Growth Accounting for Some Selected Developing, Newly Industrialized and Developed Nations from 1966-2000: A Data Envelopment Analysis

Somesh.K.Mathur[1]

Key Words: data envelopment analysis, growth accounting, technical efficiency, efficiency change, technological change, capital accumulation, human capital accumulation, kernel smoothing, cross country labor productivity distribution and counterfactual distributions

Abstract

We work out technical efficiency levels of 29 countries consisting of some selected South Asian, East Asian and EU countries using data envelopment analysis. Luxembourg has an efficiency score of one(most efficient) in all the years .Netherlands also has an efficiency score of one in 1966,1971,1976 and 1981.Japan,UK,Belgium,Ireland,Indonesia,Spain and Germany has an efficiency score of one in at least one of the years from 1966 to 2000.In the year 2000 though mean efficiency levels(without including life expectancy as input) of South Asian countries is higher than the European Union Countries and East Asian countries. Japan has the highest average efficiency followed by Hong Kong in the East Asian region in the period 1966-2000.

We also decompose labor productivity growth into components attributable to technological changes (shifts in the overall production frontier), technological catch up or efficiency changes(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 no specification of functional form for the technology nor any assumption about market structure or the absence of market imperfections. Growth accounting results tend to convey that for the East Asian and the South Asian countries efficiency changes(technological catch up) have contributed the most, while for the European countries it is the technical changes which has 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 using Kernel densities. It seems that there are other factors like trade openness,quality of governments,population rate of growth, savings rate, corruption perception indices, rule of law index, social capital and trust variables, formal and informal rules governing the society, among others, rather than the ones that are included below for the growth accounting exercise, which are **primarily** responsible for the existence of bimodal labour productivity distribution for countries included in our sample. However, from this growth accounting exercise, we do find that there is convergence in statistical terms of efficiency changes and human capital accumulation across countries of the EU, South Asian and East Asian regions.

I: Introduction

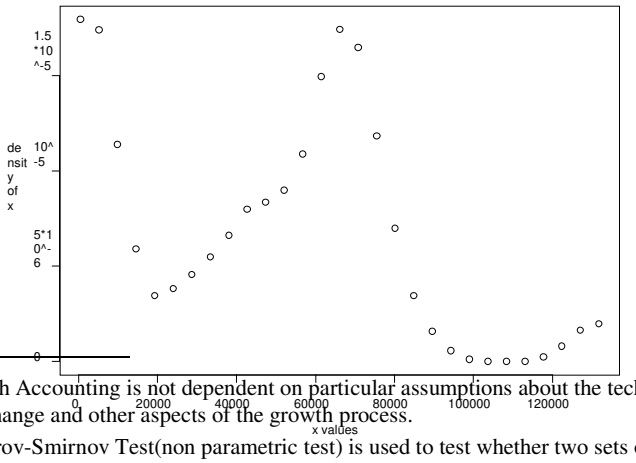
Very much in the spirit of Quah's (1993, 1996b, 1997) suggested approach (also adopted by Galor [1996] and Jones [1997]), we analyze the evolution of the entire distribution of the four growth factors: technological change, technological catch-up, capital accumulation and

[1] Lecturer,Department of Economics,Jamia Millia Islamia(JMI),new Delhi-25,India.This paper is culled out of the Phd thesis entitled "Perspective of Economic Growth in Selected South Asian and East Asian Economies".

human capital accumulation[2]. We analyze the contribution of these four components to the growth of countries labour productivity and to the 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. The countries production frontier is constructed using deterministic methods requiring no specification of functional form for the technology nor any assumption about market structure or the absence of market imperfections. Technological catch up signifies movement towards the frontier, technical change is movement of the frontier, capital accumulation is movement along the frontier and human capital accumulation implying changes in the efficiency of labor.

Quah has argued compellingly that analyses based on standard regression methods focusing on first moments of the distribution cannot adequately address the convergence issue. These arguments are buttressed by the empirical analyses of Quah and others posing a robust stylized fact about the international growth pattern that begs for explanation. A plot of the distribution of output per worker across 29 countries consisting of 5 South Asian,8 East Asian and 16 EU countries(country names are given in Appendix Table I at the last) in 2000 and 1966 appears in Figure 1 and II respectively, below. (The data and the kernel based method of smoothing the distribution is described below in the section on methodology). Over this 34 year period, the distribution of labour productivity was transformed from a tri-modal distribution in 1966 into a bimodal distribution in 2000 with a higher mean(data on output per worker is available in Table III below- column II and Column III)[3]. This transformation in turn means that, while in 1966 there were countries in the lower, middle income and upper income groups, in 2000 the world had become divided, as a stylized fact, into two categories: the rich and the poor. It seems that

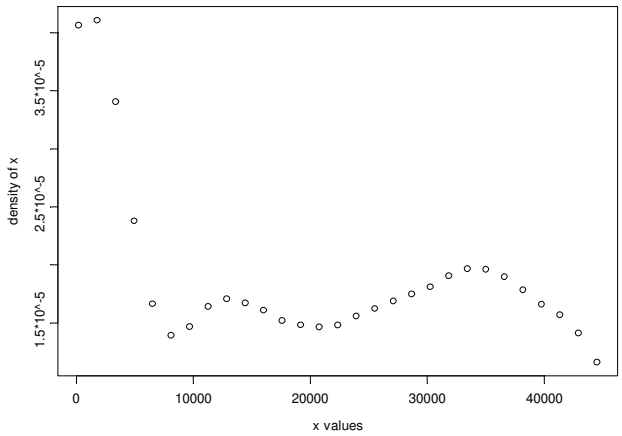
Figure I: Distribution of Output Per Worker , 2000(Bimodal)



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

[3] 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 alternative 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 II: Distribution of Output Per Worker , 1966 (Trimodal)



that almost all of the East Asian economies have joined the elite rich group . Quah (1996a, b, 1997) refers to this phenomenon as "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 is aimed at explaining this bipolarization of the distribution of output per worker, as well as its growth pattern, in terms of the tripartite and quadripartite 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 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 bimodal distribution of per capita income across countries. Also, related to the concept of labour productivity is the concept of efficiency, i.e amount by which outputs can be increased without requiring extra inputs. We will also work out the efficiency levels of countries included in our sample by using linear programming method of data envelopment analysis .

The main variables in use in this study will be 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 different countries/ regions included in our study.

The paper is organized as follows. Section II reviews literature on data envelopment analysis and on growth accounting without the need for specification of a functional form for the technology, for the assumption that technological change is neutral, or for the assumptions about market structure or the absence of market imperfections. Section III is on objectives of

the study, Section IV states the hypothesis. Section V is on Methodology. Section VI describes the variables used in the efficiency analysis and in this study and gives an account of the data source. Section VII discusses the results for efficiency levels and changes and growth accounting of the countries included in our sample .Section VIII discuses the counterfactual probability distribution and contrasts it with the labour productivity distribution of 1966. Section IX is on limitations of the study and Section X gives conclusions. References and Appendix Tables I and II are at the end.

II.Review of Literature:Data Envelopment Analysis and Growth Accounting

We have used DEA framework to work out efficiency indexes for countries included in our sample.

II.1Data envelopment analysis (DEA)

DEA is a mathematical programming approach for estimating the 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 (1957) multiple input, single output measures of TE to the multiple-output, multiple input technology. Since the early Charnes et al. work, however, DEA has developed and expanded to include a wide variety of applications. DEA has been used to assess Technical efficiency, scope, scale, and allocative efficiency. It has also been used to estimate optimal input utilization, productivity, identify strategic groups, determine benchmarks and total quality management programs, estimate social and private costs of regulating undesirable outputs and capacity (Kirkley et al. 2000). The DEA models have been extended from the static, deterministic models to include dynamics and stochastic aspects (Fare and Grosskopf 1996; Banker 1990; and Resti 2000). Procedures have been developed to deal with temporal aspects and balanced panel data (e.g., the window analysis approach of Charnes et al. (1994)).

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., output is as large as possible given the technology and input levels, or input levels are as small as possible given the output levels). The frontier technology is formed as a non-parametric, piece-wise, linear combination of observed "best-practice" activities. Data points are enveloped with linear segments, and TE scores are calculated relative to the frontier technology.

In addition to being a mathematical programming approach for estimating TE, It is non-statistical and non-parametric. When we say it is non-statistical, we are implying that estimates are not based on any statistical distribution (e.g., the normal) and noise is not explicitly considered in the estimation; that does not mean, however, that

statistical tests of the various estimates cannot be performed. An alternative view is that DEA is deterministic. When we refer to DEA as being non-parametric, we are referring to the fact that we do not have to assume a particular functional relationship between the inputs and outputs; we do not have to assume any statistical distribution; and we do not have to estimate parameters based on assumed statistical distributions.

To address the issue of DEA being non-stochastic, there has been an increasing emphasis on developing a stochastic DEA (Banker 1990; Resti 2000). Resti offers multiplicative and heteroscedastic multiplicative stochastic DEA models; Resti also presents a detailed comparison of deterministic and stochastic DEA and SPF(Stochastic Production Frontier) models. At the present time, however, developments in stochastic DEA appear to be too limited to adequately evaluate, and thus, the criticism of DEA being non-stochastic will likely remain.

Another criticism of DEA is that it is non-statistical. This may be an appropriate criticism. DEA does not yield estimates that can be easily validated with conventional statistical procedures. To address this problem, some researchers have recommended bootstrapping, which does permit confidence intervals to be estimated. In addition, a wide variety of non-parametric techniques have been employed to examine various properties of the TE estimates (Banker 1990).

Sensitivity to outliers has been another criticism of DEA (Coelli et al. 1998). Thompson et al. (1994) and Burges and Wilson (1993), however, offer evidence to the contrary. Sensitivity to outliers may also pose problems for estimating the SPF or any regression relationship. As such, the sensitivity issue is probably over-exaggerated.

