TECHNOLOGICAL CHANGE, TECHNOLOGICAL CATCH-UP, AND CAPITAL DEEPENING: RELATIVE CONTRIBUTIONS TO GROWTH AND CONVERGENCE DURING 90'S

by

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Abstract

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In this thesis labour productivity growth is decomposed into efficiency change, technological change and change of capital stock using data envelopment analysis. This approach is used to investigate the sources of growth in the world and to study the evolution of world income distribution in terms of tripartite decomposition during 90's. The author takes advantage of methodology developed by Kumar and Russell (2002) and complements their analysis by (i) including number of transition economies and by (ii) considering 90's. In contrast to previous study, which confirmed that capital deepening was the major force of growth and changing the world income distribution over 1965-1990, my analysis shows that during 90's technological change constituted the main driving force of growth and evolution of world income distribution, whereas capital accumulation played the minor role.

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GLOSSARY

Disorganization is the elimination of central planner as a ruler of supplier – buyer relationships between enterprises (Blanchard and Kremer 1997).

"Best-practice" production frontier is the upper boundary of the set, obtained by enveloping the observed data in smallest convex cone. (Kumar and Russell 2002)

Capital Deepening is a change of capital stock per worker and reflects movements along the frontier.

Efficiency change is movement toward the production frontier.

Technological catch-up and **efficiency improvement** are equivalent to efficiency change.

Technological change is the shift in the world production frontier,

Chapter 1

INTRODUCTION

In recent decades much attention has been paid to studying economic growth. Such economists as Mankiw *et al.* (1992), Sala-i-Martin (1996) and others devoted a lot of their efforts to figure out the determinants of economic growth and test the convergence hypothesis. On the one hand, growth theories helped to explain the growth phenomena and stylized facts associated with it. On the other hand, being divided into exogenous and endogenous these growth theories stress different sources of economic growth and reasons for presence or lack of convergence among economies. At the same time, growth studies empirically document the existing disagreement. That is why "… empirical and theoretical work on growth continues to be an important and lively enterprise" (Durlauf 1996, p. 1018).

While considering growth researchers stress that technology should be considered with a great care (Bernard and Jones (1996).

As the global production technology changes, countries absorb such improvement differently, that is, it influences productivities of particular countries in different ways. For example, brand new discovery of some production improvement can be employed in one country right away but it will take a while, until improvement is implemented in the other country. As a consequence, growth to the large extent depends on technology employed to turn inputs into outputs.

Furthermore, it is usually assumed that countries produce the best they can do, that is using standard regression methods does not allow to account for individual inefficiency (e.g. Mankiw *et al.* (1992). However, in the reality we observe that countries similarly endowed with resources produce different output. Such differences may occur due to market imperfections, due to specific government or union restrictions. For instance, economies in transition are characterized by already established infrastructure and existing resources and technology. After the breakdown of the USSR the ties between existing enterprises were broken and production in newly independent economies has declined. Many factories were either closed or worked just at very small portion of its previous capacity (Blanchard and Kremer (1997). However, economies possess not less capital than they used to. In this regard a natural question arises: do economies in transition really lack capital or is this a problem of technology and efficiency. In reviewing growth studies Temple (1999) raises the same issue.

In my analysis I am going to concentrate on the 90's, which is marked by considerable technological change. This refers not only to development of information technologies but also to manufacturing and services. Studies (e.g. Brynjolfsson and Hitt, 2000) analyzing the impact of computers on economic growth have documented that the effect of computers on economic development during 70's and 80's was very small, whereas during 90's computers influenced the development of countries considerably. Moreover, growth studies have mainly concentrated on growth issues using data for the periods prior to 1990[1]. Hence, it remains so far a challenge to investigate how economies evolved during 90's.

One consequence of using data for the period prior to 1990 is that researchers did not consider transition economies. Their number is large; in my sample there

[1] E.g. Mankiw et al. (1992), DeLong (1998), Sala-i-Martin (1996)

are 15 transition economies, which were not considered before and adding them to the sample may enrich the understanding of growth and the evolution of world income[2] distribution.

So, my analysis will be a cross-country analysis of economic growth during 90's. In this study I'm going to investigate, firstly, what is the major source of economic growth in the world and in transition countries in particular. I will analyse how much of the growth that we observe is due to change in technology, due to change in efficiency and due to capital accumulation. And, secondly, I will consider the entire world distribution of income. I will trace the isolated influences of components attributable to changes in technology, efficiency and in capital on the income distribution, and then compare their relative contribution to the change of distribution during 90's.

The remainder of the paper is organized as follows. I will provide a review of growth studies, which consider determinants of economic growth and testing the convergence hypothesis in the subsequent chapter. In *Chapter* 3 I describe non-parametric estimation and data envelopment analysis methods. And, finally, I present empirical evidence and concluding remarks in *Chapters* 4 and 5, respectively.

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[2] Jones (1997) suggests that GDP per worker would be most appropriate definition of welfare, and hence income, once developing countries are included into analysis.

Chapter 2

CONTRIBUTION OF CAPITAL, TECHNOLOGY AND EFFICIENCY TO ECONOMIC GROWTH AND CONVERGENCE: A REVIEW

In recent years there has been a re-emergence of the interest of economists in growth issues. Temple (1999) and Durlauf (1996) in their reviews of growth studies point out the researchers have addressed and explained growth phenomena however have not come to similar conclusions.

Researchers working on growth issues might be divided into two groups. One group is seeking to find out whether there is a tendency of economies to converge; the second group is trying to determine the sources of economic growth. Both groups have not come to an agreement and findings, which I present below, differ across growth studies.

Using a production-frontier approach, Kumar and Russell (2002) estimated productivity growth non-parametrically, and having decomposed it into change of efficiency (efficiency improvement), change of technology and change of capital stock (capital accumulation), conclude that, for example, in Japan and Taiwan growth was primarily driven by capital deepening, whereas in only some countries growth resulted from efficiency improvement. Nonetheless, in the entire sample capital accumulation was the major source of economic growth. In contrast, using parametric approach[3] Dessus (1999) found that technological catch-up was the principal force of increased productivity in Taiwan. Thus, the difference in results

[3] Total factor productivity in Dessus (1999) was calculated as a residual from Cobb-Douglas production function: $TFP_t = Y_t \big/ K^{0.3} \cdot L^{0.7}$. Coefficient α = 0.3 and β = 0.7 were estimated in regression analysis.

seems to have emerged due to using two different approaches[4]. Kumar and Russell (2002) have also shown that relationship between the contribution of efficiency to productivity growth and initial level of productivity has no clear pattern, so that efficiency improvement was not an important determinant of growth over 1965-1990.

Using the same methodology as Kumar and Russell, Salinas Jiménez (2002) concludes that Spanish regions operated at about 80% level of efficiency and that efficiency changes contribute only 20% to the growth of output, while capital deepening and technological progress were vital forces that drove productivity growth.

In their analysis Hall and Jones (1999) conclude that variables attributable to physical and human capital only partially explain a variation of output per worker across countries, the rest is the so-called Solow residual. Differences in institution and government policies have the largest effect on the variation of economic development. And institutions and policies in its turn affect efficiency of the production. Authors claim that social infrastructure influences growth of income through capital accumulation, education attainment and improvement of labour productivity.

Using Bayesian Stochastic Frontier method for measuring productivity Osiewalski *et al.* (1997) compare the performance of Poland with other western developed economies. They found out that it is efficiency change and not input accumulation that can be considered to be the major source of growth in Poland prior to 1990.

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[4] Both Kumar and Russell (2002) and Dessus (1999) used comparable samples: 1965 - 1990 and 1952 - 1990 respectively. And the data in both cases came from the same source: Penn World Tables, version 5.6. However, these two analyses use different notions of technological change: Dessus (1999) meant own Taiwanese technological change, whereas Kumar and Russell (2002) changing the Taiwanese technology relative to world technology.

Human capital is said to be another source of productivity growth. Dessus (1999) uses human capital stock variable proxied by educational attainment of the civilian population aged 15 and over. He finds that besides technological catch-up, human capital has constituted an important source of TFP growth. Considering human capital as a source of productivity growth was also done using production-frontier approach (Henderson *et al.* 2001). This examination is different from that of Kumar and Russell (2002) only by inclusion of human capital growth. The conclusion of Henderson *et al.* (2001) about human capital effects is the same as of Dessus (1999): a large part of productivity growth is attributed to the accumulation of human capital.

Empirical studies have also paid attention to testing the convergence hypothesis. In one of the earliest examination of long-run economic growth Baumol (1986) confirms the convergence phenomenon for seven industrialized countries. But extending the sample beyond free-market industrialized countries yields different results. When 72 countries are analysed (with centrally planned economies included) rather than exhibit a tendency to converge, some of the poorest countries have not been growing faster than rich ones. The argument of De Long (1988) is that Baumol's finding is not informative, since those economies, which have not converged (but were rich in the past) have been excluded from the sample and those included were bounded to converge. He concluded that such finding of convergence cannot be trusted because the sample suffers from selection bias.

