66	0.7	0.78	0.55	0.59	0.57	0.59
China	0.47	0.59	0.4	0.46	0.58	0.73	0.61	0.77	0.38	0.54
Indonesia	0.67	0.73	0.6	0.63	0.7	0.84	0.47	0.53	0.55	0.62
Japan	0.93	1	0.89	1	0.78	1	0.68	1	0.82	0.99
Philippines	0.5	0.53	0.53	0.54	0.72	0.79	0.61	0.64	0.45	0.48
Singapore	0.52	0.54	0.65	0.73	0.77	0.87	0.68	0.79	0.54	0.58
Thailand	0.7	0.74	0.73	0.74	0.68	0.81	0.44	0.49	0.52	0.55
Hong Kong	0.89	0.93	0.9	0.95	0.84	0.96	0.7	0.81	0.71	0.75
Mean	0.75	0.81	0.74	0.82	0.74	0.88	0.67	0.80	0.6651	0.7544
SA Mean	0.84	0.87	0.75	0.76	0.75	0.79	0.74	0.77		
EU Mean	0.78	0.84	0.77	0.90	0.75	0.92	0.69	0.86		
EA Mean	0.67	0.72	0.67	0.71	0.72	0.85	0.59	0.70		

Note: Technical Efficiency is calculated using Onfront Software. Higher values mean higher technical efficiency; while the value of 1 means that the country is moving along the best production frontier. Efficiency Indices are calculated using input and output data. Inputs are labour force, capital stock (constant 1995 US$) and life expectancy (in years); output is GDP at constant 1995 US$. LE denotes life expectancy included in efficiency measurement; WLE denotes efficiency measurement without life expectancy.

Figures 3 and 4.

Linear-Fit Plot of Relationship between Change in Efficiency and Efficiency Index, 1966

Figure 3.

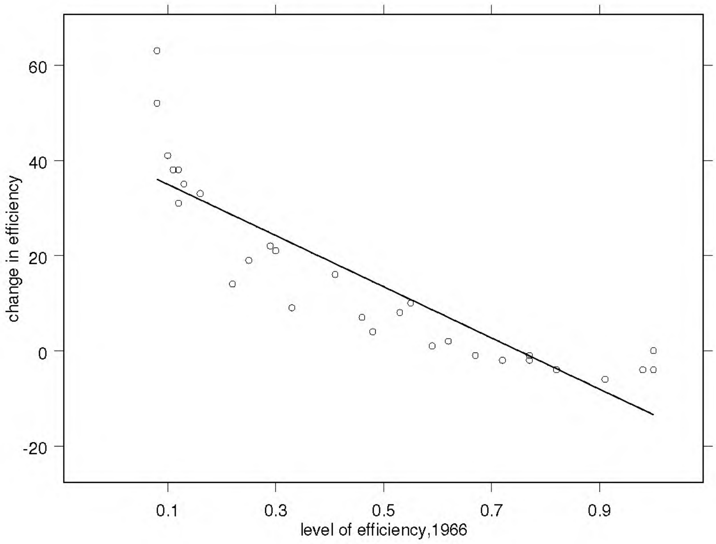
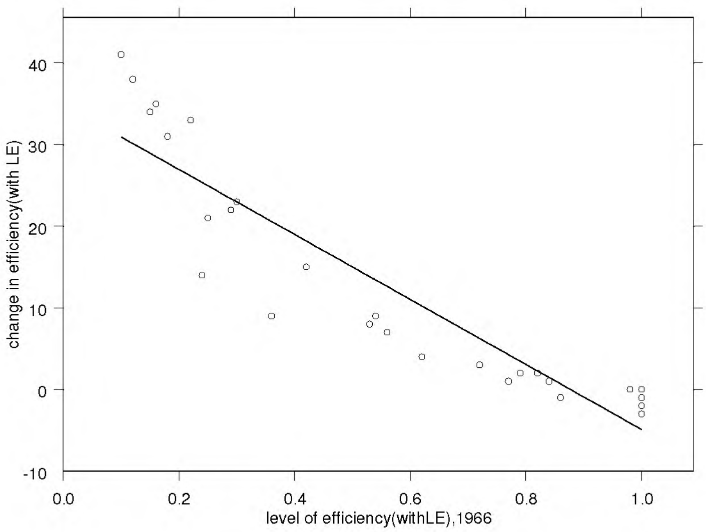


Figure 4.



The mean efficiency scores with life expectancy as an input are found – in all the years under study – to be greater than the efficiency scores without life expectancy. This seems to suggest that some of the measured inefficiency in the simpler model, in fact, has been attributed to a relative paucity of the quantity of human capital.

Ordinary least squares regression of the change in efficiency on the level of efficiency (without life expectancy) in 1966 (Regressing column 5 of Table 3 on Regressing Column 2 in Table I) yields a coefficient of –53.760 with *t*-statistics of –9.74, while ordinary least squares regression of the change in efficiency on the level of efficiency (with life expectancy) in 1966 (Regressing Column 5 of Table 4 on Regressing Column 3 in Table 2) yields a coefficient of -39.807 with *t*-statistics of –12.641, indicating that less efficient countries in 1966 have, on balance, benefited from efficiency improvements more than have the more efficient countries. Figures 3 and 4 confirm negative relationship between the two. These two results seem to imply that there is a tendency for technology transfer to reduce the gap between the rich and poor countries in the sample.