Another common but erroneous criticism is that DEA does not adequately address the underlying economics. It is a primal approach. This is a serious misconception of DEA. DEA can easily accommodate economic behavior by using cost and revenue specifications. Fare et al. (1997) offer one approach for estimating profit efficiency using a DEA model. More important, the economic-based DEA models allow decomposition of economic efficiency into technical and allocative components (Fare et al. 1994); Coelli et al. 1998). From a cost or revenue-based framework, total economic efficiency (EE) can be decomposed into the product of allocative (AE) and technical efficiency (TE). Moreover, TE Can be further decomposed into scale efficiency (SE), congestion (CN), and a residual TE components (TE(u,y|V,W)), where the residual is a TE measure given variable returns to scale and weak disposability. Overall, EE can subsequently be decomposed into the product of AE, SE, CN, and TE(u,y|V,W) relative to a cost (input orientation or revenue (output) orientation (Fare et al. (1994) and Ceolli et al. (1998) provide detailed discussions on EE and the relative decompositions).

Coelli et al. (1998) offer 11 possible limitations that one may encounter in conducting a DEA, and a comparison of the advantage and

disadvantage of DEA and the SPF(Stochastic Production Frontier) approach. They also note that the 11 problems are likely applicable to the SPF approach. Coelli et al. conclude that the SPF approach may be more applicable in situations where the data are heavily influenced by measurement error and random effects.In this study we use DEA analysis for working out efficiency index.

II.2 Growth Accounting

The results of total factor productivity estimation differ due to different assumptions made in respect of production functions and limitations of data availability on productivity of capital and labor and quality of workers.Kumar and Russell(KR,2002) and Henderson and Russell(2003) studies are exceptions.

Kumar and Russel (2002) use frontier methods to analyze international macroeconomic convergence. In particular, they decompose the labor-productivity growth of 57 industrial, newly industralized, and developing countries into components attributable to (1) technological change (shifts in the world production frontier),(2) technological catch-up (movements toward 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, for the assumption that technological change is neutral, or for assumptions about market structure or the absence of market imperfections. Indeed, market imperfections, as well as technical inefficiencies, are possible reasons for countries falling below the world-wide production frontier. Taking a cue from the Quah critique spelled out in the introduction of this study, KR(2002) go on to analyze the evolution of the entire distribution of these three growth factors.

Although the analysis of KR is quite simple, it yields somewhat striking results:

(1) While there is substantial evidence of technological catch-up (movements toward the 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—indeed, possibly some implosion—at very low capital/labor ratios, modest expansion at relatively low capital/labor ratios, and rapid expansion at high capital/labor ratios.

(3) Both growth and bimodal polarization are driven primarily by capital deepening.

Henderson and Russell(2003) introduce human capital into the Kumar and Russell(KR,2002) growth accounting analysis of international macroeconomic convergence.They amend the KR methodology by (1) adopting the Diewert(1980) approach to dynamic frontier analysis,thus precluding implosion of the worldwide production frontier over time and (a) changes in the mean and (b) mean-preserving shifts in the distribution of productivity.Their principal conclusions were

* Over half of the increase in mean productivity attributed to KR to the accumulation of physical capital was,in fact, the result of the accumulation of human capital.

* In contradiction to the KR conclusion that capital accumulation also accounts for the shift in the distribution, primarily from unimodal to bimodal, their analysis indicates that efficiency changes account for the qualitative shift from unimodal to bimodal,whereas the accumulation of physical and human capital account for the increased worldwide dispersion of productivity.

*There is evidence of technological progress in the developed nations only.

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

III. Objectives of the study

- To work out technical efficiency index for each of the 29 countries in the sample and examine the impact of some of its determinants on the efficiency levels for five year interval period starting from 1966 and ending in year 2000.

- To undertake growth accounting exercise which can decompose labor 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.
- Identify reasons for the existence of bimodal labour productivity distribution prevailing across countries by particularly analyzing the evolution of cross country distribution over time for the 29 countries included in our sample consisting of some South Asian,East Asian and EU countries

IV.Hypothesis

1.To test whether technological change, technological catch up ,capital accumulation and human capital accumulation are primarily responsible for differential growth in labor productivity across countries and regions and are also responsible for the existence of bimodal labour productivity distribution across countries included in our sample.

V.Methodology

The level of efficiency for each country has been worked out using Data Envelopment Analysis(DEA)[4] for five year interval period starting from 1966 and ending in year 2000.

Further, we decompose labor productivity into its components, efficiency change, technological change, capital accumulation and human capital accumulation. Technological change reflects shifts in the world production frontier, determined conceptually by the state-of-the-art, potentially transferable technology; while efficiency change reflects the movements toward (or away from) the frontier as countries adopt "best practice" technologies and reduce (or exacerbate) technical and allocative inefficiencies; and the third capital accumulation reflects movements along the frontier. The world production frontier at each point in time is constructed using deterministic, nonparametric (mathematical programming) methods (essentially, finding the smallest convex cone enveloping the data) and efficiency is measured as the (output-based) distance from the 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 about the absence of market imperfections; market imperfections, as well as technical inefficiencies, are possible reasons for countries falling below the worldwide production frontier. We proxy human capital accumulation by life expectancy changes.Introduction of human capital results in a quadripartite decomposition of productivity growth.

V.1Non Parametric Construction of Technologies and Efficiency Measurement (Technological Catch Up)

Our approach to constructing the worldwide production frontier and associated efficiency levels of individual economies (distances from the frontier), motivated in part by the first such effort in this direction by Fare, Grosskopf, Norris, and Zhang (1994), Charnes et. al(1978),followed by Kumar and Russell(2002) and Henderson and Russell,(2003) which in turn is based on the pioneering work of Farrell (1956) and Afriat (1972). The basic idea is to envelop the data in the "smallest", or "tightest fitting", convex cone, and 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 – labor, physical capital, and human capital(proxied by life expectancy in years). Let $\left(Y_t^j, L_t^j, K_t^j, H_t^j\right)$ t = 1, …, T, j =- 1, 1… J, represent T observations on these four variables for each of the 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 :

$$T_t = \left\{ \left(Y, L, K, H\right) \in R_+^3 \mid Y \le \sum_{\tau \le t} \sum_j z_\tau^j Y_\tau^j \wedge \right. \tag{1}$$

$$\left. L \ge \sum_{\tau \le j} \sum_j z_\tau^j L_\tau^j \wedge \; K \ge \sum_{\tau \le j} \sum_j z_\tau^j K_\tau^j, H \ge \sum_j z^j H, z^j \ge 0 \forall j \right\}$$

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)].

[4] 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).

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

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

This index is the inverse of the maximal proportional amount that output Y_t^j can be expanded while remaining technologically feasible, given the technology τ_t and the input quantities L_t^j, K_t^l,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 a scalar output, the output based efficiency index is simply the ratio of actual to potential output evaluated at the actual input quantities, but in multiple-output technologies the index is a radial measure of the (proportional) distance of the actual output vector from the production frontier.

In our simple case, we deal with only three macroeconomic variables: aggregate output and two aggregate inputs: labor and capital. Let $\left(\mathrm{Y_t^j, L_t^j, K_t^j}\right), \mathrm{t} = 1,..,\mathrm{T}, \mathrm{j} = 1,...\mathrm{J},$ represent T observations on these three variables for each of the J countries. The constant-returns-to-scale reference technology (the "Farrell cone") for the world in period t is defined by

$$\tau_1 = \left\{(\mathrm{Y,L,K}) \in \mathrm{R_+^3} \,|\, \mathrm{Y} \le \sum_{\mathrm{j}} \mathrm{z^j Y_t^j, L} \qquad (3)\right.$$

$$\left. \ge \sum_{\mathrm{j}} \mathrm{z^j L_t^j, K} \ge \sum_{\mathrm{j}} \mathrm{z^j K_t^j}, \mathrm{z^j} \ge 0 \forall \mathrm{j}\right\}$$

In this construction, each observation is interpreted as a unit operation of a linear process, zj represents the level of operation of the process and every point in the technology set a linear combination of observed output/input vectors or a point dominated by a linear combination of observed points. The constructed technology is a polyhedral cone, and isoquants are piecewise linear.5

Or course, typically some observed input-output combinations will be redundant in constructing the technologies, in that the observed output can be produced by some other process (generated by an alternative observed input-output vector) or by some linear combination of other processes using less of one input and no more of the other. These dominated processes are technologically inefficient. The Farrell (output-based) efficiency index for country) at time t is defined by

---

5 The non increasing-returns-to scale (NIRS) technology is constructed by restricting the process operation levels as satisfy $0 \le \mathrm{z^j} \le 1$ for all j, so that observed process can be radially contracted but not expanded. The variable-returns-to-scale (VRS) technology is constructed by adding the restriction $\sum_{\mathrm{j}} \mathrm{z^j} \le 1$, resulting in increasing returns as scale at low levels of input. By construction, efficiency indexes calculated under the assumption of constant returns to scale are no higher than those calculated under the assumption of NIRS, which in turn are no greater than those constructed under the assumption of VRS (see Fare et al. [1994] for details).

$$E(Y_t^j, L_t^j, K_t^j)$$

$$= \min\left\{\lambda \,|\, (Y_t^j \setminus \lambda, L_t^j, K_t^j) \in \tau_t\right\} \qquad (4)$$

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

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

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

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

$$L^j \geq \sum_k z^k L_t^k$$

$$K^j \geq \sum_k z^k K_t^k$$

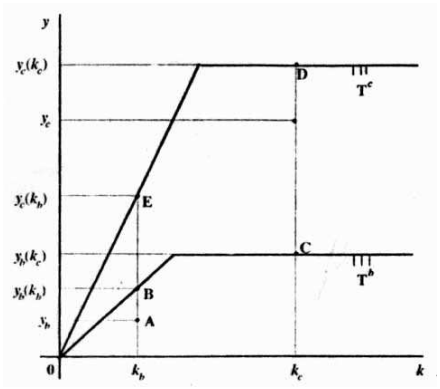
$$z^k \geq 0 \forall k.$$

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

V.2 Tripartite Decomposition of the Factors Affecting Labor Productivity

The decomposition of the factors affecting productivity growth exploits the assumption of constant returns to scale, in which case the benchmark technology sets can be drawn in (k, y) space, where k = K/L and y = Y/L. Very simple hypothetical (polyhedral) technologies for two periods, say a base period b and a current period c, are drawn in Figure III below. In this simple example, the single kink in each of the polyhedral technologies would indicate that a single economy – the only efficiency economy – defines the frontier.