In their research Mankiw *et al.* (1992) and Sala-i-Martin (1996) have confirmed the results of other studies on the failure of incomes across countries to converge. There is no tendency for the poor economies to perform better than rich ones.

Other authors concerned the distribution of world per capita income and productivity. Abramovitz (1986) was among first researchers to conclude that convergence could take place only within a group of economies. The main finding of Quah (1996, 1996b), who explicitly focused on the shape of the distribution, is that the world is moving toward a bimodal income distribution, the so-called "twin-peaks" distribution phenomena. Jones (1996) examines convergence among countries using neoclassical growth model and treats differences in technologies as exogenously given. And again, it is concluded that in the sample of today's rich countries there is tendency to converge, while the sample, which includes large number of economies (the world), shows opposite evidence.

The main idea of using non-parametric approach is to account for inefficiency. Consequently, using DEA in analyzing growth will add up a fresh insight. Such one has been made by Kumar and Russell (2002). In particular, their analysis allowed to distinguish between different sources of convergences. In lines with Quah (1996), it was justified that the distribution of labour productivity levels has turned bimodal by 1990. the main finding of Kumar and Russell (2002) and Henderson and Russell (2001) is that during 1965 – 1990 time-span international divergence of labour productivity took place and that input deepening (accumulation of human and physical capital) constituted the most of that. Kumar and Russell (2002) also found that in spite of the occurrence of technological catch-up occurred, defined as change in efficiency (countries moved toward production possibility frontier) it did not significantly changed the distribution of labour productivity in the world.

Kumar and Russell (2002) analysis included only developing, newly industrialized countries as well as original OECD countries. They did not examine countries in transition. This can be explained by the limitation of the data availability. Data came from Penn World Tables (version 5.6) in which a lot of transition countries were not present and U.S.S.R. represented most of them, so that no distinction or revealing peculiarities for transitional countries could be made for this period.

It appears to me that the most researches involved in studying growth have made inferences using samples prior to 1990. So, my contribution to understanding growth will be a direct continuation of research made by Kumar and Russell (2002) extending it in two aspects: (i) I include emerging economies, i.e. transition economies, which have not been taken into account before and (ii) I look at 90's, which can be truly considered to be the time of technology acceleration, and, consequently, this period would very interesting to analyse.

Chapter 3

THEORETICAL FRAMEWORK

In the literature dedicated to the analysis of productivity, authors use either a parametric approach, that is, they assume a specific form of production function (e.g. Edwards 1998, Bernard and Jones 1996), or a nonparametric approach (Färe *et al.* 1994). On one hand, the nonparametric approach is more powerful since it distinguishes between technological catch-up (change of efficiency) and technological change; it does not require specification of functional form and does not need neutrality of technological change. On the other hand, returns to scale have to be assumed from the very beginning. The main flaw of the parametric approach is that the assumed specific form of production function may be false and the inferences, which are drawn from the regression analysis, might be unreliable. The non-parametric approach, though, is not flawless either. The limitation of the non-parametric estimation is an assumption about the returns to scale. In the production-frontier approach constant returns to scale are usually assumed. Adherents of regression analysis would argue that they necessarily test for returns to scale, not assume. Nonetheless, it appears that the results in a production-frontier approach are robust with the respect to the assumption about returns to scale (Kumar and Russell 2002).

3.1 Data envelopment analysis

From methodology point of view I follow Kumar and Russell (2002); for convention I also employ their notation. The idea of production-frontier approach is non-parametric estimation of the technology through enveloping the data by the smallest convex free disposable cone of the observed data on inputs and outputs, the upper boundary of which would be the observed "best-practice" World production frontier.

To start with, let T^t be the technology set that characterizes world production technology in period t, defined as

$$T^t = \left\{ \left(K^t, L^t, Y^t\right): \quad \left(K^t, L^t\right) \; can \; produce \; Y^t \right\} \tag{1}$$

where K_t is capital stock, L_t is labour input and Y_t is output at t time period. The technology set is then estimated via activity analysis model:

$$\hat{T}^t = \left\{ \left(K^t, L^t, Y^t\right): \quad \begin{array}{l} \sum_{n=1}^{N} z_n^t \cdot K_n^t \leq K^t, \\ \sum_{n=1}^{N} z_n^t \cdot L_n^t \leq L^t, \\ \sum_{n=1}^{N} z_n^t \cdot Y_n^t \geq Y^t, \\ z_n^t \geq 0, \qquad n = 1,2,\ldots,N \end{array} \right\} \tag{2}$$

I will assume technology that exhibits constant returns to scale[5]. This assumption in common and widely used in growth theory and growth measurement. Here $\left(L_n^t, K_n^t, Y_n^t\right) \quad n = 1,2,\ldots,N$ is input and output vector at period t, N is the number of countries and $z_n^t, \quad n = 1,2,\ldots,N$ are *Intensity Variables*, one for every activity and for time period. These variables are non-negative real numbers and they indicate to what extent a particular activity is involved in turning inputs into outputs.

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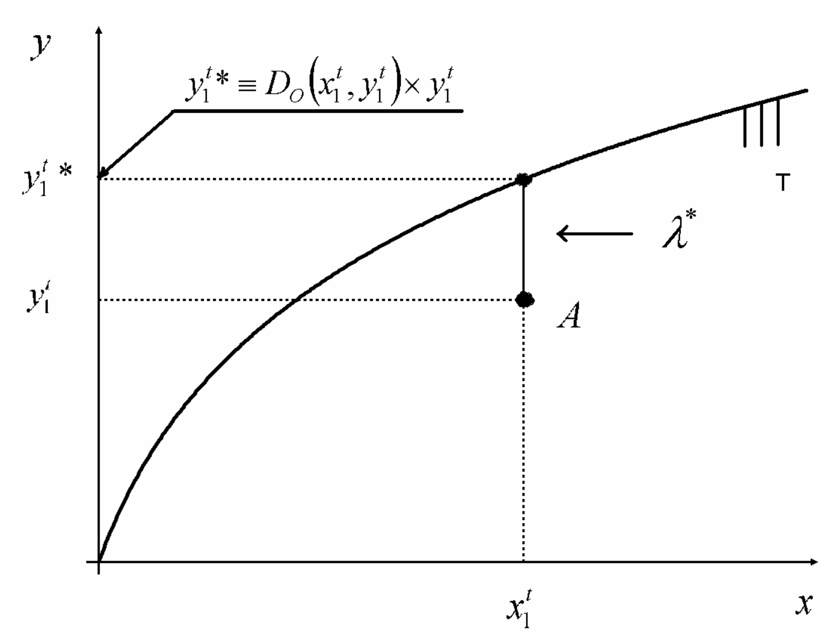
[5] Non-increasing and variable returns to scale can be models adding conditions $\sum z \leq 1$ and $\sum z = 1$, respectively.

Further, I use the Shephard output distance functions as the basic tool for productivity and efficiency measurement, which is defined as:

$$D_O^t\left(K^t, L^t, Y^t\right) = \inf\left\{\lambda : \left(K^t, L^t, \frac{Y^t}{\lambda}\right) \in T^t\right\} \tag{3}$$

The following figure will help to interpret formula (3).

Figure 1 (explaining distance function)



On this figure we see some observation $\left(x_1^t, y_1^t\right)$ (point A) and technology set T, with the help of which input x is turned into output y. We notice that given this input intensity x_1^t country could have produced $y_1^t *$, which is on the "best-practice" production frontier. Hence, in this figure the distance between $y_1^t *$ and y_1^t will represent inefficiency, with which x_1^t is used. Distance function for this particular hypothetical case means the smallest λ (in this particular figure it is λ^*), by which y_1^t should be divided so that the observation in point A would be on the frontier, i.e. produce $y_1^t *$.

The empirical analogue of the Shephard output distance functions is the Farrell output oriented technical efficiency measure. For country n in period t it will be defined as follows[6]:

$$e_n^t\left(K_n^t, L_n^t, Y_n^t\right) = \inf\left\{\lambda : \left(K_n^t, L_n^t, \frac{Y_n^t}{\lambda}\right) \in \hat{T}^t\right\} \qquad n = 1,2,\ldots,N \tag{4}$$

These indices are the reciprocal of the largest radial expansion of output, provided that inputs remain constant and expanded output is still in the technology set. Indices are $e_n^t(\cdot) \in (0,1]$ and take the value of 1 if only if observation in period t is on the production possibility frontier. Efficiency indices can be calculated by solving a linear programming problem for each observation j $(j = 1,\ldots,N)$ at s time period (Färe, Grosskopf and Lovell, 1995).

$$e_j^s = \left(D_O^s\left(K_j^s, L_j^s, Y_j^s\right) \right)^{-1} = \max_{(\theta, Z_1,\ldots,Z_N)} \theta$$

$$\text{subject to} \qquad \sum_{n=1}^{N} z_n \cdot Y_n^s \geq Y_j^s \cdot \theta, \tag{5}$$

[6] In the literature the reciprocal of (4) is often used to define Farrell output-based measure of technical efficiency (and it is equal to the reciprocal of output-based Shephard distance function), however, I use the Kumar and Russell (2002) notation for convention.

$$\sum_{n=1}^{N} z_n \cdot K_n^s \le K_j^s,$$
$$\left.\sum_{n=1}^{N} z_n \cdot L_n^s \le L_j^s, \quad z_n \ge 0, \qquad n = 1,2,\ldots,N \right\}$$

Having made such computations for each country I will construct observed "best-practice" world production frontier and output-based distances to this frontier would stand for inefficiency.