VI1.2. Empirical Results for Tri-partite and Quadri-partite Decomposition of the Factors Affecting Labour Productivity

We carried out the above calculations for the years 1966, 1971, 1976, 1981, 1986, 1991, 1996, and 2000 both with and without including life expectancy as an input in addition to capital stock and labour force. The conceptual decomposition is discussed in the section on Methodology. Appendix Tables (available with the author) give the results for finding out average efficiency changes, technological changes, capital accumulation, and human capital accumulation from 1966 to 2000. The results of tripartite decomposition of labour productivity are summarized in Table 3, while the results of quadripartite decomposition are summarized in Table 4.

Table 3 lists percentage changes in labour productivity and each of the three components from 1966 to 2000: (1) change in efficiency, (2) technological change, and (3) capital deepening for the 29 countries, along with the sample mean percentage changes. The overall averages provide striking evidence that none of the three factors was decisive for productivity changes in this period. The change in efficiency accounted for less than 16% of productivity change, technological change accounted for less than 15% of productivity change, while the contribution of capital deepening was strikingly negative. The same trend is true for South Asian and East Asian regions: change in efficiency accounted for 29.40 % of their labour productivity growth, technological change accounted for only 10.60% of this growth, while capital accumulation showed negative value for the South Asian region.

Table 3.

Percentage Change of Tri-partite Decomposition Indices

Country	Output Per Worker, 1966	Output Per Worker, 2000 p.	Productivity Change (1966–2000)	(EFF-1) *100	(TECH-1) *100	(KACC-1) *100
Bangladesh	468	706	50.65	22	6	–13
India	428	1036	141.84	38	14	–18
Nepal	285	521	82.6	8	9	–2
Pakistan	657	1376	109.23	38	11	–18
Sri Lanka	864	2055	137.86	41	13	–20
Belgium	34083	74499	118.58	–1	12	2
Austria	29628	70335	137.39	–1	13	1
Denmark	43.752	69.814	59.57	–4	7	5
Finland	26063	63509	143.67	1	14	0
France	32043	66330	107	–2	11	2
Germany	40514	65671	62.09	–6	7	7
Greece	14479	30449	110.29	9	12	–6
Ireland	16835	66177	293.1	16	22	–11
Italy	21508	46789	117.54	4	12	–2
Luxembourg	44493	131722	196.05	0	17	0
Netherlands	38955	67133	72.34	–4	8	5
Portugal	9721	25425	161.53	14	16	–10
Spain	18238	39339	115.69	7	12	–2
Sweden	36477	57916	58.77	–4	7	4
UK	23580	44412	88.53	10	10	–4
Norway	34465	72988	111.77	–2	11	2
Malaysia	3541	11602	227.59	33	19	–8
China	185	1375	641.68	31	34	–18
Indonesia	647	2095	223.83	63	19	–8
Japan	27609	83224	201.44	2	18	0
Philippines	2152	2731	26.91	52	4	–17
Singapore	10194	57290	461.96	19	29	–10
Thailand	1232	4656	277.69	35	22	–8
Hong Kong	11891	46671	292.49	21	22	–7
Grand Mean	**18103**	**41649.86**	**166.53**	**15.17**	**14.17**	**–5.31**
SA Mean	540.40	1138.8	104.44	29.40	10.60	–14.2
EU15 + Norway Mean	29052	62031	122.11	2.31	11.94	–44
EA Mean	7181	26205	294.20	32	20.88	–9.5

Table 4.

Percentage Change of Quadri-partite Decomposition Indices

Country	Output per Worker, 1966	Output per Worker, 2000	Productivity Change (1966–2000)	(EFF-1) *100	(TECH-1) *100	(KACC-1) *100	(HACC-1) *100
Bangladesh	468	706	50.65	22	–1	–13	7
India	428	1036	141.84	7	7	–1	6
Nepal	285	521	82.6	8	2	–2	7
Pakistan	657	1376	109.23	38	5	–18	6
Sri Lanka	864	2055	137.86	41	10	–20	3
Belgium	34083	74499	118.58	2	10	–2	2
Austria	29628	70335	137.39	3	11	–2	2
Denmark	43752	69814	59.57	–1	6	2	1
Finland	26063	63509	143.67	4	12	–4	2
France	32043	66330	107	1	9	–1	2
Germany	40514	65671	62.09	–2	5	3	2
Greece	14479	30449	110.29	9	10	–7	2
Ireland	16835	66177	293.1	15	20	–10	2
Italy	21508	46789	117.54	1	10	–1	2
Luxembourg	44493	13172	196.05	0	15	0	2
Netherlands	38955	67133	72.34	–3	7	3	1
Portugal	9721	25425	161.53	14	13	–10	2
Spain	18238	39339	115.69	–3	10	4	2
Sweden	36477	57916	58.77	–1	5	1	1
UK	23580	44412	88.35	0	8	0	2
Norway	34465	72988	111.77	2	10	–1	1
Malaysia	3541	11602	227.59	35	14	–9	5
China	185	1375	641.68	9	25	–2	12
Indonesia	647	2095	223.83	33	11	–1	8
Japan	27609	83224	201.44	0	15	0	3
Philippines	2152	2731	26.91	31	0	–10	4
Singapore	10194	57290	461.96	21	25	–13	3
Thailand	1232	4656	277.69	34	16	–7	5
Hong Kong	11891	46671	292.49	23	18	–9	3
Grand Mean	**18103**	**41649**	**166.53**	**11.83**	**10.62**	**–4.48**	**3.44**
SA Mean	540.40	1138.8	104.44	23.20	4.6	–10.8	5.8
EU15 + Norway Mean	29052	62031	122.11	2.5625	10.06	–1.56	1.75
EA Mean	7181	26205	294.20	23.25	15.50	–6.38	5.38