FIGURE III:ILLUSTRATION OF TRIPARTITE DECOMPOSITION OF LABOUR PRODUCTIVITY



The two points, (k_b, y_b) and (k_c, y_c), represent observed values of the two ratios in the two periods for some hypothetical economy. By construction, potential outputs for this economy in the two periods are $\overline{y}_b(k_b) = y_b le_b$ and $\overline{y}_c(k_c) = y_c le_c$, where e_b and e_c are the values of the efficiency indexes in the two periods, calculated as in (4) above. Therefore,

$$\frac{y_c}{y_b} = \frac{e_c \times \overline{y}_c(k_c)}{e_b \times \overline{y}_b(k_b)} \qquad \text{(x)}$$

Multiplying top and bottom by $\overline{y}_b(k_c)$, the potential output labor ratio at current period capital intensity using the base period technology, we obtain

$$\frac{y_c}{y_b} = \frac{e_c}{e_b} \times \frac{\overline{y}_c(k_c)}{\overline{y}_b(k_c)} \times \frac{\overline{y}_b(k_c)}{\overline{y}_b(k_b)} \qquad \text{(xi)}$$

This identify decomposes the relative change in the output-labor ratio in the two periods into (i) the change in efficiency – i.e., the change in the distance from the frontier (the first term on the right); (ii) the technology change – i.e., the shift in the frontier (the second term); and (iii) the effect of the change in the capital labor ratio – i.e., movement along the frontier (the third term).

The decomposition in (xi) measures technological change by the shift in the frontier in the output direction at the current period capital labor ratio from point C to point D in Figure V and it measures the effect of capital accumulation along the base-period frontier – from point B to point C. We can alternatively measures technological change at the base-period capital-labor ratio – from point B to point E in Figure Vand capital accumulation by movements along the current period frontier from point E to point D by multiplying the top and bottom of (x) by the potential output labor ratio at base period capital intensity using the current period technology, $\overline{y}_c(k_b)$ yielding the decomposition,

$$\frac{y_c}{y_b} = \frac{e_c}{e_b} \times \frac{\overline{y}_c(k_b)}{\overline{y}_b(k_b)} \times \frac{\overline{y}_c(k_c)}{\overline{y}_c(k_b)} \qquad \text{(xii)}$$

Thus, the decomposition of (discrete) productivity changes (not attributable to efficiency changes) into the technological change and capital deepening components is path dependent, and the choice between (xi) and (xii) is arbitrary. There is no avoiding this arbitrariness, unless technological change is Hicks neutral, in which case the proportional vertical shift in the frontier is independent of the value of the capital labor ratio. It is this assumption (along with constant returns to scale) that enabled Solow (1957), and the legions of growth accountants who have followed his lead, to unambiguously decompose productivity growth into components attributable to technological change and capital

deepening. But without constraining technological change to be Hicks neutral, the proportional (vertical) shift in the frontier varies in unspecified ways. In fact, this arbitrariness is not, per se, attributable to the decomposition itself. It is endemic to the basic task of measuring technological change, as is evident in the necessity of normalizing on one of two technologies in the (Malmquist) productivity index proposed in the pioneering paper of Douglas W. Caves et al. (1982a).

We follow the approach of Caves et al. (1982a) and Fare et al. (1994b) by adopting the "Fisher ideal" decomposition, based on geometric averages of the two measures of the effects of technological change and capital accumulation, obtained by multiplying top and bottom of (x) by $(\overline{y}_b(k_c)\overline{y}_c(k_b))^{1/2}$.

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

$$\times\left(\frac{\overline{y}_b(k_c)}{\overline{y}_b(k_b)} \times \frac{\overline{y}_c(k_{c)}}{\overline{y}_c(k_b)}\right)^{1/2}$$

= : EFF × TECH × KACCUM.

V.3Quadriparite Decomposition of the Factors Affecting Labor Productivity

Conceptual Decomposition

The tripartite decomposition of productivity growth can be applied forwardly to the growth of output per efficiency unit of labor as follows Letting b and c stand for the base period and the current period, respectively, we see, by definition, that potential (frontier) outputs per efficiency unit of labor in the two periods are given by $\hat{\overline{y}}_b(k_b) = \hat{y}_b / e_b$ and $\hat{\overline{y}}_c(k_c) = \hat{y}_c / e_c$ where e_b and e_c are the values of the efficiency indexes in the respective periods. Thus,

$$\frac{\hat{y}_c}{\hat{y}_b} = \frac{e_c.\hat{\overline{y}}_c(\hat{k}_c)}{e_b.\hat{\overline{y}}_b(\hat{k}_b)}$$

Now denote potential output per unit of efficiency unit of labor at current-period capital intensity using the base-period technology by $\hat{\overline{y}}_b(k_c)$. Similarly, potential output per unit of efficiency labor at base-period capital intensity using the current-period technology is denoted $\hat{\overline{y}}_c(k_b)$. Multiplying top and bottom of alternatively by $\hat{\overline{y}}_b(k_c)$ and $\hat{\overline{y}}_c(k_b)$ yields two alternative decompositions of the growth of $\hat{y}$:

$$\frac{\hat{y}_c}{\hat{y}_b} = \frac{e_c}{e_b}.\frac{\hat{\overline{y}}_c(k_c)}{\hat{\overline{y}}_b(k_c)}.\frac{\hat{\overline{y}}_b(k_c)}{\hat{\overline{y}}_b(k_b)}$$

$$\frac{\hat{y}_c}{\hat{y}_b} = \frac{e_c}{e_b}.\frac{\hat{\overline{y}}_c(k_b)}{\hat{\overline{y}}_b(k_b)}.\frac{\hat{\overline{y}}_c(k_c)}{\hat{\overline{y}}_c(k_b)}.$$

The decomposition in measures technological change by the shift in the frontier in the output direction at the current-period capital/efficiency labor ratio and measures the effect of capital accumulation along the base-period frontier. The decomposition in measures technological change at the base-period capital/labor ratio and capital accumulation by movements along the current-period frontier. These two decompositions do not yield the same results; that is, the decomposition is path dependent. In fact, in the absence of neutrality of technological

change (as assumed by Solow [1957] and the many studies building on his pioneering paper), this ambiguity is endemic to growth accounting exercises. In the tradition of Caves, Christensen, and Diewert [1982b] and Fare, Grosskopf, Lindgren, and Roos [1994c], we adopt measures of the effects of technological change and capital accumulation, obtained by multiplying top and bottom by $\left(\hat{\bar{y}}_b(k_c)\hat{\bar{y}}_c(k_b)\right)^{1/2}$:

$$\frac{\hat{y}_c}{\hat{y}_b} = \frac{e_c}{e_b}\left(\frac{\hat{\bar{y}}_c(k_c)}{\hat{\bar{y}}_b(k_c)}\cdot\frac{\hat{\bar{y}}_c(k_b)}{\hat{\bar{y}}_b(k_b)}\right)^{1/2}\left(\frac{\hat{\bar{y}}_b(k_c)}{\hat{\bar{y}}_b(k_b)}\cdot\frac{\hat{\bar{y}}_c(k_c)}{\hat{\bar{y}}_c(k_{b)}}\right)^{1/2}$$

= : EFF × TECH × KACC.

The growth of productivity, $y_t = Y_t / L_t$, can be decomposed into the growth of output per efficiency unit of labor and the growth of human capital, as follows:

$$\frac{y_c}{y_b} = \frac{H_c}{H_b}\cdot\frac{\hat{y}_c}{\hat{y}_b}$$

Combining we obtain the quadripartite decomposition :

$$\frac{y_c}{y_b} = \frac{e_c}{e_b}\left(\frac{\hat{\bar{y}}_c(k_c)}{\hat{\bar{y}}_b(k_c)}\cdot\frac{\hat{\bar{y}}_c(k_b)}{\hat{\bar{y}}_b(k_b)}\right)^{1/2}\left(\frac{\hat{\bar{y}}_b(k_{c)}}{\hat{\bar{y}}_b(k_b)}\cdot\frac{\hat{\bar{y}}_c(k_c)}{\hat{\bar{y}}_c(k_b)}\right)^{1/2}\frac{H_c}{H_b}$$

= : EFF × TECH × KACC × HACC.

V.4Kernel Densities

We employ kernel based density functions for estimating the cross country labor productivity distribution for various years.The density estimates are computed using the Rosenblatt-Parzen kernel density estimator.We use an optimal bandwidth parameter chosen as h=1.0592*σ*N^(-.20) where σ is the standard deviation of the data and N is the number of observations.Splus software has been used to estimate the Kernel smoothers.