For my analysis I will also need to calculate Malmquist Productivity Index, which involves computation of two mixed period distance functions:

$$D_O^{t+1}\left(K_j^t, L_j^t, Y_j^t\right) \qquad \text{and} \qquad D_O^t\left(K_j^{t+1}, L_j^{t+1}, Y_j^{t+1}\right). \tag{6}$$

In the first distance function the technology is from period $t+1$ and the input and output vectors being evaluated are from period t. In the second distance function time periods are reversed. These efficiency indices can be calculated by solving a linear programming problem for each observation j at t and $t+1$ time periods, respectively:

$$\left(D_O^{t+1}\left(K_j^t, L_j^t, Y_j^t\right) \right)^{-1} = \max_{(\theta, Z_1, \ldots, Z_N)} \theta$$

$$\text{subject to} \qquad \sum_{n=1}^{N} z_n \cdot Y_n^{t+1} \ge Y_j^t \cdot \theta, \tag{7}$$
$$\sum_{n=1}^{N} z_n \cdot K_n^{t+1} \le K_j^t,$$
$$\left.\sum_{n=1}^{N} z_n \cdot L_n^{t+1} \le L_j^t, \quad z_n \ge 0, \qquad n = 1,2,\ldots,N \right\}$$ [7]

[7] The optimal values of intensity variables $z_1, \ldots, z_N$ will be different for different linear programming problems (as for example in (5), (6) and (7))

and

$$\left(D_O^{t+1}\left(K_j^t, L_j^t, Y_j^t\right) \right)^{-1} = \max_{(\theta, Z_1, \ldots, Z_N)} \theta$$

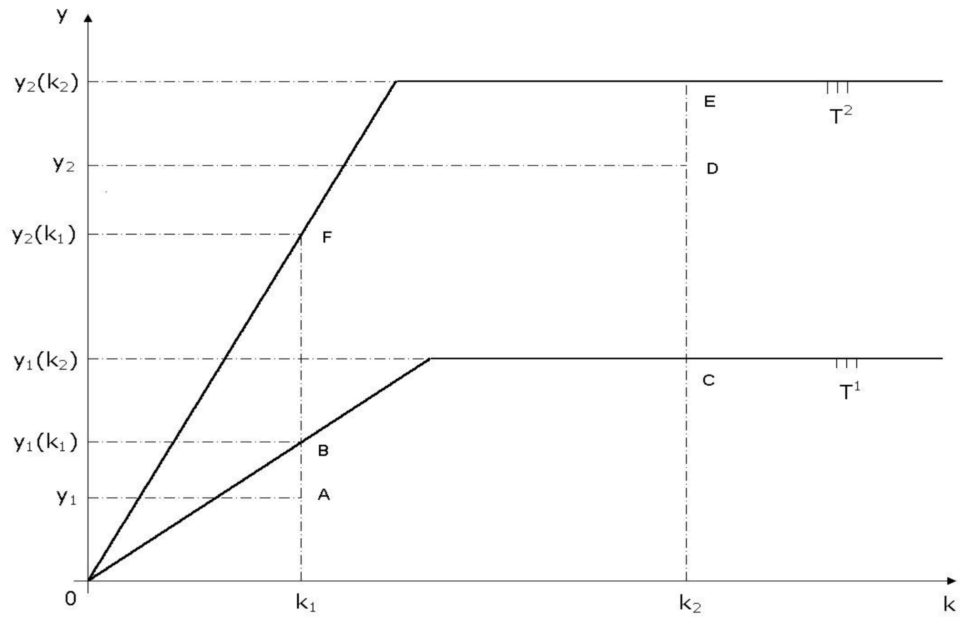
$$\text{subject to} \quad \left.\begin{aligned} &\sum_{n=1}^{N} z_n \cdot Y_n^t \geq Y_j^{t+1} \cdot \theta, \\ &\sum_{n=1}^{N} z_n \cdot K_n^t \leq K_j^{t+1}, \\ &\sum_{n=1}^{N} z_n \cdot L_n^t \leq L_j^{t+1}, \quad z_n \geq 0, \qquad n = 1,2,\ldots,N \end{aligned}\right\} \qquad (8)$$

3.2 A non-parametric approach to decomposing labour productivity growth

In this subsection I will follow the main conceptual result of Kumar and Russell (2002) and explain how growth of productivity is decomposed into three components: technology change, efficiency improvement and capital accumulation. The first component would be attributable to shifts in world possibility frontier; the seconds would show the movement toward or away from the frontier reflecting countries' adopting "best-practice" technologies and eliminating (or increasing) technological and allocative inefficiencies; the third would reveal movements along the frontier.

In my particular case with one output (Y) and two inputs (K and L) technology can be represented in (k, y) space, where $k = K/L$ and $y = Y/L$. For the sake of an illustration a simple technology is depicted in *Figure* 2.

Figure 2 (conceptual decomposition)[8]



The points A and D with coordinates (k_1, y_1) and (k_2, y_2), respectively, represent observed values for two periods. Whereas potential values, which would be efficient, are point B at $(k_1, y_1(k_1))$ and point E at $(k_2, y_2(k_2))$ respectively. By construction $y_1(k_1) \equiv \frac{y_1}{e_1}$ and $y_2(k_2) \equiv \frac{y_2}{e_2}$, where e_1 and e_2 stand for efficiency indices in periods 1 and 2, respectively and estimated using linear programming problem as in (5). Hence:

$$\frac{y_2}{y_1} = \frac{e_2}{e_1} \cdot \frac{y_2(k_2)}{y_1(k_1)} \tag{9}$$

[8] Adopted from Kumar and Russell (2002).

In this expression the first term reflects change in efficiency and the second term represents the shift in the frontier (the technological change) and effect of change in capital-labour ratio (movements along the frontier).

The second term can be decomposed in two ways. First, technological change can be measured by the shift in the frontier at period 2, $\frac{y_2(k_2)}{y_1(k_2)}$, while capital would be measured along period 1 frontier, $\frac{y_1(k_2)}{y_1(k_1)}$. Alternatively I could measure technological change relative to period 1, $\frac{y_2(k_1)}{y_1(k_1)}$, and capital accumulation along period 2 frontier, $\frac{y_2(k_2)}{y_2(k_1)}$. Following Kumar and Russel (2002), who in turn adopted the idea of Fisher "ideal" index, based on geometric average of these two decompositions, I arrive at the key formula:

$$\frac{y_2}{y_1} = \frac{e_2}{e_1} \cdot \left(\frac{y_2(k_2)}{y_1(k_2)} \cdot \frac{y_2(k_1)}{y_1(k_1)} \right)^{\frac{1}{2}} \cdot \left(\frac{y_1(k_2)}{y_1(k_1)} \cdot \frac{y_2(k_2)}{y_2(k_1)} \right)^{\frac{1}{2}}$$

$$= \quad \Delta EFF \quad \times \quad \Delta TECH \quad \times \quad \Delta CAP \qquad (10)$$

This is the main formula I use to analyse how a relative change in the output per labour ratio is influenced by efficiency change (ΔEFF), technological change $(\Delta TECH)$ and capital accumulation (ΔCAP).

In my research I will take into account these three components only. When analyzing productivity, researches say that since human capital is important determinant of productivity growth it should be accounted for. For the reasons I will explain later I am not going to include human capital into my analysis. After I decompose the growth of labour productivity and analyse its sources, I will trace isolated effects of change in technology, change in efficiency and change in capital stock on the growth of productivity. With the help of nonparametric kernel-based density estimates I then would be able to determine the contribution of each of components of decomposition to evolution of the distribution of productivity, and hence, to division of the world sample of countries into the groups of poor and rich.

The reason why I do not include human capital in my research is the following. First, human capital is proxied by schooling data. However, such methodology ignores investment in health, among other factors (Mankiw *et al.* 1992). Second, even if I was to use the schooling data, they are simply missing for number of countries in World Development Indicators database or Penn World Tables (version 6.1). Third, using schooling data as a proxy for human capital can be misleading once I include transition countries. Education in transition countries does not pay back the same way it does in developed countries. A very large part of population has higher education but this does not imply higher income. These reasons make me deny using schooling data and leave finding a better proxy for human capital for the future.