For the East Asian region, the change in efficiency accounted for 32% of their labour productivity growth, technological changes accounted for 20.88% of labour productivity growth, while capital accumulation showed negative value. For the EU15 + Norway region, the change in efficiency accounted for mere 2.31% of its labour productivity growth, only 11.94% of growth was contributed by technological changes, while capital accumulation showed negative value. Such results seem to convey that there are factors, other than decomposed in the growth accounting exercise, which may have profound affects on labour productivity growth rates across the sampled countries. We found earlier in the conditional convergence analysis that trade openness, population's growth rate and savings rate may be key in explaining differential levels of growth per capita across nations included in our sample. It seems that there are more important factors, in particular for the South Asian Region, besides the ones taken here in the growth accounting exercise, which can have greater impact on labour productivity and GDP per capita growth rates. These may be, among others, the policies directed towards higher infrastructure spending, making bureaucracy efficient, reducing corruption, less restrictive labour regulations, achieving political stability, implementing rule of law, understanding institutions.

Figure 5 summarizes these calculations by plotting the four growth rates (labour productivity and its three components against labour productivity in 1966). OLS regression lines are also plotted.

Figure 5(a) indicates that the increases in average productivity reflect positive growth over this period for the countries included in our sample. The prominent spikes at lower relative incomes reflect the economic emergence of the Asian «miracle» countries. They are consistent with the observation about the movement of probability mass from lower and middle income group to higher income group in the cross country distribution (see introduction of section I). The negative slope coefficient of 0.0282 with t-value as 1.855, while not statistically significant at 5% level of significance without inclusion of critical conditioning variables, is the empirical result that led many to argue that productivity growth patterns support absolute convergence[5] among South Asian, European Union 15 + Norway and East Asian countries together (Mathur, 2004).

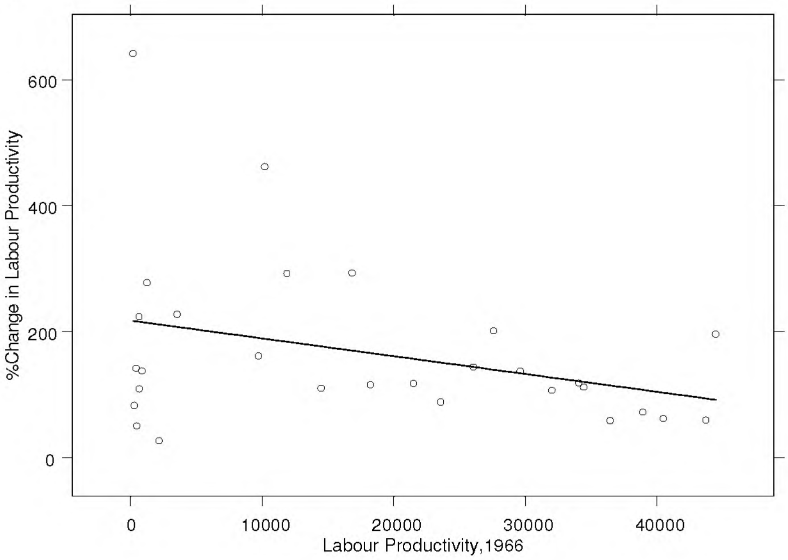
---

[5] If the poor country's initial income per head is below the rich country's income per head, then the poor country must grow more rapidly (higher marginal productivity and attracting capital from abroad) than the rich country in order for both to ultimately achieve the common level of income per head (assuming same technology, production, population, preferences across countries). This is called absolute beta convergence (also called unconditional convergence because it implies that all countries/regions are converging to common steady state level of income). In its strongest form, the implication of this hypothesis is that, in the long run, countries or regions should not only achieve the same steady state of income per capita, but also the same per capita growth rates. However, these structural parameters differ across countries and regions, and countries may not converge to a common level of income per capita, but to their own steady state level (long-run potential level of income). Therefore, economies with lower levels of per capita income (expressed relative to their steady state levels of per capita income) tend to grow faster. Such convergence is called conditional convergence.

Figure 5.

Percentage Changes in Labour Productivity and Three Decomposition Indices during 1966–2000 Plotted Against Labour Productivity in 1966

a)



b)