A conceptually simple approach to a representation of the weight sequence $\left[\mathrm{W_{ni}(x)_{i=l}^{n}}\right]$ is to describe the shape of the weight function $\mathrm{W_{ni}(x)}$ by a density function with a scale parameter that adjusts the size and the form of the weights near x. It is quite common to refer to this shape function as a kernel K. The kernel is continuous, bounded and symmetric real function K which integrates to me,

$$\int \mathrm{K(u)du} = 1.$$

The weight sequence for kernel smoothers (for one-dimensional x) is defined by

$$\mathrm{W_{ni}(x) = K_{h_n}(x - X_i)/\hat{f}_{h_n}(x),} \qquad \text{.(xiii)}$$

where

$$\hat{\mathrm{f}}_{\mathrm{h_n}}(\mathrm{x}) = \mathrm{n}^{-1}\sum_{\mathrm{i=1}}^{\mathrm{n}}\mathrm{K_{h_n}(x - X_i)} \qquad \text{(xiv)}$$

and where

$$\mathrm{K_{h_n}(u) = h_n^{-1}K(u/h_n)}$$

is the kernel with scale factor h_n. Suppressing the dependence of $h=h_n$ on the sample size n, the kernel weight sequence is conveniently abbreviated as $\{W_{hi}(x)\}_{i=1}^{n}$. The function $\hat{f}_h(.)$ in (xiv) is the Rosenblatt-Parzen kernel density estimator (Rosenblatt 1956; Parzen 1962) of the (marginal) density of X. The form of kernel weights $W_{hi}(x)$ in (xiii) has been proposed by Nadaraya (1964) and Watson (1964) and therefore

$$\hat{m}_h(x) = \frac{n^{-1}\sum_{i=1}^{n} K_h(x - X_i)Y_i}{n^{-1}\sum_{i=1}^{n} K_h(x - X_i)}$$

is often called the Nadaraya – Watson estimator. The shape of the kernel weights is determined by K, whereas the size of the weights is parameterized by h, which is called the bandwidth.

VI.Data and Variable Description

For the 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+16 EU Countries) over the period 1966-2000,using data from the World Development indicators on CDROM(various years).The included countries are identified in Appendix Table I. For DEA ,Our measure of aggregate output is GDP calculated at constant 1995 US $.Aggregate inputs used in the DEA model are capital stock, labor 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 described in the appendix II at the end. 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 and Contribution of Such Factors to Labour Productivity Changes(1966-2000)

VII.1 Empirical Results: Technical Efficiency and Technological Catch Up(Efficiency changes)

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

Table I:Efficiency Indexes

	WLE	LE	WLE	LE	WLE	LE	WLE	LE
Country	1966	1966	1971	1971	1976	1976	1981	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
Netherland	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
Phillipines	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
HongKong	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
EU(16) 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

Source :Authors calculations

Note: Efficiency Indexes are calculated using inputs 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; WLE Denotes without Life Expectancy

Table II (Continued):Efficiency Indexes

	WLE	LE	WLE	LE	WLE	LE	WLE	LE	Mean Efficiency WLE 1966-2000	Mean Efficiency LE 1966-2000
Country	1986	1986	1991	1991	1996	1996	2000	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**
Netherland	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**
Phillipines	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**
HongKong	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		

Source: Authors calculations

Note: Efficiency Indexes are calculated using inputs 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; WLE Denotes without Life Expectancy considered as input.

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

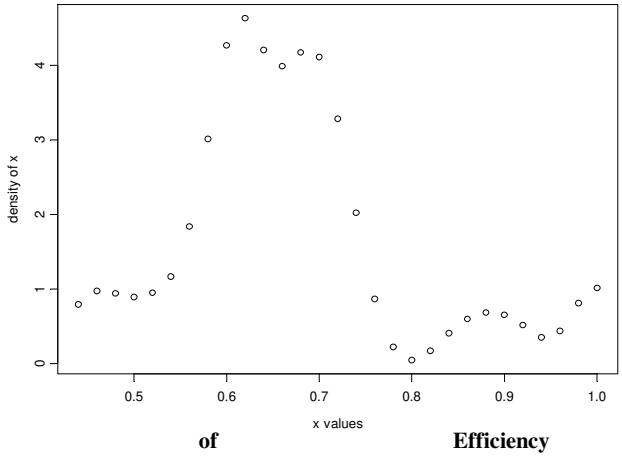
Bangladesh and India too have scores of one in atleast one of the years from 1966 to 2000.It seems peculiar that these countries are on the frontier.The interpretation of this finding is that

Bangladesh and India have relatively low per capita incomes because it seems that they are relatively undercapitalized and not because they make inefficient use of the relatively meager capital inputs that it has. 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 labour ratios[6].

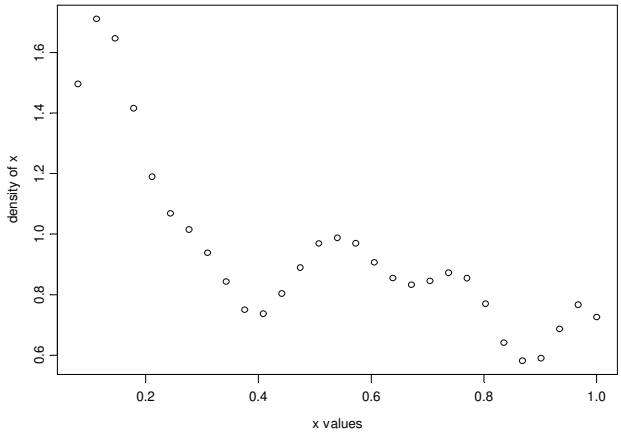
The mean efficiency scores with life expectancy included as an input,in all the years included in our study, is always found to be greater than the efficiency scores which does not take into account life expectancy as an input. This seems to suggest that some of the measured inefficiency in the simpler model, in fact, have been attributed to a relative paucity of the quantity of human capital.

In the context of our structure, the state of worldwide technology is represented by a production surface in output/input space, and technological catch up is represented by movement toward the frontier, reflected by increases in efficiency. Figure IV and V show the distributions of the level of efficiency

Figure IV:Distribution of Efficiency Index,2000



FigureV:Distribution of Efficiency Index,1966



[6] 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 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 indexes and the components of tripartite and quadripartite decomposition of productivity changes.

across countries in 1966 and 2000,obtained under the assumption of constant returns to scale and without including life expectancy as input[7].The 2000 distribution is changed into a single modal distribution with probability mass converging between 0.5 to 0.8.

Figure VI:Distribution of Efficiency Index(Including Life Expectancy as Input),1966

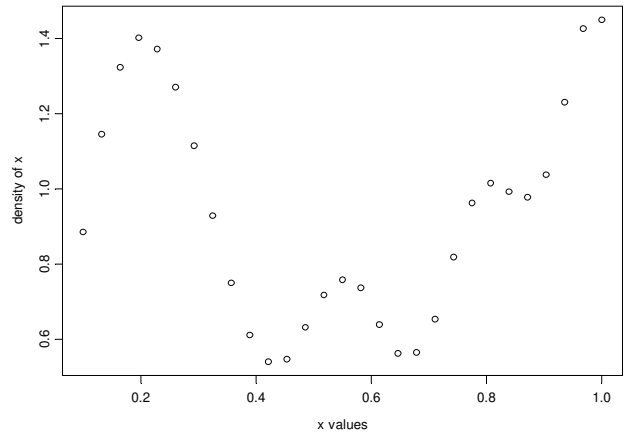


Figure VI1:Distribution of Efficiency Index(Including Life Expectancy as Input),2000

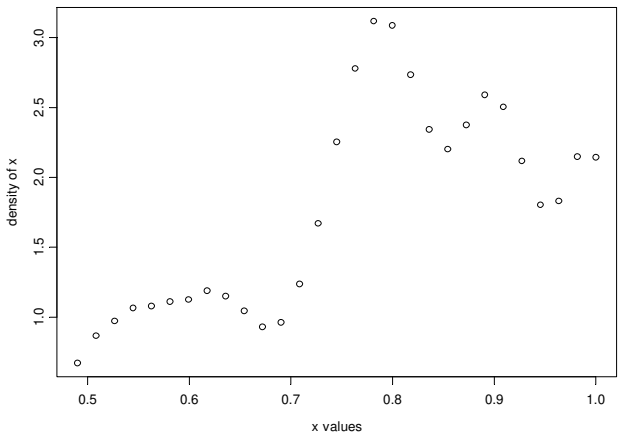
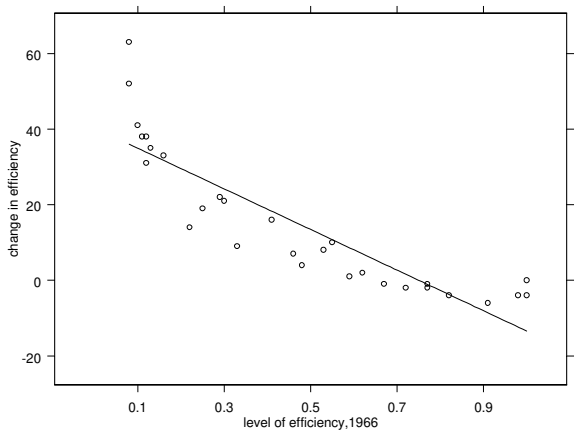


Figure VI and VII show the distributions of the level of efficiency across countries in 1966 and 2000 under the assumption of constant returns to scale and including life expectancy as input with others: capital stock and labour force.The 1966 distribution is a bimodal distribution with probability mass concentrated between 0.1 to 0.4 and between 0.4 to 0.6.The 2000 distribution seems to be four modal distribution with probability mass concentrated between 0.5 to 0.7,0.7 to 0.85 , between 0.85 to 0.95 and between .95 and one.

[7] Kumar and Russell(2002) in their study of 57 countries note that efficiency indexes are not perceptibly affected by recalculation of the efficiency indexes under the alternative assumptions of nonincreasing returns to scale or variable returns to scale.