C h a p t e r 4

EMPIRICAL EVIDENCE

4.1 Data description

The data for empirical analysis are taken from World Development Indicators (Online) and from Penn World Tables, version 6.1. The sample I use in my analysis consists of 72 countries. Sample includes developing, developed and transition countries. There are 15 transition countries 10 of which are former USSR republics. The choice of countries was conditioned on the availability of the data in both sources.

For the purpose of investigation I need data on output, labour and capital stock. The measures of output, the Gross Domestic Product (real) and Total Labour Force are taken from World Development Indicators. Investment data (real) are taken from the Penn World Tables, version 6.1. Physical capital stock variable is constructed using perpetual inventory method[9]. The initial level of capital stock K_0 is estimated as follows: $K_0 = I_0/(g+\varphi)$, where g is calculated as the average geometric growth rate of the investment series and I_0 is the value of the first observed investment level. In evaluating initial capital stock I assume depreciation rate $\varphi = 0.06$ for all countries[10]. Next, stocks of capital are calculated using the following formula: $K_T = (1-\varphi)^T \cdot K_0 + \sum_{t=0}^{T-1} I_t \cdot (1-\varphi)^t$ for $\forall t$ in the sample.

[9] I used Penn World Tables methodology (Summers and Heston, 1991) and methodology by Nehru and Dhareshwar (1993).

[10] This is consistent with other studies: e.g Hall and Jones (1999).

4.2 Countries' Performance

The beginning of transition is commonly characterized by fall in output. The period to be analysed is 1992 to 2000. I will break this time-span into two periods: 1992–1996 and 1996–2000. This separation will distinguish relative contribution of efficiency change, technological change and capital accumulation to the growth in the beginning of the transition and thereafter.

Table 1 (efficiency indices for 1992, 1996 and 2000)

Country	1992	1996	2000
Argentina	0.42	0.39	0.29
Armenia	0.02	0.02	0.02
Australia	0.65	0.69	0.63
Austria	0.71	0.72	0.70
Azerbaijan	0.02	0.01	0.01
Belgium	0.71	0.64	0.58
Brazil	0.31	0.30	0.24
Bulgaria	0.03	0.03	0.03
Canada	0.67	0.67	0.61
Chile	0.11	0.12	0.10
China	0.07	0.07	0.06
Colombia	0.06	0.05	0.04
Costa Rica	0.09	0.09	0.08
Czech Republic	0.10	0.11	0.10
Denmark	0.68	0.75	0.77
Dominican Republic	0.06	0.07	0.07
Ecuador	0.05	0.04	0.03
Estonia	0.07	0.08	0.09
Finland	0.56	0.62	0.71
France	0.71	0.72	0.73
Germany	0.81	0.82	0.79
Greece	0.29	0.26	0.23
Guatemala	0.09	0.08	0.07
Hong Kong	0.48	0.53	0.52
Hungary	0.10	0.09	0.09
Iceland	0.50	0.46	0.42
Indiaonesia	0.02	0.02	0.02
Ireland	1.00	1.00	1.00
Israel	0.49	0.55	0.50
Italy	0.47	0.42	0.35
Jamaica	0.05	0.05	0.04
Japan	0.87	0.78	0.63
Kazakhstan	0.04	0.03	0.03
Kenya	0.01	0.01	0.01
Korea, Republic of	0.21	0.22	0.20
Kyrgyzstan	0.04	0.02	0.02

Country	1992	1996	2000
Lithuania	0.11	0.07	0.06
Luxembourg	1.00	1.00	1.00
Madagascar	0.01	0.00	0.00
Malaysia	0.24	0.24	0.18
Mauritius	0.09	0.10	0.11
Mexico	0.14	0.12	0.12
Moldova	0.06	0.03	0.02
Morocco	0.07	0.07	0.05
Netherlands	0.73	0.78	0.80
New Zealand	0.52	0.56	0.49
Nigeria	0.01	0.01	0.01
Norway	0.70	0.79	0.76
Paraguay	0.05	0.05	0.03
Peru	0.14	0.15	0.11
Philippines	0.04	0.04	0.04
Poland	0.10	0.11	0.10
Portugal	0.24	0.21	0.19
Romania	0.03	0.03	0.02
Russia	0.07	0.05	0.05
Sierra Leone	0.01	0.01	0.00
Singapore	0.65	0.80	0.78
Slovak Republic	0.08	0.08	0.08
Slovenia	0.19	0.19	0.18
Spain	0.38	0.34	0.30
Sri Lanka	0.02	0.03	0.03
Sweden	0.57	0.60	0.63
Switzerland	1.00	1.00	1.00
Tajikistan	0.02	0.01	0.01
Thailand	0.06	0.07	0.06
Ukraine	0.06	0.03	0.03
United Kingdom	0.83	0.80	0.66
United States	1.00	1.00	0.88
Uruguay	0.19	0.21	0.18
Venezuela	0.11	0.08	0.06
Zambia	0.01	0.01	0.01
Zimbabwe	0.03	0.03	0.02

Efficiencies in the *Table 1* are calculated[11] for years 1992, 1996 and 2000. The average efficiency in the sample increased from 1992 to 1996. Though, it remained the same during 1996-2000 period.[12] Countries that formed "best-practice" World frontier in all considered years are Ireland, Luxemburg, Switzerland and United States, except for United States, which had 0.88 efficiency index in 2000. Efficiencies of transition countries increased in the considered period: Armenia and Estonia. In Azerbaijan, Hungary, Kazakhstan, Kyrgyztan, Lithuania, Romania, Russia, Slovenia, Tajikistan and Ukraine efficiency indexes fell, while in Czech Republic, Poland, Slovak Republic efficiencies remained the same. Even though the indices changed, the changes are not dramatic. Since estimating efficiencies is not the goal of my research and is only a tool for further analysis, I next focus on the determinants of growth. Here I would only like to mention one interesting result about transition economies. On the subsequent figures I present the year to year efficiency growth rates for post-soviet countries during 90's.

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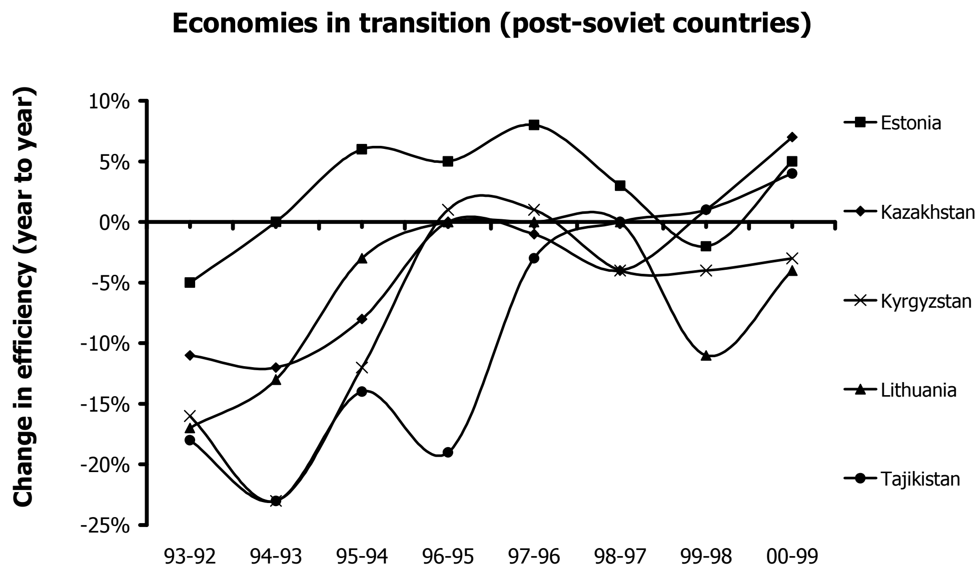
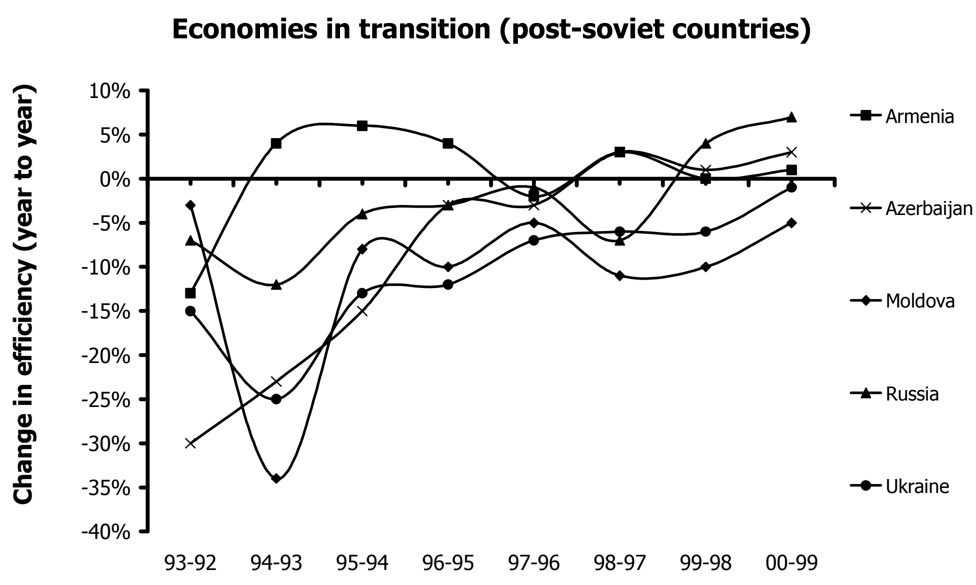
11 Efficiency calculations were carried out with the help of *OnFront* software OnFront 2.0 (available from www.emq.com)

12 As Kumar and Russell (2002) point out this mathematical method does not take measurement error, sampling error into account. Since I am interested in the statistical significance of the components of decomposition of productivity changes, I do not concern about statistical significance of efficiency of individual country. I the subsequent subchapter I will take care of significance of distribution shifts.