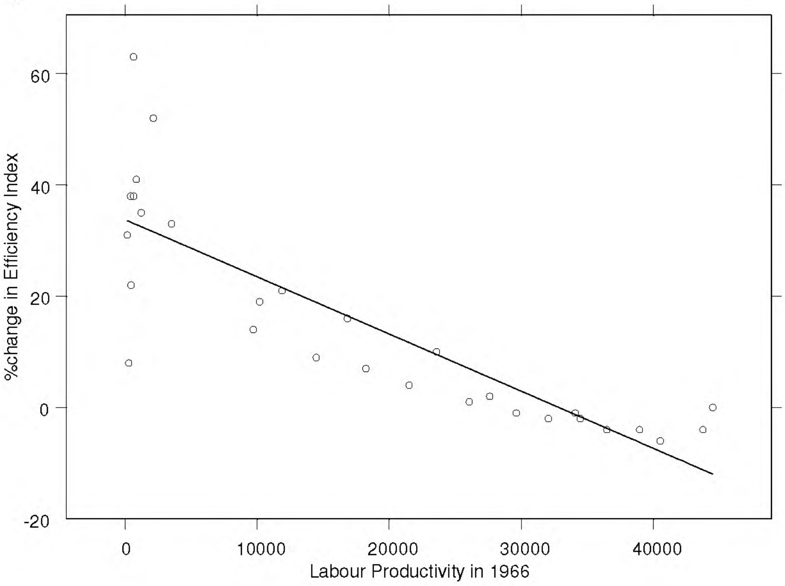
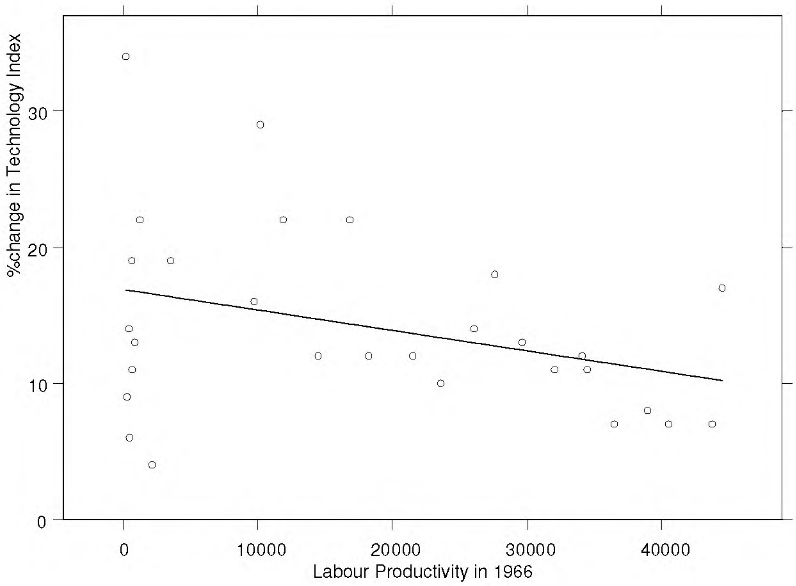


Figure 5 (Continued)

c)



d)

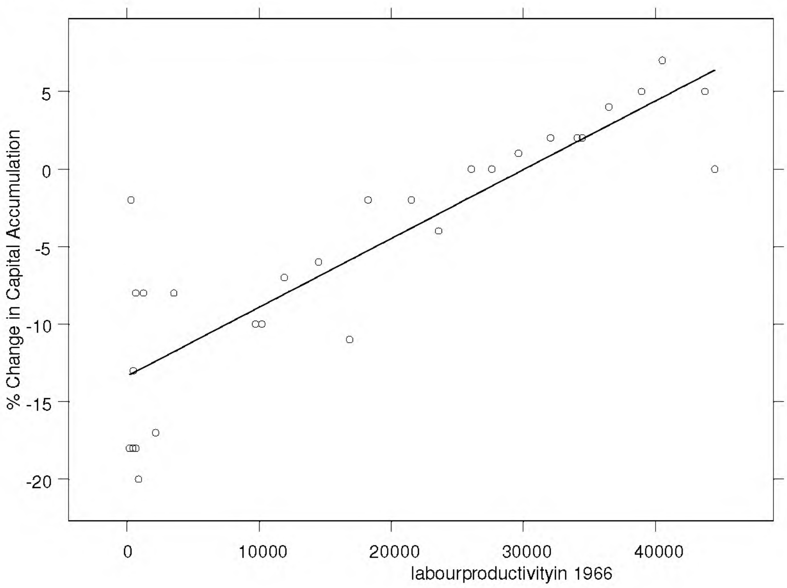


Figure 5(b) shows negative relationship between the percentage change in efficiency index and the initial level of productivity. Beta coefficient has negative value of –0.00103 with *t*-value of –8.255 and R^2 of .716. The results suggest that technological catch-up is partly responsible for closing some of the gap between the rich and the poor nations, which is true at least for the East Asian economies, since the developed nations have been partly responsible for technology transfers to their region (then underdeveloped) since the 1960s. Technological transfer, however, in the South Asian countries is relatively low, but it can play an important role in increasing their growth rates.

Figure 5(c) shows that the relationship between technological changes and initial level of labour productivity is negative (–0.00015), though not significant (*t*-value of –1.875). For the East Asian region, technological change is responsible for larger than average contribution to growth. It has been quite moderate for the South Asian and EU15 + Norway regions.

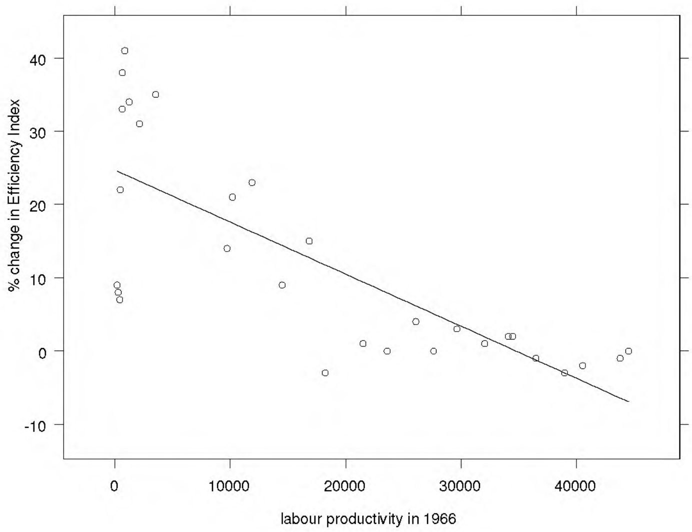
Figure 5(d) shows that the relationship between capital accumulation and growth is positive and significant (coefficient value is 0.000443 with *t*-value of 9.120). The positive regression slope coefficient suggests that relatively wealthy countries have benefited more from capital accumulation than have the less developed economies.