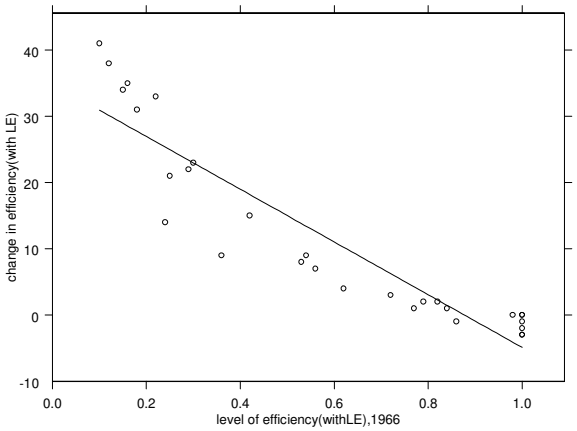


Figure VIII Figure IX

Figure VIII and IX:Linear Fit Plot between Change in Efficiency and Efficiency Index,1966

Ordinary least squares regression of the change in technical efficiency on the level of technical efficiency(without life expectancy included as an input) in 1966(Regressing Column V of Table III on Regressing Column 2 in Table I) yields a coefficient of -53.760 with a t statistic of -9.74 while Ordinary least squares regression of the change in technical efficiency on the level of technical efficiency(with life expectancy included as an input) in 1966(Regressing Column V of Table IV on Regressing Column 3 in Table II) yields a coefficient of -39.807 with a t statistic of -12.641, both indicating that the less efficient countries in 1966 have, on balance,benefited from efficiency improvements than the more efficient countries.Figures VIII and IX confirm the negative relationship between the two.These two results seems to imply that there is a tendency for technology transfer to reduce the gap between the relatively rich and poor countries in the sample.

VII.2 Empirical Results for Tripartite and Quadripartite Decomposition of the Factors Affecting Labour Productivity

We have 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 besides the other inputs of capital stock and labour force. The conceptual decomposition is discussed in the section on Methodology. The tables giving the results for finding out the average efficiency changes, technological changes ,capital accumulation and human capital accumulation from 1966 to 2000 are available with the author. The results of tripartite decomposition of labour productivity are summarized in Table III while the results of Quadripartite decomposition are summarized in Table IV

Table III lists the percentage changes from 1966 to 2000 in labour productivity and each of the three components: (I) change in efficiency,(ii)technological change, and (iii) capital deepening,for all 29 countries,along with the sample mean percentage changes.The overall averages provide striking evidence that none of the three factors are primarily responsible for most of the productivity improvements over this period(contradicts the Kumar and Russel

result that capital accumulation is primarily responsible for the existence of differential levels of per capita income and growth rates across nations).The efficiency factor accounted for less than 16 %,technological change accounted for less than 15 % while the contribution of capital deepening is strikingly negative.One finds the same trend for the the South Asian and East Asian regions;the efficiency factor accounts for 29.40 % of their labour productivity growth,only 10.60% is accounted by technological changes while capital accumulation shows negative value for the South Asian region.For the East Asian region the efficiency factor accounts for 32 % of their labour productivity growth, 20.88% is accounted by technological changes while capital accumulation shows negative value.For the EU region the efficiency factor accounts for mere 2.31 % of their labour productivity growth,only 11.94% is accounted by technological changes while capital accumulation shows negative value.Such results seems to convey that there are some other factors besides the ones decomposed in the growth accounting exercise which may have profound affects on labour productivity growth rates across the countries included in our sample.Barro-and Xavier-Sala-I-Martin(1995,2003) and Sachs et.al(1997) tests the conditional convergence hypothesis and show that trade openness,quality of governments,population rate of growth, savings rate,among others 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 particularly for 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 policies directed towards higher infrastructure spending,making bureaucracy efficient, reducing corruption, less restrictive labor regulations, achieving political stability, implementing rule of law,understanding institutions,among others(Global Competitiveness Report,2003-04)

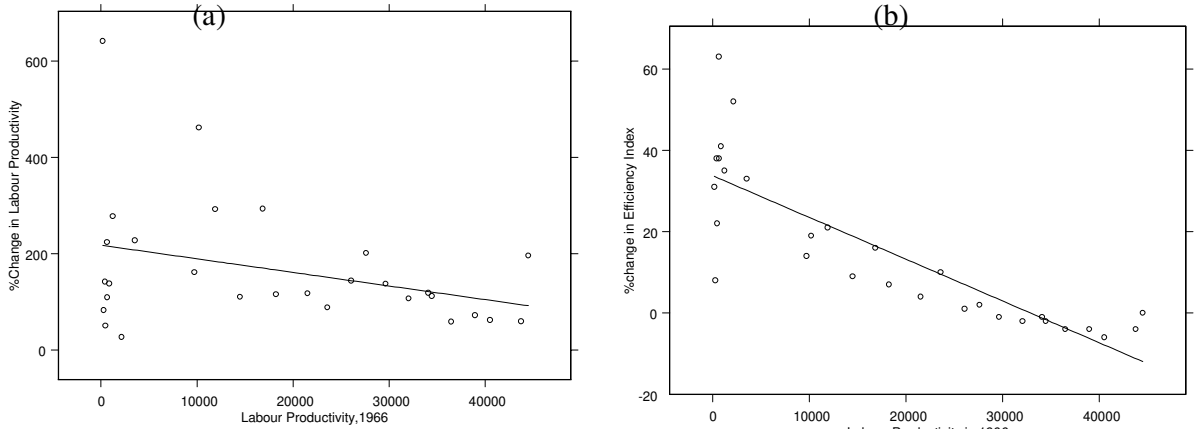
Table III:Percentage Change of Tripartite Decomposition Indexes

Country	Output Per Worker, 1966	Output Per Worker 2000	Productivity Change (2000-1966)	(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	43752	69814	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
Netherland	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	88.35	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
Phillipines	2152	2731	26.91	52	4	-17
Singapore	10194	57290	461.96	19	29	-10
Thailand	1232	4656	277.69	35	22	-8
HongKong	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**
EU Mean	**29052**	**62031**	**122.11**	**2.31**	**11.94**	**-.44**
EA Mean	**7181**	**26205**	**294.20**	**32**	**20.88**	**-9.5**

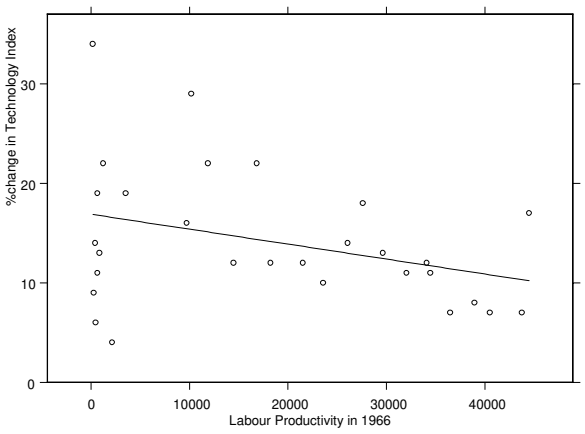
Source:Authors Calculations

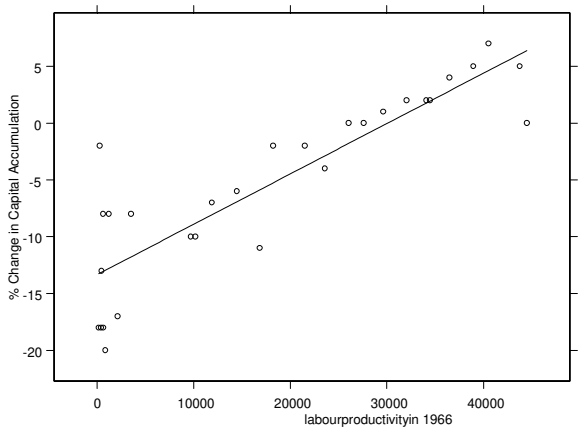
Figure X summarizes these calculations by plotting the four growth rates(labour productivity and its three components against labour productivity in 1966.

Figure X:Percentage Changes Between 1966 and 2000 in Labour Productivity and Three Decomposition Indexes Plotted Against 1966 Labour Productivity



(c) (d)





OLS regression lines are also plotted.Figure X(a) indicates that the increases in average productivity reflects positive growth over this period for the countries included in our sample.The prominent spikes at the lower relative incomes reflect the economic emergence of the Asian "miracle" countries and is 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 section I on introduction).The negative slope coefficient of -.0282 with t value as 1.855,while not statistically significant at 5% level of significance without inclusion of critical conditioning variables,is essentially the empirical result that led many to argue that productivity growth patterns support absolute convergence[8] among South Asian, European Union and East Asian countries together(Mathur,2004).

Figure X(b),shows the negative relationship between the percentage change in efficiency index and the initial level of productivity .The beta coefficient has negative value of -.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 rich and poor nations,which is atleast true for the East Asian economies since the developed nations were partly responsible for technology transfers to their region(then underdeveloped) since the 1960s.Technological transfers, however, in the South Asian region is relatively low but can play an important role in increasing their growth rates.

Figure X(C) shows that the relationship between technological changes and initial level of labour productivity is negative(-.00015) though not significant(t value -1.875).While for the East Asian region technological change is responsible for larger than average contributions to

[8] 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 inviting capital from abroad) than the rich country, 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)..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.

growth,it has been quite moderate for the South Asian and EU regions.
Figure X(d) shows that the relationship between capital accumulation and labour productivity in 1966 is positive and significant.(coefficient value is .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 less developed economies.