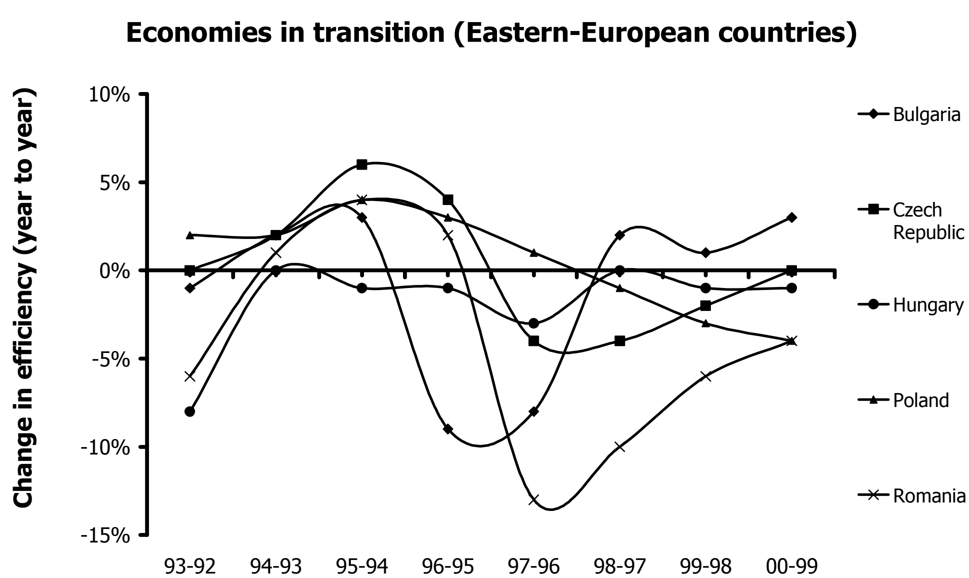
Figure 3 (efficiency growth rates in post-soviet countries)





From these two figures it can be seen that the general pattern of efficiencies in transition economies gets better and better. At the beginning of transition the efficiency fell dramatically; afterwards the decrease was becoming smaller and for some economies efficiency has even grew year to year in the end of 90's. By the end of transition period the fell of efficiencies was roughly identical for all post-soviet countries in the sample. This pattern is consistent with study of Blanchard and Kremer (1997), in which they point at disorganization as a source of output plummeting in transition countries. After transition started most seller-buyer economic relationships between former soviet enterprises broke down (i.e. transition eliminated the central planner), the new contracts were hard to enforce and trade between soviet republics has fallen. Later on, enterprises could find more reliable suppliers and, as a result, situation started improving. This very situation can be read from *Figure* 3. The beginning of transition started with considerable drop in efficiency in most post-soviet economies and then year by year fall reduced.

Figure 4 (efficiency growth rates in Eastern-European countries)



Furthermore, *Figure* 4 illustrates different pattern for Eastern-European countries. In these countries the fall in efficiency was not such considerable during 90's and in general it was not changing as much as in post–soviet countries. This is again consistent with Blanchard and Kremer study, in which authors showed that disorganization appears to have played a smaller role in Central- and Eastern-European countries than in the former Soviet Union.

4.3 Tripartite decomposition: empirical results

Having formula $\frac{y_2}{y_1} = \Delta EFF \times \Delta TECH \times \Delta CAP$ in mind I carried out such calculations for all countries. The four-year interval calculations can be seen in the Appendix, *Table A1*.

The average[13] increase in the productivity in the entire sample (1992 - 2000) is 8.1%, with growth of 1.39% in the first half (1992 - 1996) and 6.61% in the second (1996 - 2000). This average (in the sample) increase was primarily due to technological change 30.62% (8.43% and 20.48% in the first and second halves, respectively), while capital deepening constituted only 0.16% (0.19% and -0.04%) on average. The main factor that prevented growth was a worsening of the efficiency – 17.37% (–6.67% and –11.47%, respectively). This might mean that on average world labour productivity in 90's was increased almost entirely with development of technology. Overall in the considered sample during 90's technological change constituted the most of the labour productivity growth, while capital accumulation has played very negligible role. This finding is completely different from that obtained by Kumar and Russell (2002), who document that over 1965 – 1990, the capital accumulation was the primal source of labour productivity growth while technological change and efficiency change explained very little of growth.

[13] I used the simple (equal weights) geometric average.

Table 2 (decomposition of labour productivity growth in transition countries)

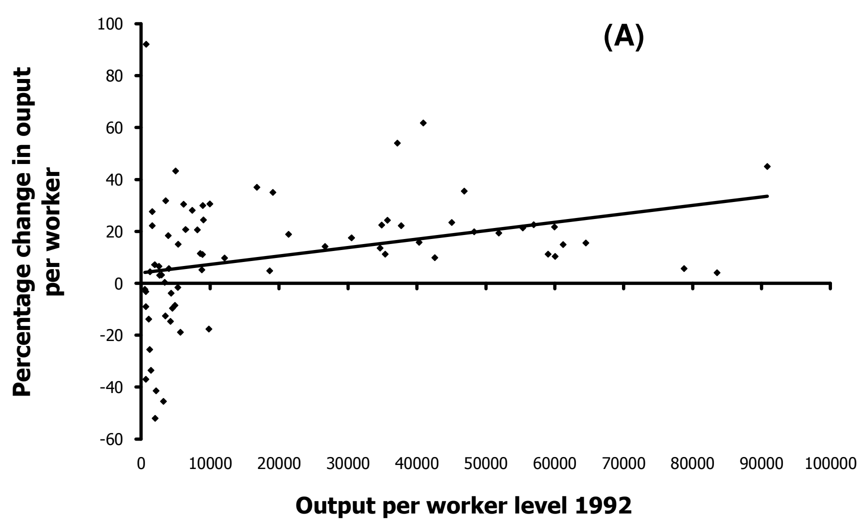
Period	Country	Productivity change	=	Efficiency change	Change in technology	Capital accumulation
1992\1996	Armenia	4.96	=	-0.58	6.29	-0.68
1996\2000	Armenia	16.44	=	2.43	15.09	-1.22
1992\2000	Armenia	22.21	=	1.83	22.29	-1.86
1992\1996	Azerbaijan	-48.64	=	-55.54	15.51	0.01
1996\2000	Azerbaijan	29.50	=	3.18	25.51	0.00
1992\2000	Azerbaijan	-33.49	=	-54.13	44.99	0.00
1992\1996	Bulgaria	-4.33	=	-4.93	0.59	0.04
1996\2000	Bulgaria	7.84	=	-2.22	10.15	0.12
1992\2000	Bulgaria	3.17	=	-7.03	10.82	0.14
1992\1996	Czech Republic	12.15	=	12.21	-0.11	0.05
1996\2000	Czech Republic	-0.59	=	-9.41	9.49	0.22
1992\2000	Czech Republic	11.49	=	1.65	9.39	0.27
1992\1996	Estonia	4.80	=	5.80	-1.01	0.07
1996\2000	Estonia	24.45	=	14.93	8.41	-0.12
1992\2000	Estonia	30.43	=	21.60	7.28	-0.02
1992\1996	Hungary	4.45	=	-9.44	15.16	0.16
1996\2000	Hungary	19.04	=	-4.55	23.88	0.67
1992\2000	Hungary	24.34	=	-13.56	42.76	0.76
1992\1996	Kazakhstan	-24.95	=	-27.60	3.83	-0.15
1996\2000	Kazakhstan	16.41	=	3.03	13.23	-0.21
1992\2000	Kazakhstan	-12.63	=	-25.41	17.56	-0.36
1992\1996	Kyrgyzstan	-34.16	=	-42.74	17.71	-2.31
1996\2000	Kyrgyzstan	13.26	=	-9.82	32.37	-5.13
1992\2000	Kyrgyzstan	-25.43	=	-48.36	55.81	-7.32
1992\1996	Lithuania	-16.14	=	-30.21	18.45	1.45
1996\2000	Lithuania	14.72	=	-15.13	34.07	0.82
1992\2000	Lithuania	-3.80	=	-40.78	56.59	3.73
1992\1996	Moldova	-36.70	=	-46.92	17.68	1.34
1996\2000	Moldova	-7.43	=	-27.83	32.38	-3.11
1992\2000	Moldova	-41.40	=	-61.69	55.78	-1.81
1992\1996	Poland	21.15	=	12.19	8.62	-0.58
1996\2000	Poland	18.21	=	-7.26	27.43	0.03
1992\2000	Poland	43.21	=	4.05	38.30	-0.47
1992\1996	Romania	16.46	=	0.80	15.52	0.01
1996\2000	Romania	-11.48	=	-29.47	25.51	0.00
1992\2000	Romania	3.09	=	-28.91	45.00	0.00
1992\1996	Russia	-25.94	=	-24.46	-1.82	-0.14
1996\2000	Russia	9.55	=	2.31	7.36	-0.27
1992\2000	Russia	-18.87	=	-22.71	5.43	-0.43
1992\1996	Tajikistan	-56.44	=	-56.16	-0.34	-0.30
1996\2000	Tajikistan	10.13	=	1.77	8.80	-0.54
1992\2000	Tajikistan	-52.03	=	-55.39	8.45	-0.85
1992\1996	Ukraine	-46.70	=	-51.37	8.02	1.46
1996\2000	Ukraine	2.37	=	-19.19	26.14	0.42
1992\2000	Ukraine	-45.44	=	-60.70	36.34	1.82