Table 4 lists percentage changes in labour productivity and each of the four components from 1966 to 2000: (I) change in efficiency, (II) technological change, (III) capital deepening, and (IV) human capital accumulation for all 29 countries, along with the sample mean percentage changes. The overall averages provide striking evidence that none of the four factors was decisive in most of the productivity improvements over this period. Change in efficiency accounted for less than 12%, technological change accounted for less than 11%, human capital accumulation accounted for less than 4% of labour productivity growth, while the contribution of capital deepening was strikingly negative. One finds the same trend for South Asian and East Asian regions: the change in efficiency accounted for 23.20% of their labour productivity growth, only 4.6% of labour productivity growth was produced by technological changes, human capital accumulation accounted for 5.8%, while capital accumulation showed negative value for the South Asian region. For the East Asian region, the change in efficiency accounted for 23.25% of its labour productivity growth, 15.50% if it was generated by technological changes, human capital accumulation accounted for 5.38% of labour productivity growth, while capital accumulation showed negative value. For the EU15 + Norway region, the change in efficiency accounted for mere 2.56% of its labour productivity growth, 10% was produced by technological changes, 1.75% was produced by human capital accumulation, while capital accumulation showed negative value. Such results convey that there are other factors, besides the ones decomposed in the growth accounting exercise, which have important bearing on the rates of labour productivity growth in the countries of European (EU15 + Norway), South Asian and East Asian regions.

Figure 6.

Percentage Changes in Labour Productivity between 1966 and 2000 and Four Decomposition Indices Plotted Against 1966 Labour Productivity

a)



b)

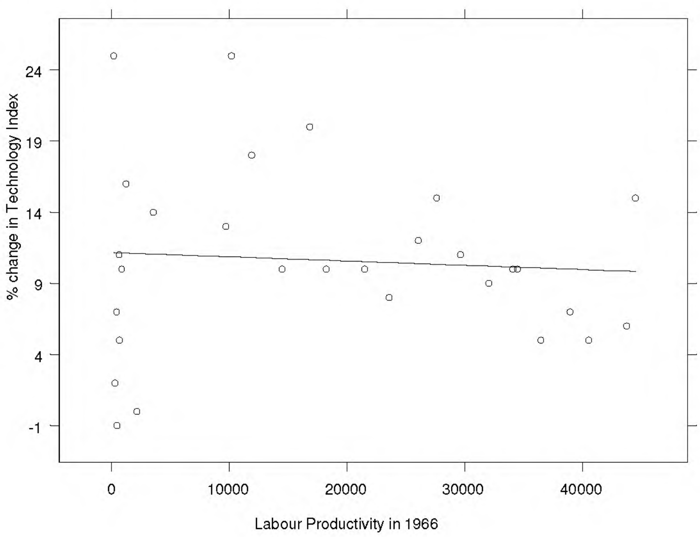
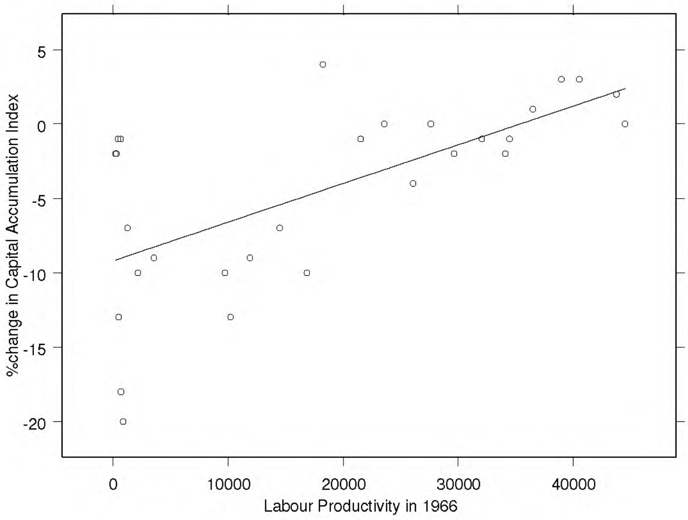


Figure 6 (Continued).

c)



d)

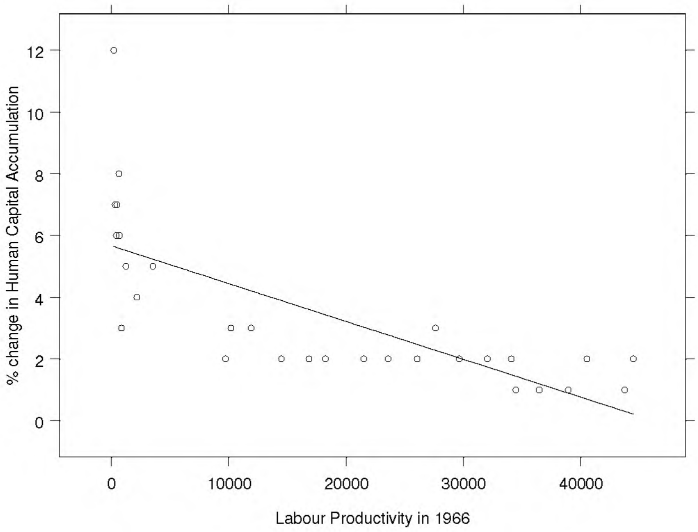


Figure 6 summarizes these calculations by plotting the four growth rates (four labour productivity components) against labour productivity of 1966. This exercise includes life expectancy (human capital) as an input in addition to capital stock and labour force. OLS regression lines are also plotted.