Table IV lists the percentage changes from 1966 to 2000 in labour productivity and each of the four components: (I) change in efficiency,(ii)technological change, and (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 are primarily responsible for most of the productivity improvements over this period.The efficiency factor accounted for less than 12 %,technological change account for less than 11 %,Human Capital accumulation accounted for less than 4% while the contribution of capital deepening is strikingly negative.One finds the same trend for the the South Asian and East Asian regions;the efficiency factor accounts for 23.20 % of their labour productivity growth,only 4.6% is accounted by technological changes,human capital accumulation accounts for 5.8% while capital accumulation shows negative value for the South Asian region..For the East Asian region the efficiency factor accounts for 23.25 % of their labour productivity growth, 15.50% is accounted by technological changes,human capital accumulation accounts for 5.38% while capital accumulation shows negative value.For the EU region the efficiency factor accounts for mere 2.56 % of their labour productivity growth,10% is accounted by technological changes,1.75 % is accounted by human capital accumulation while capital accumulation shows negative value.Such results convey that there are some other factors besides the ones decomposed in the growth accounting exercise which have important bearing on the labour productivity growth rates the countries of the EU,South Asian and East Asian region.

Figure XI summarizes these calculations by plotting the four growth rates(four labour productivity components) against labour productivity of 1966.This exercise includes technical efficiency index calculated on the basis of life expectancy(human capital) as an additional input besides capital stock and labour force.OLS regression lines are also plotted.Figure XI(a),shows the negative relationship between the percentage change in efficiency index and the initial level of productivity. The beta coefficient has negative value of -.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 rich and poor nations(then East Asian countries).

Figure XI(b) shows that the relationship between technological changes and initial level of labour productivity which is found to be negative(-.00002) though not significant(t value -.383).
Figure XI(c) shows that the relationship between capital accumulation and labour productivity in 1966 is positive and significant.(coefficient value is .00026 with t value of 4.343).The positive regression slope coefficient suggests that relatively wealthy countries have benefited more from the capital accumulation than have less developed economies.
Figure XI(d) shows that the relationship between human capital accumulation and labour productivity in 1966 is negative and significant.(the beta slope coefficient is -.000123 and t value is -5.677).Countries which had lower labour productivity in the sixties accumulated human capital at faster rates than economies which were relatively developed in the sixties;apparently human capital accumulation has contributed to convergence of productivity

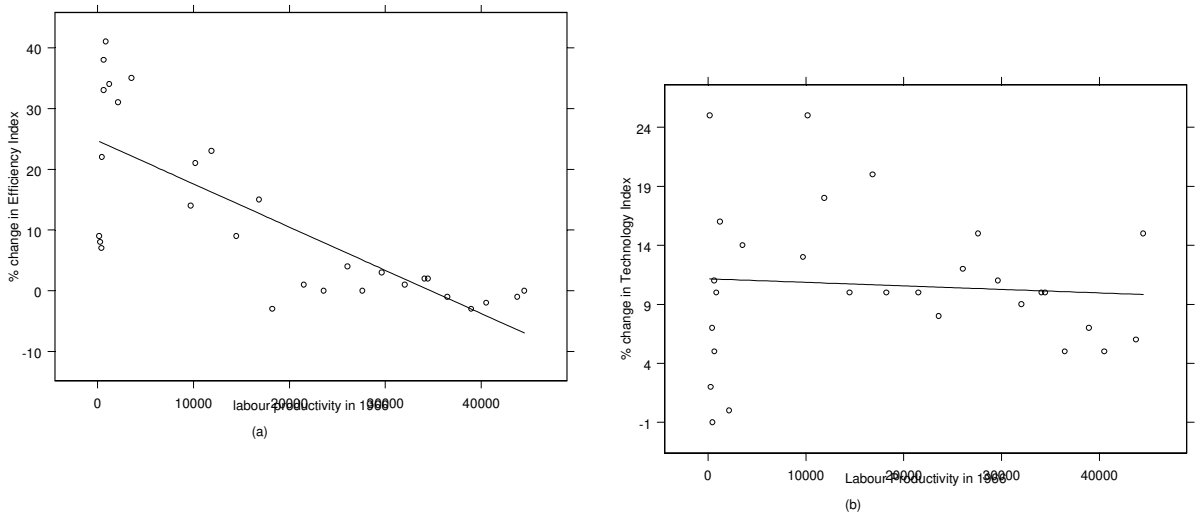
levels.

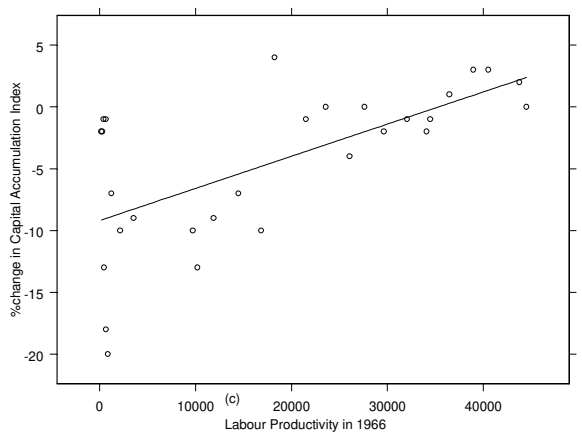
Table IV:Percentage Change of Quadripartite Decomposition Indexes

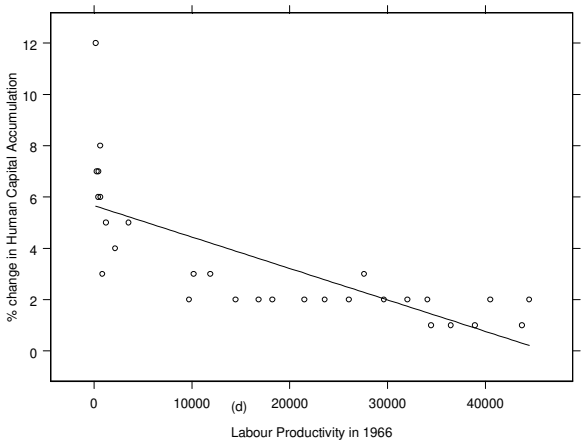
Country	Output Per Worker, 1966	Output Per Worker 2000	Productivity Change (2000-1966)	(EFF-1) *100	(TECH-1) *100	(KACC-1)*100	(HACC-1)*100
Bangladesh	468	706	50.65	22	-1	-13	7
India	428	1036	141.84	7	7	-1	6
Nepal	285	521	82.6	8	2	-2	7
Pakistan	657	1376	109.23	38	5	-18	6
Sri lanka	864	2055	137.86	41	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
Netherland	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
Phillipines	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
HongKong	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**
EU 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**

Source:Authors calculations

Figure XI:Percentage Changes Between 1966 and 2000 in Labour Productivity and Four Decomposition Indexes Plotted Against 1966 Labour Productivity







VIII.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 trimodal distribution in 1966 to bimodal distribution in 2000 with higher mean.The distributions are reproduced again here for convenience(Figure XIIa:1966 distribution and XIIb 2000 distribution)

Figure XII(a)

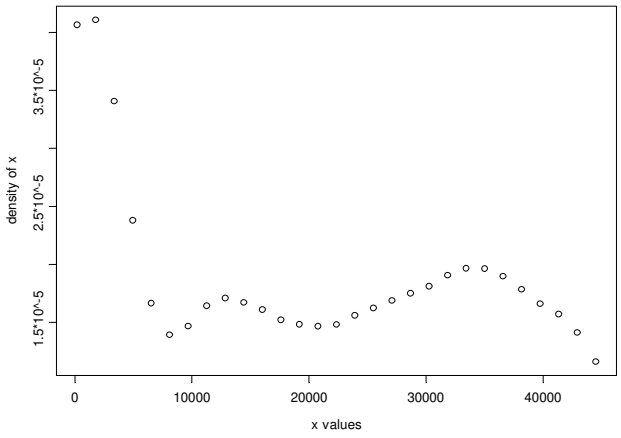


Figure XII(b)

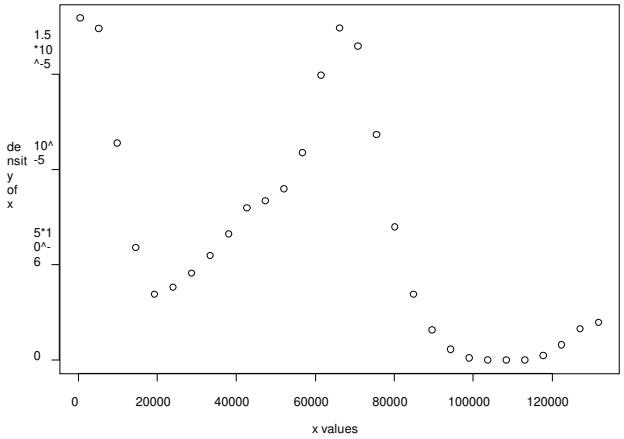
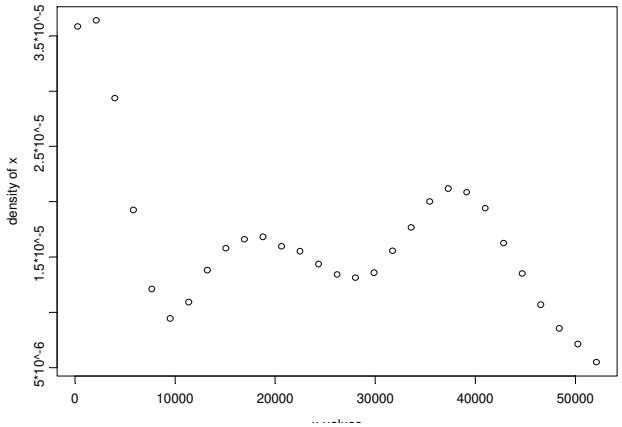


Figure XIII:Counterfactual Distribution of Labour Productivity,2000(including LE)



The distribution we employ are nonparametric kernel based density estimates,essentially Rosenblatt Parzen kernel density estimator.(details are given in the section on Methodology).