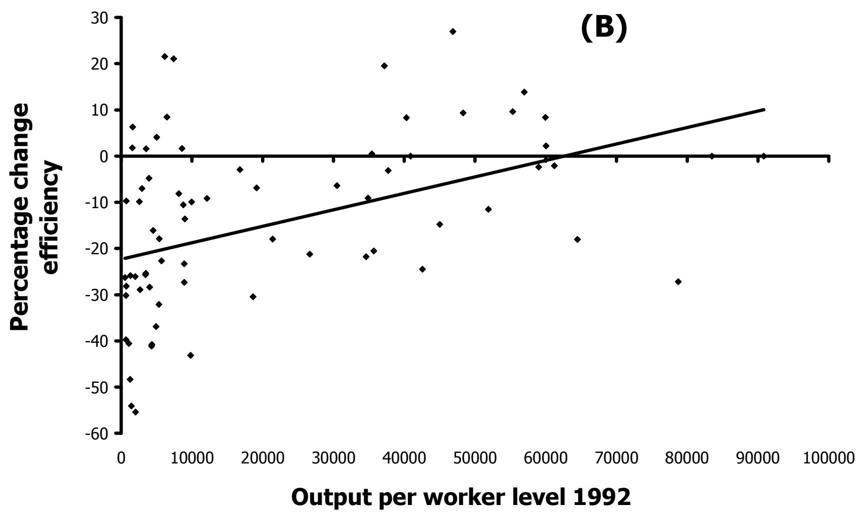
In some transition countries labour force has increased, while in others decreased. It turns out that in transition countries as well as on average in the sample, capital accumulation played the minor role in changing the labour productivity,. As it can be seen from the table, the main source of economic growth in transition countries is still technological change, as in on average in the world. This is not the case for Czech Republic, Estonia and Poland, where productivity growth was primarily driven by efficiency growth in one or two halves of 90's. At the same time, the main factor that prevented growth in transition countries was collapse of efficiency; the same result as in the entire sample.

There is one more interesting observation. The growth of labour productivity was greater in the second half of 90's (or equivalently the fall was smaller) for transition economies and in unison the fall in efficiency was larger in the first half in comparison to the second half. This implies, that for transition economies the productivity change has very similar pattern as the efficiency change and that growth is very much linked to efficiency.

As in Kumar and Russell (2002), considering the entire period I will summarize decomposition calculations for the entire world with the following figures and regression lines plotted on them.

Figure 5 (percentage changes between 1992 and 2000 in labour productivity, efficiency technology and capital plotted against output per worker level in 1992)





It can be clearly seen from the *Figure* 5 (panel A) that in those countries, where output per worker was initially relatively larger, increase in labour productivity was also larger. The positive slope of the regression[14] line indicates that there is no tendency for poorer economies to grow faster then richer, thus confirming results of previous studies[15]. However, I need to consider the entire distribution of labour productivity and this will be made in the subsequent section.

In *Figure* 5 (panel B) the relationship between the contribution of change in efficiency to productivity growth and initial level of output per worker in 1992 represents the same pattern as the whole pattern of labour productivity. Moreover, the coefficients of regressions are almost identical. This panel shows that relatively rich countries have benefited more from the growth in efficiency than relatively poor countries. This result will also be seen form the analysis of estimated world income distributions ,which I will do in the subsequent section.

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[14] The results of regressions are presented in the *Table* A2 in appendix.

[15] E.g. DeLong (1988)

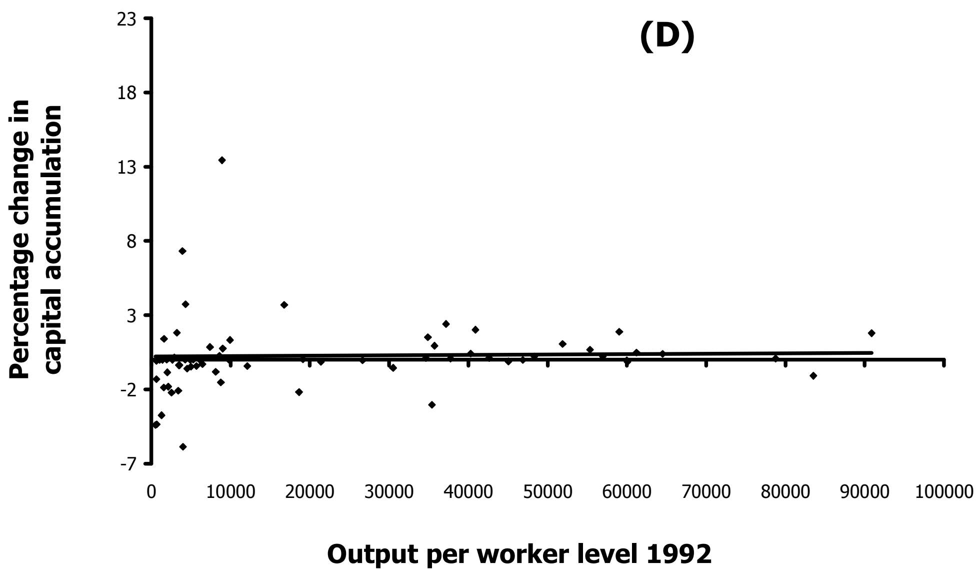


Figure 5 (panel C) indicates that technology change has positively contributed to the growth of labour productivity for both rich and poor countries. However, the negative regression coefficient, though being very small and only marginally significant $(p - value = 0.09)$ implies that relatively poor countries have gained more from technological change than more developed countries (these very results will be confirmed with estimation of income distribution). And *Figure* 5 (panel D) confirms that the capital accumulation was neutral[16] during 90's in the sense that relatively rich and poor countries have benefited equally from change in capital per worker. This does not mean that capital has been accumulated in the same way in both relatively rich and poor countries, but that the relative contribution of capital deepening to the labour productivity growth was on average negligible regardless of the development of an economy.

4.4 Analysis of productivity distributions

In this subsection, again following Kumar and Russell (2002), but with new data, I analyse world's productivity distribution and its sources, obtained from the tripartite decomposition, described in the subsection 3.2. The goal of such analysis is to assess the relative contribution of technological change, technological catch-up and capital deepening to the evolution of world labour productivity distribution. The idea is to watch how would distribution look like if labour productivity were affected only by

- one of the components (ΔEFF, or $\Delta TECH$, or ΔCAP)
- two of the components (ΔEFF and $\Delta TECH$, or ΔEFF and ΔCAP, or $\Delta TECH$ and ΔCAP).

We can rewrite the formula of conceptual decomposition (10) in such a way:

$$y_2 = \left(\Delta EFF \times \Delta TECH \times \Delta CAP \right) \times y_1$$

[16] The regression slope coefficient is statistically insignificant at any conventional levels.

which conceptually implies that labour productivity in 2000 can be obtained by multiplying labour productivity in1992 by all three factors of decomposition.