Figure 6(a) shows negative relationship between the percentage change in efficiency index and the initial level of productivity. Beta coefficient has negative value of –0.000711 with *t*-value of –6.369. The results suggest (as before) that technological catch-up is partly responsible for closing some of the gap between the rich and the poor nations (then East Asian countries).

Figure 6(b) shows that the relationship between technological changes and initial level of labour productivity is found to be negative (–0.00002), though not significant (*t*-value –0.383).

Figure 6(c) shows that the relationship between capital accumulation and growth is positive and significant (coefficient value is 0.00026 with *t*-value of 4.343). The positive regression slope coefficient suggests that relatively wealthy countries have benefited more from capital accumulation than have the less developed economies.

Figure 6(d) shows that the relationship between human capital accumulation and growth is negative and significant (beta slope coefficient is –0.000123 and *t*-value is –5.677). The countries with lower labour productivity in the 60-s accumulated human capital at faster rates than did the economies that were relatively developed in the 60-s. Apparently, human capital accumulation has contributed to convergence of productivity levels.

VII.3. The Analysis of Productivity Distributions

Our objective is to assess whether the three components and then the four components of labour productivity can together change account for the deformation of the distribution of labour productivity from tri-modal distribution in 1966 to bi-modal distribution in 2000 with higher mean. The distributions are reproduced again here for convenience (Figure 7a – 1966 distribution and 7b – 2000 distribution).

The distribution we employ is non-parametric kernel-based density estimates, essentially Rosenblatt Parzen kernel density estimator (details are given in the Objectives and Methodology section).

Let us rewrite the quadripartite decomposition of labour productivity changes as follows:

$$y_c = (EFF \times TECH \times KACC \times HACC)^* \, y_b$$

Figure 7(a).

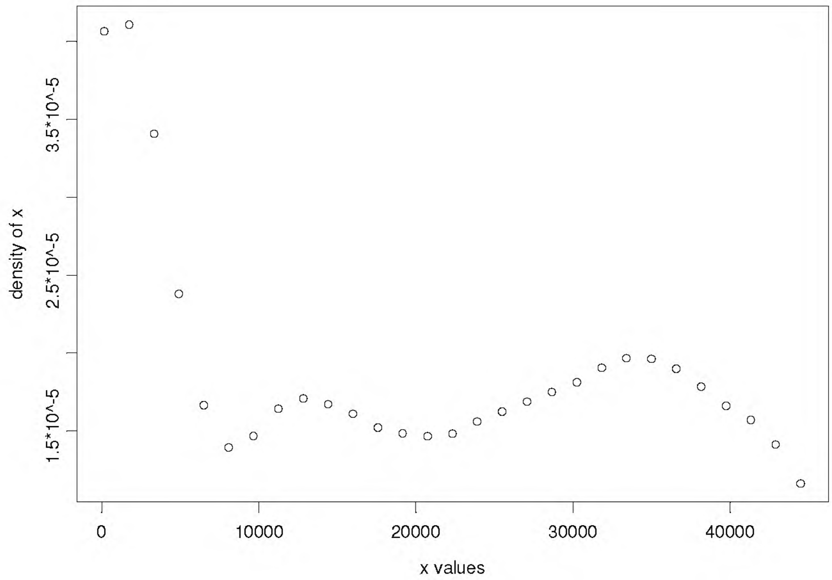


Figure 7(b).

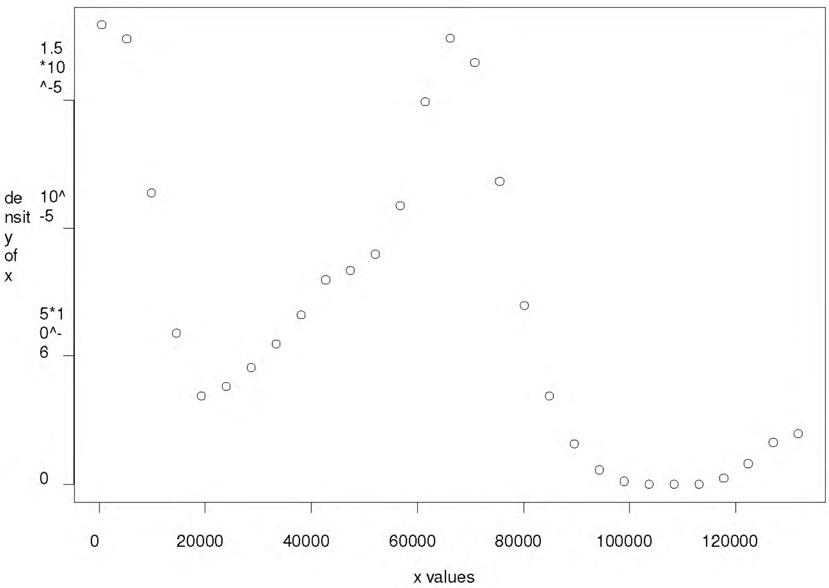
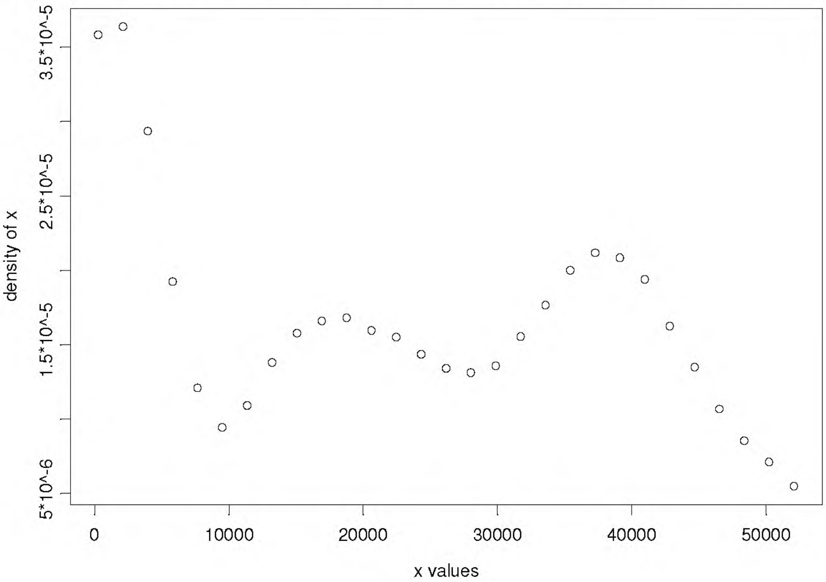