Rewrite the quadripartite decomposition of labour productivity changes as follows:

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

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 XIII) by multiplying the average decomposition figures successively with the 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 bimodal distribution of labour productivity.In another words ,It is found that counterfactual distribution of 2000 is similar to 1966 labour productivity distribution and the decomposing factors of labour productivity have not been able to transform the 1966 distribution into that of the 2000 labour productivity distribution[9].
This means that some other factors like savings rate, trade openness,role of institutions, geography, rate of growth of population, quality of institutions among others(Sachs,et.al,1997 and Barro and Xavier-Sala-I-Martin,2003,1995) which may be more responsible for the transformation of tri modal distribution of 1966 into the bimodal distribution of 2000.

IX. Limitations of the study

1)In recent times, cross country analysis has come under criticism from the"Twin-Peaks" literature led by Danny Quah (1996b, 1997). The researcher is interested in the evolution of the distribution of the world distribution of income and the variance is only one aspect of this distribution. Quah noticed that, in 1960, the world distribution of income was uni-modal whereas, in the 1990s, the distribution became bi-modal. He then used Markov transitional matrices & non parametric method to estimate the probabilities that countries improve their position in the world distribution. Using these matrices, he then forecasted the evolution of this distribution overtime. His conclusion was that, in the long run, the distribution will remain bi-modal, although the lower mode will include a lot fewer countries than the upper mode.

Even though Quah's papers triggered a large body of research, his conclusion does not appear to be very robust. Jones (1997) and Kremer, Onatski and Stock (2001) have recently shown that a lot of these results depend crucially on whether the data set includes oil-producers (for example, the exclusion of Trinidad and Tobago or Venezuela from the sample changes the prediction of a bi-modal steady state distribution to a uni-modal distribution; the reason is that these are two examples of countries that were relatively rich but have become poor so if they are excluded from the sample, the probability of "failure" - that is, the probability of a country moving down in the distribution- lowers substantially).

We find that for the sample of 29 countries(consisting of some South Asian,East Asian and EU countries) included in our study ,the cross country per capita distribution were tri modal in 1966 and it is only in the 1990s that it has been transformed from tri modal to

---

[9] Two-Sample Kolmogorov-Smirnov Test confirms the acceptance of the null hypothesis-two sample kernel probability distributions are same; data: x: Counterfactual labour productivity distribution in 2000(V1) , and 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 with the author.

bimodal distribution. It seems that neither technological change, technological catch-up ,capital accumulation and life expectancy are primarily responsible for this transformation.

2)We proxy human capital simply by life expectancy in years.The results of DEA depend heavily on the conceptual measurement of human capital and the underlying process of human capital accumulation. Most of the studies take years of education as one of the ways in measuring human capital which we have avoided because of unsureity of the sign such proxy of human capital in the cross country growth literature. Neverthless, theoretical and empirical research, as well as simple intuition suggests that human capital is an element of the growth process that is too important to ignore.

X Conclusions

We work out efficiency levels of 29 countries included in our sample using data envelopment analysis. Luxembourg has an efficiency score of one in all the years with or without life expectancy(human capital).Netherlands also has an efficiency score of one in 1966,1971,1976 and 1981.Japan,UK,Belgium,Ireland,Indonesia,Spain and Germany has an efficiency score of one in at least one of the years from 1966 to 2000.In the year 2000 though mean efficiency levels(without including life expectancy as input) of South Asian countries is higher than the European Union Countries and East Asian countries. Japan has the highest average efficiency followed by Hong Kong in the East Asian region in the period 1966-2000.

We decompose labor 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 no specification of functional form for the technology nor any assumption about market structure or the absence of market imperfections. Growth accounting results tend to convey that for the East Asian and the South Asian countries efficiency changes have contributed the most while for the European countries it is the technical changes which has contributed to labour productivity changes between 1966-2000.We analyze the evolution of cross country distribution for the 29 countries included in our sample consisting of some South Asian, East Asian and EU countries using Kernel densities. It seems that there are other factors like trade openness,quality of governments,population rate of growth, savings rate, corruption perception indices, rule of law index, social capital and trust variables, formal and informal rules governing the society, among others rather than the ones that are included above for the growth accounting exercise which are primarily responsible for the existence of bimodal labour productivity distribution for countries included in our sample. This particular research problem may be take up by researchers in future. Our results contradicts the Kumar and Russel(2002) and Henderson and Russell(2003) results which found that different rate of capital accumulation and human capital across nations are 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 bimodal distribution of labour productivity today across nations. In a way their results(KR) confirmed the use of simple and extended Solow model(Solow,1956,Jones,2002) along with their factor accumulation assumptions in analyzing the convergence process of per capita incomes across nations.Our growth accounting exercise and regression exercise suggest that there is some evidence of absolute convergence(supports the use of Solovian model(1956) in this context) and convergence in statistical terms of efficiency changes and human capital accumulation across countries of the EU, South Asian and East Asian regions.

Generally, speaking policies that will increase labour productivity and particularly in the services sector, open up trade with all countries, increase 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 efficiency levels of countries, help more in reducing per capita income differences and growth rates across countries and regions, and also help in achieving the basic goal of planning- i.e., improve the living standards of the people .

References

Abramovitz,M(1986),"Catching Up,Forging Ahead and Falling Behind."Journal of Economic History(June):385-406.

Alesina, Alberto &Rodrik, Dani(1994)," Distributive Politics and Economic Growth". The Quarterly Journal of Economics 109 (2)465-90 (RePEc:tpr:qjecon:v:109:y:1994:i:2:p:465-90)

Afriat, Sydney(1972). "Efficiency Estimation of Production Functions." International Economic Review, October 1972, 13 (3), pp. 568-98.

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

Barro, R.J. (1989), `Economic growth in cross section of countries', NBER working paper, no. 3120, Cambridge, Mass:National Bureau of Economic Research.

Barro, Robert, (1991), Economic growth in a cross section of countries, Quarterly Journal of Economics, volume 106, no. 2, May, 407-43.

Barro,Robert J. and Xavier Sala-I-Martin(1991),"Convergence across States and Regions",Brookings Papers on Economic Activity, pp. 107-58.

Barro,Robert J. and Xavier Sala-I-Martin(1994)"Quality Improvements in Models of Growth" , NBER Working Paper #4610, January

Barro,Robert J. and Xavier Sala-I-Martin(1995),Economic Growth,McGraw-Hill ,Inc,US.

Barro,Robert J. and Xavier Sala-I-Martin(2003),Economic Growth,Second Edition,McGraw-Hill ,Inc,US.

Barro, R., G. Mankiw and X. Sala-i-Martin,(1995) "Capital Mobility in Neoclassical Models of Growth",American Economic Review, March

Barro, R. J. and X. Sala-i-Martin,(1997) "Technological Diffusion, Convergence, and Growth", Journal of Economic Growth, Vol. 2

----------(1992),"Convergence",Journal of Political Economy,100(May):223-252.

Barro,Robert J(1997). Determinants of Economic Growth:A Cross-Country Empirical Study ,MIT Press.

Baumol, W. (1986). Productivity Growth, Convergence, and Welfare: What the Long-Run Data Show,American Economic Review 75, 1072-85.

Bernard,A and S .Durlauf(1995),"Convergence in International Output", Journal of Applied Econometrics,19,97-108.

Bernard, A. and S. Durlauf (1996). Interpreting Tests of the Convergence Hypothesis, Journal of Econometrics 71, 161-73.

Bernstien, J., and M. Nadiri.(1989). "Research and development and intraindustry spillovers: An empirical implication of dynamic duality". Review of Economic Studies 56: 249-68.

Burgess, J.F. and P.W. Wilson(1993). Technical efficiency in Veterans Administration hospitals. In Fried, H., C.A.K. Lovell, and S. Schmidt (Eds.) The Measurement of Productivity and Efficiency: Techniques and Applications. New York: Oxford University Press, 1993.

Caves, Doughas W.; Christensen, Laurits R. and Diewert, W. Erwin(1982a). "Multilateral Comparisons of Outputs, Inputs and Productivity Using Superlative Index Number." Economic Journal, March 1982a, 92(365), pp. 73-86.

Caves, Doughas W.; Christensen, Laurits R. and Diewert, W. Erwin(1982b). "The Economic Theory of Index Numbers and the Mesaurement of Input,Output,and Productivity,"Econometrica 50:1393-1414

Charnes, Abraham;Cooper, William W. and Rhodes, E(1978). "Measuring the Efficiency Of Decision-Making Units." European Journal of Operational Research, 1978, 3.pp 429-444

Charnes, Abraham; Cooper, William W.; Lewin, Arie Y. and Seiford, Lawrence M.(1994) Data envelopment analysis: Theory, methodology, and application, Boston, MA: Kluwer,.

Chou,Ji(1993),"Old and New Development Models:The Taiwanese Experience",Paper presented at the NBER-East Asia seminar in Economics Fourth Annual Conference.

Coelli, T., D.P. Rao, and G. Batteese(1998). An introduction to efficiency and productivity analysis. London, Kluwer Academic Publishers. 1998.

Coe, D.T., and Helpman, E. (1995). "International R&D Spillovers." European Economic Review 39(5): 859-887.

Coe, D.T., and Helpman, E., and Hoffmaister, A. W. (1995). “North-South Research and Development Spillovers.” NBER Working Paper no 5048.

Denison, E-F. (1962) Source of Economic Growth in the United States and the Alternative Before Us. New York: Committee for Economic Development.