In the same fashion I construct counterfactual distribution by introducing just one component. The counterfactual distribution of the variable $y^e = y_{1992} \times \Delta EFF$ isolates the effect of efficiency, i.e. assuming no changes in technology and no capital deepening.

By the same token, the counterfactual distribution of the variable $y^{et} = y_{1992} \times \Delta EFF \times \Delta TECH$ isolates the effect of efficiency and technology, assuming no changes in capital, or in other words, isolates the effect of technology, compared to variable $y^e = y_{1992} \times \Delta EFF$.

For the completeness of analysis, I also plot two distributions: y_{2000} and $y^{etc} = y_{1992} \times \Delta EFF \times \Delta TECH \times \Delta CAP$ (which are the same by construction).

For estimating these distributions I employ kernel density estimation, which is roughly speaking "smoothed" histogram of labour productivity. A kernel density estimate is formed by summing the weighted values calculated with the kernel function K as in:

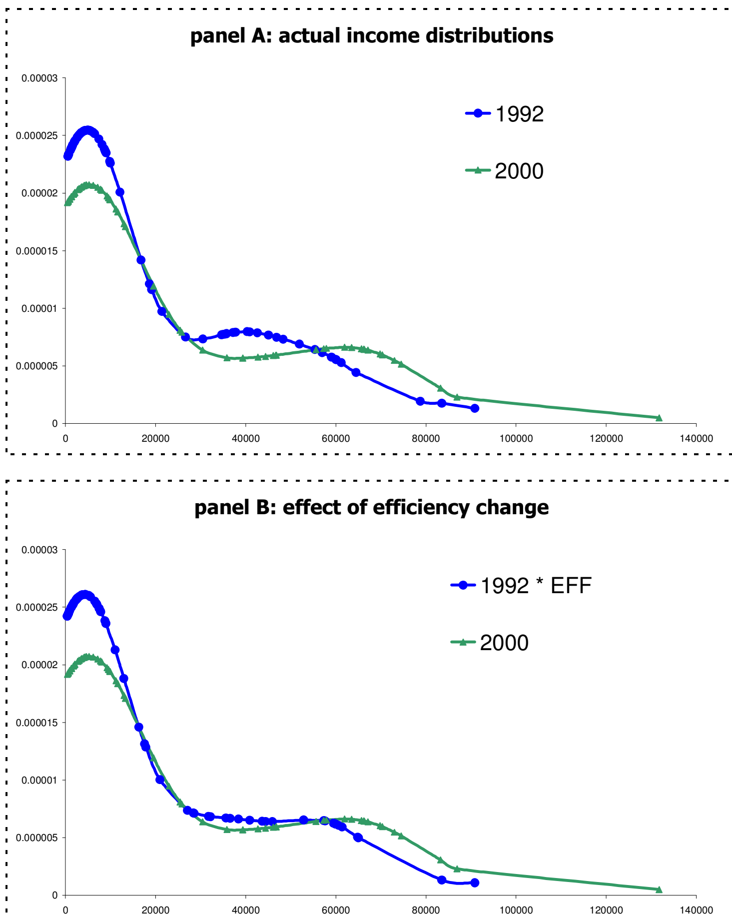
$$\hat{f}_{K,h} = \frac{1}{N \cdot h} \times \sum_{i=1}^{N} K\left[\frac{x - X_i}{h}\right]$$

where h is the bandwidth, chosen using some optimal criterion (the choice of h will define how many values are included in estimating the density at each point), N is the number of observations and $\{X_t\}_{t=1}^{N}$ is observed data. From existing kernel functions I choose the Gaussian kernel (standard normal) in my estimation. The bandwidth[17] is specified as follows: $h = 0.9 \cdot A \cdot N^{-\frac{1}{5}}$

where $A = \min\left(\sqrt{\operatorname{var}(x)},\ \frac{\operatorname{int}(x)}{1.349}\right)$, and $\operatorname{int}(x)$ stands for interquartile range [18].

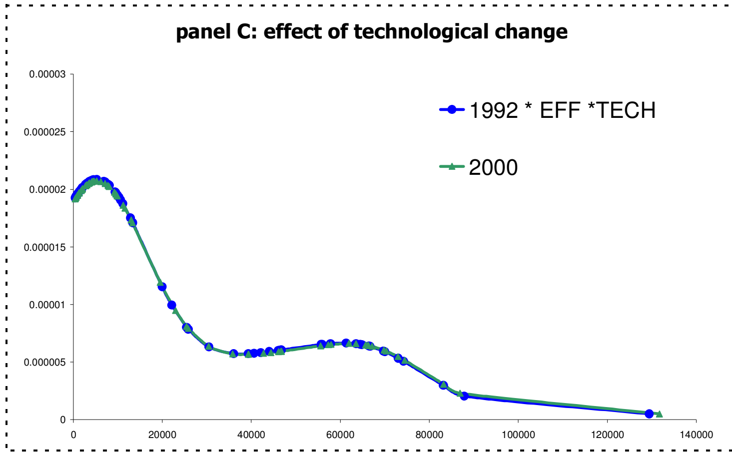
The estimated kernel density functions are presented below:

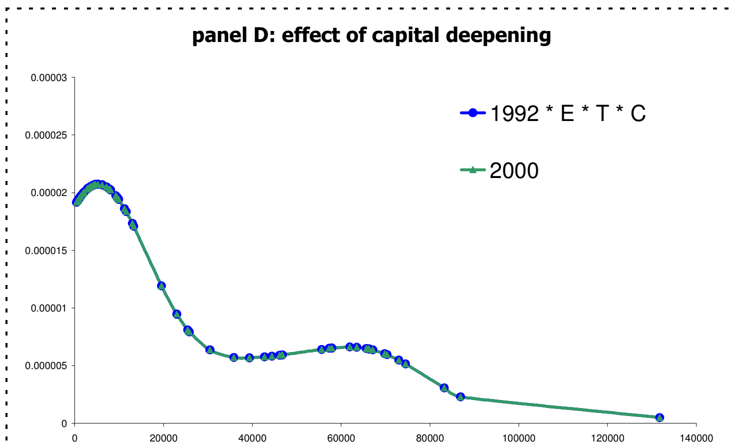
Figure 6 (counterfactual distributions of output per worker)



17 By Silverman (1986)

18 Interquartile range is the difference between the 75th and the 25th percentiles of the sample in X. The interquartile range is a robust estimate of the spread of the data, since changes in the upper and lower 25% of the data do not affect it.





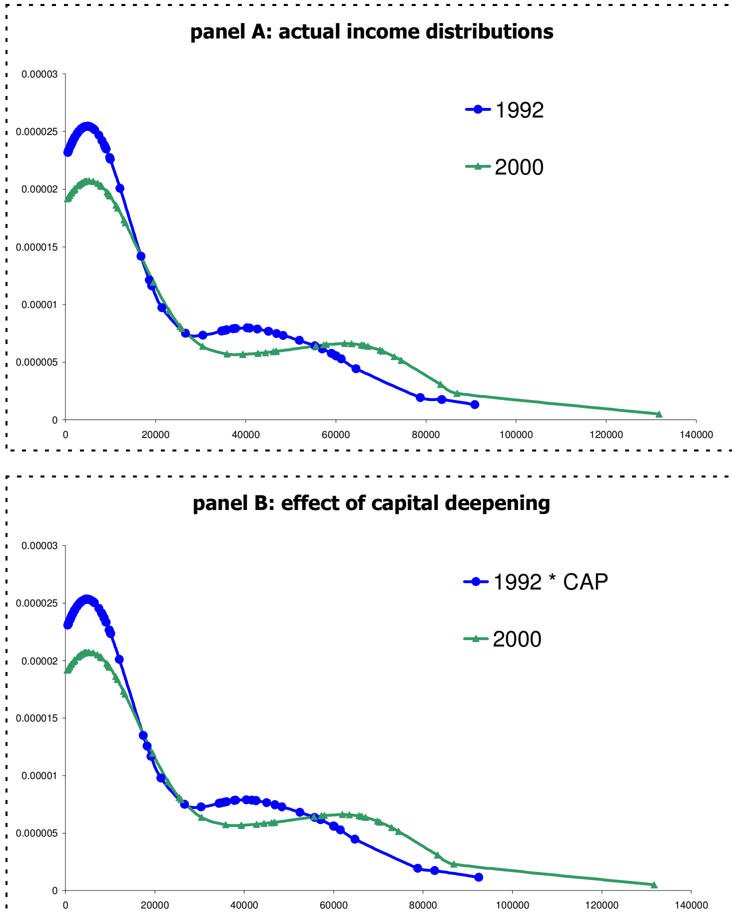
The "eye-ball" analysis of panel (A) of *Figure* 6 suggests that the distribution of labour productivity has changed during 90's. Fewer countries have remained poor, while the mode for richer countries has slightly shifted to the right. This implies that overall the world has become richer. When we compare two distributions of $y_{1992} \times \Delta EFF$ and of y_{2000} (panel B) we see that distributions of y_{1992} and of $y_{1992} \times \Delta EFF$ are not much different at the mode, but the 'rich' peak (at about 40000), representing middle-income countries, started to move to the right. Hence, I conclude that efficiency has not added a lot to the evolution of income distribution during 90's for poor countries, but did benefited richer countries, making them even richer. This very result was observed on the panel B of *Figure* 5. However, should we look at panel C of *Figure* 6, we notice that the income distribution of $y_{1992} \times \Delta EFF \times \Delta TECH$ has shifted considerably in comparison to $y_{1992} \times \Delta EFF$ (compare panel B and panel C of *Figure* 6), so that the technological change has contributed very much to the change of distribution of $y_{1992} \times \Delta EFF$ and, consequently, of y_{1992} especially within poor countries (see the 'poor' mode at about 5000). Recall that the same conclusion has been drawn from analysis of panel C of *Figure* 5 As we visually observe from the last figure (comparing panel (C) and panel (D) of *Figure* 6), we notice that estimated distributions of $y_{1992} \times \Delta EFF \times \Delta TECH$ and of $y_{1992} \times \Delta EFF \times \Delta TECH \times \Delta CAP$ [19] are almost identical, implying that capital deepening has contributed very little to evolution of labour productivity distribution.