Figure 8.

Counterfactual Distribution of Labour Productivity, 2000 (LE Included)



Thus, the labour productivity distribution in 2000 can be constructed by successively multiplying labour productivity in 1966 by each of the four factors. The counterfactual distribution of 2000 is constructed (Figure 8) by multiplying the average decomposition figures successively by labour productivity in 1966. It seems from the figure that the distribution remains tri-modal and, therefore, the four decomposition factors of labour productivity: efficiency change, technological change, capital accumulation, and human capital accumulation together have not been able to transform the 1966 distribution and bring it at par with the actual 2000 bi-modal distribution of labour productivity[6]. This means that some other factors like savings rate, trade openness, and population's growth rate might be responsible for the transformation of tri-modal distribution of 1966 into the bi-modal distribution of 2000. It is found that constructing counterfactual distribution of 2000 by decomposing labour productivity into three factors also does not change the results. This reconfirms our earlier findings in the previous section.

[6] Two-Sample Kolmogorov-Smirnov Test confirms the acceptance of the null hypothesis-two sample kernel probability distributions are the same; data: *x*: Counterfactual labour productivity distribution in 2000 (V1); *y*: labour productivity distribution in 1966 (V2); *ks* = 0.1034; p-value = 0.9985; alternative hypothesis: *cdf* of *x:* V1 in SP66 does not equal the cdf of *y*: V2 in SP66 for at least one sample point. Statistical software SPLUS has been used. The data set is in Appendix Table (AVAILABLE WITH AUTHOR).

Conclusions

We estimate efficiency levels of 29 sampled countries using the data envelopment analysis. Luxembourg has efficiency scores of 1 in all the years with or without life expectancy (human capital). The Netherlands also have an efficiency score of 1 in 1966, 1971, 1976 and 1981. Japan, UK, Belgium, Ireland, Indonesia, Spain, and Germany have efficiency scores of 1 in at least one of the years from 1966 to 2000. In 2000 though, mean efficiency levels (life expectancy not included) of South Asian countries are higher than those of the European (EU15 + Norway) and East Asian countries. Japan has the highest average efficiency followed by Hong Kong in the East Asian region in the period of 1966–2000. Also, the initial level of labour productivity and efficiency index in 1966 had significant impact on efficiency changes from 1966 to 2000, signifying that there is evidence of technological upturn among the countries which were relatively backward in 1960s. This seems to hold in respect to East Asian economies that got the boost due to technological transfers from the developed nations during the same period and also because they started to open their economies at the same time. South Asian economies, on the other hand, remained closed in 1960s and subsequently could not grow at faster rates.

We decompose labour productivity growth into components attributable to technological changes (shifts in the overall production frontier), technological catch-up (movement towards or away from the frontier), capital accumulation (movement along the frontier), and human capital accumulation (proxied by life expectancy). The overall production frontier is constructed using deterministic methods requiring neither specification of functional form for the technology, nor any assumption about market structure or absence of market imperfections. Growth accounting results tend to convey that for East Asian and South Asian countries, efficiency changes contributed the most, while for the European countries (EU15 + Norway), it is technical changes that contributed to labour productivity changes between 1966–2000. We also analyze the evolution of cross-country distribution for the 29 countries included in our sample and consisting of some South Asian, East Asian and European countries (EU15 + Norway) using Kernel densities. It seems that there are factors like savings rate, trade openness, quality of institutions, geography, etc., other than the ones included in the above growth accounting exercise, which are primarily responsible for the existence of bi-modal labour productivity distribution for the sampled countries (Mathur 2005). This particular research problem may be taken up by researchers in the future. Our results contradict the Kumar and Russel's (2002) and Henderson and Russell's (2003) results that found that different rates of capital accumulation and human capital across nations were primarily responsible for the existence of differential levels of per capita income levels and growth rates across nations respectively, and further, such factors were also responsible for the evolution of bi-modal distribution of labour productivity existing today across nations. In a way, the Kumar and Russel's results confirmed the use of simple and extended Solow model (Solow, 1956; Jones, 2002) along with factor accumulation assumptions in analyzing the convergence process of per capita incomes across nations. Our growth accounting and regression exercises suggest that there is some evidence of absolute convergence (which supports the use of the Solowian model (1956) in this context) and convergence in statistical terms of efficiency changes and human capital accumulation across countries of European (EU15 + Norway), South Asian and East Asian regions.