Diewert,E(1980),"Capital and the Theory of Productivity Measurement,"American Economic Review 70:260-267

Dowrick, S., and Nguyen, D., (1989), `OECD Comparative Economic growth 1950-85, Catch-up and Convergence’ American Economic Review, 79:1010-30.

Evans,P(1996),"Using Cross Country Variances to Evaluate Growth Theories",Journal of Economic Dynamics and Control 20:1027-1049

Evans,P(1998)," Using panel data to evaluate growth theories. International Economic Review, 39(2), May, 295-306.

Farrell, Michael J(1957). “The Measurement of Productive Efficiency”, Journal of the Royal Statistical Society, Series A, General, 1957, 120(3), pp. 253-82.

Fare, R., S. Grosskopf, and C.A.K. Lovell(1994). Production frontiers. New York, Cambridge University Press. 1994

Fare, R.,and C.A.K. Lovell(1997). ,"Measuring the technical efficiency of production,"Journal of Economic Theory,19:150-162

Fare, R and S. Grosskopf. (1996.) Intertemporal Production Frontiers: With Dynamic DEA. London: Kluwer Academic Publishers.

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.

Fare, Rolf; Grosskopf,B Lindgren,and P Roos(1994c),"Productivity Developments in Swedish Hospital:A Malmquist Output Index Approach," in Charnes,Cooper,Lewin and Seiford(1994)

Galor, Oded(1996), “Convergence? Inferences from Theoretical Models”, Economic Journal, July, 106(437), pp. 1056-69.

Gerschenkron,Alexander(1952),"Economic Backwardness in Historical Perspective", in The Progress of Underdeveloped Areas,ed.Bert F.Hoselitz.Chicago:University of Chicago Press.

Gijbels, Irene; Mammen, Enno; Park Byeong U. and Simar, Leopold.(1999) “On

Estimation ofMonotone and Concave Frontier Functions." Journal of the American Statistical Association, March 1999, 94(445), pp. 220-28.

Giles,D.E.A(2001),"Output Convergence and International Trade:Time Series and Fuzzy Clustering Evidence from New Zealand and Her Trading Partners,1950-1992",Econometrics Working Paper EWP0102,Department of Economics,University of Victoria.

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

Ito,Takatoshi(1992),"U.S. Political Pressure and Economic Liberalization in East Asia"Working Paper A.257,Institute for Economic Research,Japan.

Islam, N. (1995). "Growth empirics: a panel data approach." Quarterly Journal of Economics,110,1127-1170.

Jaffe, A.B. (1986). "Technological opportunity and spillovers of R&D: Evidence from firms' patents, profits, and market value." American Economic Review 76: 984-1001.

Jones, Charles I. (1995). Time series tests of endogenous growth models. Quarterly Journal of Economics, 110, May, 495-525.

Jones, C. I.,(1997) "On the Evolution of the World Income Distribution", Journal of EconomicPerspectives, Summer

Jones, Charles I. (1998). Population and ideas: a theory of endogenous growth. Manuscript, Stanford University.

Jones,Charles.,I(2002),Introduction to Economic Growth,Second Edition,WW Norton and Company,Incorporation,US.

Kirkley, J., R. Fare, S. Grosskopf, K. McConnell, I.Strand, and D. Squires(2000). Assessing capacity in fisheries when data are limited. North American Journal of Fisheries Management

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.

Kremer, M, A. Onatski and J. Stock(2001), "Searching for Prosperity", NBER Working paper 8250,US

Krugman, Paul(1994), "The Myth of Asia's Miracle," Foreign Affairs, 73:6, 62-78.

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

Lee, Kevin; Pesaran, M. Hashem, and Smith, Ron (1998): "Growth empirics: a panel data approach - a comment". Quarterly Journal of Economics, 113(1), February, 319-323.

Lucas,Robert E.,Jr(1988),"On the Mechanics of Economic Development."Journal of Monetary Economics 22(July):3-42.

Maddison,Angus(1982),"Phases of Capitalist Development,Oxford,Oxford University Press

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.

Mankiw, G. D. Romer, and D. Weil (1992). A Contribution to the Empirics of
Economic Growth, Quarterly Journal of Economics 107, 407-37.
Nadaraya,E.A(1964),"On estimating regression",Theory,Probability Applications 10,186-90

Parzen,E(1962),"On estimation of a probability density and mode"Annals of Mathematical Statistics,35,1065-76

Phelps, E.S.(1961). "The golden rule of accumulation: A fable for growthmen"American Economic Review 51: 638-43.

Quah(1993),"Galton's Fallacy and Tests of Convergence Hypothesis,"Scandinavian Journal of Economics,95,4,427-443
_____,(1996a) "Convergence Empires across Economies with (Some) Capital Mobility." Journal of Economic Growth, March 1996a. 1(1), pp. 95-124.

Quah, D.(1996b) "Twin Peaks: Growth and Convergence in Models of Distribution Dynamics",Economic Journal, July

Quah, D. (1997). Empirics for Growth and Distribution: Stratification, Polarization,and Convergence Clubs, Journal of Economic Growth 2, 27-59.

Raut,L(1991),"R&D spillover and productivity growth: Evidence from Indian private firms.", Department of Economics, University of California, San Diego.Processed.

Raut, L. and T.N.Srinivasan (1991),"Endogenous fertility, technical change and growth in a model of overlapping generations" ,Economic Growth Centre Discussion Paper no.628.Yale University

Rao, V.V.B. and Lee(1995),," Sources of growth in the Singapore economy and its manufacturing and service sectors". Singapore Economic Review 1995; 40: 83[115.

Resti, A(2000)." Efficiency measurement for multi-product industries: a comparison of classic and recent techniques based on simulated data." European Journal of Operational Research, 121: 559-578.

Rosenblatt,M(1956) Remarks on some nonparametric estimates of a density function.Annals of Mathematical Statistics,27,642-69

Sachs,Jeffrey D.,Bajpai,Nirupam and Ananthi Ramiah(2001),"Understanding Regional Economic Growth in India",Paper prepared for the Asian Economic Panel meeting held in Seoul on October 25-26.

Sachs,J.,Radelet S., and J.W.Lee(1997),"Economic Growth in Asia,"Development Discussion Paper No 609,Harvard Institute for International Development,Harvard University.

Sachs,J and A.Warner(1995a),"Economic Reforms and the Process of Global Integration,"Brooking Paperson Economic Activity,1-118.

Sachs Jeffrey D. & Andrew M. Warner, (1995b). "Natural Resource Abundance and Economic Growth," NBER Working Papers 5398, National Bureau of Economic Research, Inc.

Sala-i-Martin, Xavier, (1996), The classical approach to convergence analysis, The Economic Journal, volume 106, no. 437, July, 1019-36.

Sala-I-Martin, Xavier, (1997), “I Just Ran Four Million Regressions.” NBER WorkingPaper 6252, Cambridge: National Bureau of Economic Research..12

Sarel,M(1995)," Growth in East Asia: What We Can and What We Cannot Infer From It ",Reserve Bank of Australia ,Working Paper No.15.

Sengupta, J.K., (1991), `Rapid growth in NICs in Asia: Tests of New Growth Theroy or Korea’, Kyklos, vol. 44, no. 4.

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

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

Swan, T. W.(1956), "Economic Growth and Capital Accumulation", Economic Record, 1956.

Solow,Robert M(1956),"A Contribution to the Theory of Economic Growth,"Quarterly Journal of Economics 70(February):65-94

----------(1957),"Technical Change and the Aggregate Production Function",Review of Economics and Statistics,August,39(3),pp 312-20

Thompson, R.G., L. Langemeier, E. Lee, and R. Thrall.(1994) DEA sensitivity analysis of efficiency measures with an application to Kansas Farming. In Charnes, W. Cooper, A. Lewin, and L. Seiford (Eds.) Data Envelopment Analysis: Theory, Methodology, and Applications. Boston: Kluwer Academic Publishers, 1994.

Watson,G.S(1964),"Smooth regression analysis",Sankya,Series A,26,359-72

World Bank(1998),East Asia on the Path of Recovery,World Bank Publication

Appendix Table I:Countries and Regions Included in the Study

Countries(44)/Regions(4)
South Asia(5)
Bangladesh
India
Nepal
Pakistan
Sri-Lanka
European Union(16includingUK)
Belgium
Austria
Denmark
Finland
France
Germany
Greece
Ireland
Italy
Luxembourg
Netherlands
Portugal
Spain
Sweden
United Kingdom
Norway
EAST ASIA(8)
Malaysia
China
Indonesia
Japan
Phillipines
Singapore
Thailand
Hong Kong

Appendix II: Measurement of Capital Stock

We measure the capital stock series in the form

$$K(t) = K(t-1) + I(t) - D(t) \qquad \text{A1}$$

where K(t) is the capital stock at period t, I(t) is the gross fixed investment, and D(t) is the capital depreciation allowance(assumed to be 2% of the investment in this study).. We calculate the initial stock[10] by

$$K(1) = \frac{I(0)e^{\theta}}{\theta}, \qquad \text{A2}$$

where I(0) and θ are the estimated coefficients of the constant term and TIME in the following form, by ordinary least squares estimation :

$$\ln I(t) = C + \theta TIME. \qquad \text{A3}$$

The estimation is that (1) the capital stock in the first period is the sum of all past investments :

$$K(1) = \int_{t=-\infty}^{1} I(t)dt; \qquad \text{A4}$$

and (2) the investment series may be approximated by an exponential time trend:

$$I(t) = I(0)e^{\theta t}. \qquad \text{A5}$$

Inserting equation into equation yields equation. Taking natural logarithms of equation, we obtain equation A3 where the constant term c is 1n I(0).

[10] The approach of calculating initial capital stock is suggested by William W.F. Chao and Lawrence Lau(Chou,1993).