Generally speaking, the policies that will increase labour productivity (particularly in the services sector), open up trade with all countries, increase the share of savings in GDP, reduce adverse administrative regulations, increase infrastructure spending, policies that support private capital flows (along with technology and human capital skills transfers) from rich to poor nations can increase the countries' efficiency levels, contribute to reducing per capita income differences and growth rates across countries and regions, as well as help achieving the basic goal of planning, which is to improve the living standard of the people.

Bibliography

1. Afriat, Sydney (1972). Efficiency Estimation of Production Functions // International Economic Review, October 1972, 13 (3), pp. 568–598.
2. Banker, R. D. (1990). Stochastic data envelopment analysis. – Working Paper, Department of Economics and Department of Agricultural and Resource Economics,Oregon State University, Corvallis, OR. 97331 USA.
3. Charnes, Abraham, Cooper, William W., and Rhodes, E. (1978). Measuring the Efficiency Of Decision-Making Units // European Journal of Operational Research, 1978, pp. 429-444.
4. Charnes, Abraham; Cooper, William W.; Lewin, Arie Y. and Seiford, Lawrence M. (1994). Data envelopment analysis: Theory, methodology, and application, Boston, MA: Kluwer Academic Publishers.
5. Chou, Ji (1993). Old and New Development Models:The Taiwanese Experience. – Paper presented at the NBER-East Asia seminar in Economics Fourth Annual Conference.
6. Coelli, T., D.P. Rao, and G. Batteese (1998). An introduction to efficiency and productivity analysis. London, Kluwer Academic Publishers.
7. Diewert, E (1980). Capital and the Theory of Productivity Measurement // American Economic Review, 70, pp. 260–267
8. Farrell, Michael J. (1957). The Measurement of Productive Efficiency», Journal of the Royal Statistical Society, Series A, General, 1957, 120 (3), pp. 253–82.

9. Fare, Rolf; Grosskopf, Shawna; Norris, M. and Zhang, Z. (1994b). Productivity Growth, Technical Progress and Efficiency Change in Industrialized Countries // American Economic Review, March , 84 (1), pp. 66–83.
10. Galor, Oded (1996). Convergence? Inferences from Theoretical Models // Economic Journal, July, 106 (437), pp. 1056–69.
11. Gijbels, Irene; Mammen, Enno; Park Byeong U. and Simar, Leopold (1999). On Estimation of Monotone and Concave Frontier Functions // Journal of the American Statistical Association, March 1999, 94 (445), pp. 220–28.
12. Henderson, D. J. and R. Robert Russell (2003). Human Capital and Convergence: A Production-Frontier Approach. – Revised August 2003, University of California, Riverside Working Paper No. 29.
13. Jones, C. I. (1997). On the Evolution of the World Income Distribution// Journal of Economic Perspectives, Summer 1997.
14. Jones,Charles I. (2002). Introduction to Economic Growth. – Second Edition, WW Norton and Company, Incorporation, US.
15. Kneip, Alois, Park, Byeong U. and Simar, Leopold (1998). A Note on the Convergence of Non-parametric DEA Estimates for Production Efficiency Scores // Econometric Theory, December 1998, 14 (6), pp. 783-93.
16. Kumar, Subodh and Robert Russell (2002). Technological Change, Technological Catch-up and Capital Deepening: Relative Contributions to Growth and Convergence // American Economic Review, Volume 92, No. 3.
17. Mathur, Somesh K. (2004). Absolute Convergence: Its Speed for Selected Countries for 1961–2001 // Journal of Indian School of Political Economy, Volume XVI, January-March Issue.
18. Mathur, Somesh K. (2005). Perspectives of Economic Growth in Selected South Asian and East Asian Countries. – PhD submitted to the International Trade Division, JNU, Delhi, India.
19. Quah, D. (1993). Galton's Fallacy and Tests of Convergence Hypothesis // Scandinavian Journal of Economics, 95 (4), pp. 427–443.
20. Quah, D. (1996). Convergence Empires across Economies with (Some) Capital Mobility // Journal of Economic Growth, March 1996a. 1(1), pp. 95–124.
21. Quah, D. (1996). Twin Peaks: Growth and Convergence in Models of Distribution Dynamics // Economic Journal, July.
22. Quah, D. (1997). Empirics for Growth and Distribution: Stratification, Polarization,and Convergence Clubs // Journal of Economic Growth 2, pp. 27–59.
23. Rosenblatt, M. (1956). Remarks on some nonparametric estimates of a density function // Annals of Mathematical Statistics, 27, pp. 642–69.

24. Simar, Leopold (1996). Aspects of Statistical Analysis in DEA-Type Frontier Models // Journal of Productivity Analysis, July,7 (2–3), pp. 177–85.

25. Simar, Leopold and Wilson, Paul W. (2000). A General Methodology for Bootstrapping in Non Parametric Frontier Models // Journal of Applied Statistics, August, 27(6), pp. 779–802.

26. Solow, Robert M. (1956). A Contribution to the Theory of Economic Growth // Quarterly Journal of Economics, 70 (February), pp. 65–94.

The article was received on April 2, 2005.