One more observation deserves attention. Looking at panels A and B, we notice that one of the modes of y_{1992} ('richer' mode at about 40000) "started" to move to the right due to efficiency change and distribution of $y_{1992} \times \Delta EFF$ becomes flat in the region 30000 to 60000. This implies that efficiency has helped middle-income countries to get closer to the richest countries.

So far, I have chosen the sequence ΔEFF, $\Delta TECH$, ΔCAP (multiplication of decomposition components) to obtain distribution of y_{2000} out of distribution of y_{1992}. Had I introduced components in different order, the densities might have looked differently, suggesting additional insights. Thus, I proceed with ΔCAP, ΔEFF, $\Delta TECH$ order.

[19] Keep in mind that distributions of $y_{1992} \times \Delta EFF \times \Delta TECH \times \Delta CAP$ and of y_{2000} are the same.

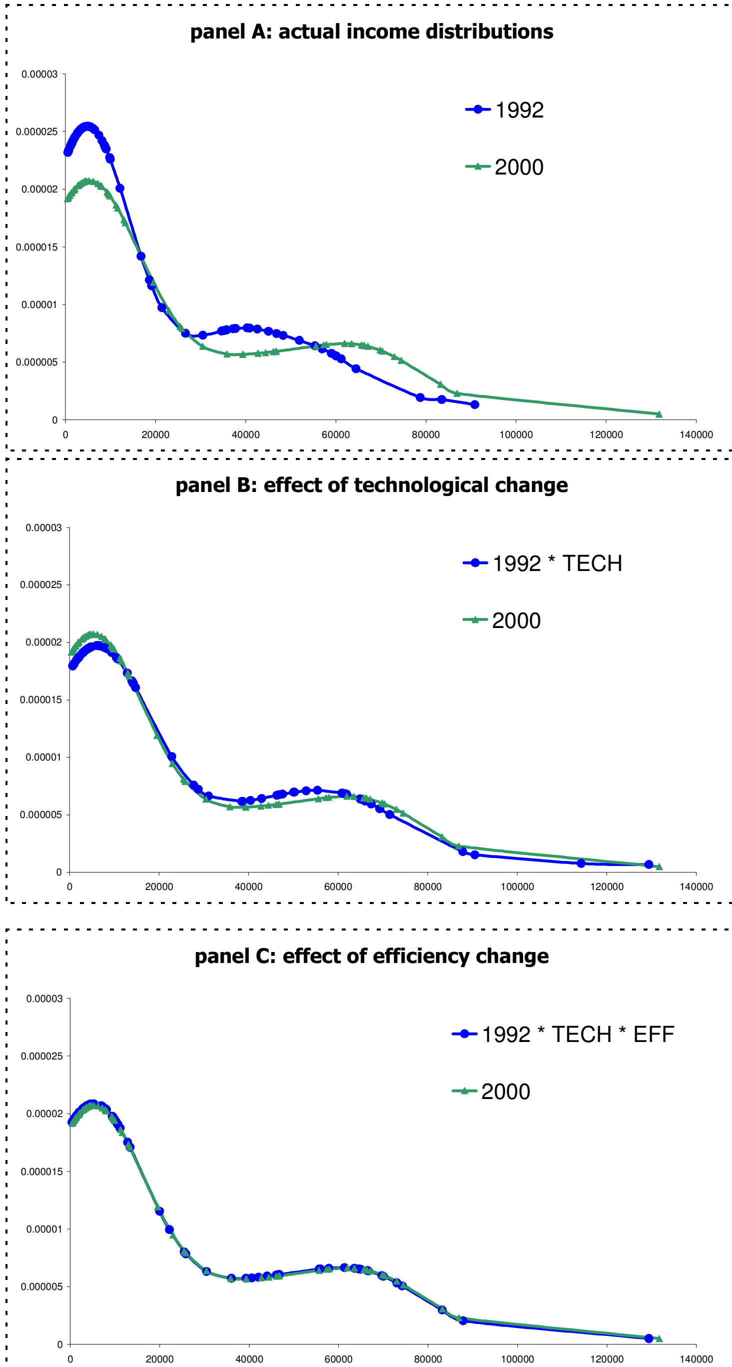
Figure 7 (counterfactual distributions of output per worker: ΔCAP, ΔEFF, $\Delta TECH$ order)

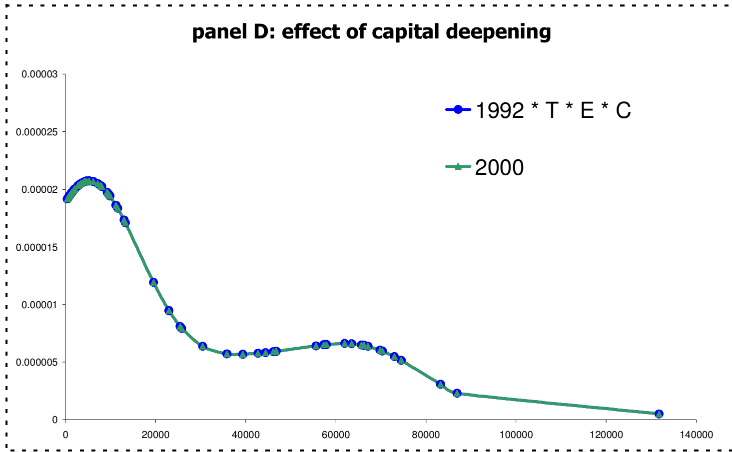


This figure does not provide larger insight than previous one. The only conclusion that can be drawn from is that, since distributions of y_{1992} and of $y_{1992} \times \Delta CAP$ are not different, capital deepening had tiny effect on the 1992 income distribution. Two other panels with effects of technological and efficiency change can be found in the *Figure* A1 in appendix.

Now I introduce $\Delta TECH$, ΔCAP, ΔEFF order of components to move from y_{1992} towards y_{2000} income distribution.

Figure 8 (counterfactual distributions of output per worker: $\Delta TECH$, ΔCAP, ΔEFF order)





This provides an insight, which is worthy of note. As we compare distributions of y_{1992} and of $y_{1992} \times \Delta TECH$ (panels A and B of *Figure* 8), we notice that not only effect of technological change shifts distribution of y_{1992} almost to distribution of y_{2000}, but that within relatively poor countries (see 'poor' mode of distributions of y_{1992} at about 5000) distribution of $y_{1992} \times \Delta TECH$ is now slightly under distributions of y_{2000}, whereas within middle-income countries (see 'rich' mode of distributions of y_{1992} at about 40000) distributions of y_{1992} and of $y_{1992} \times \Delta TECH$ become almost identical. This is also in accordance with previously obtained results from panel B of *Figure* 5 and *Figure* 6. This implies that technological change alone could have made some poor countries richer and middle-income countries even richer. I use condition 'could' because as we compare panels B and C of *Figure* 8, we observe how effect of efficiency change shifts the distribution of $y_{1992} \times \Delta TECH$ upward, implying that in some countries efficiency deterioration prevented from becoming more developed. Again, as well as *Figures* 6 and 7, *Figure* 8 confirms negligible impact of capital deepening on the change of income distribution.

Overall, these findings are absolutely different from that of Kumar and Russell (2002) study. Authors have found[20] that while technological change has not contributed to shifting the income distribution of the year 1965, analysis yields strong evidence that capital accumulation was the primary driving force of altering the distribution. Such striking difference has two explanations. First, in my analysis I add transition countries and, second, I analyse 90's, during which technological progress was much faster than during time-span, considered by Kumar and Russell (2002).

Same as Kumar and Russell (2002), using recent developments by Li (1996) and Fan and Ullah (1999), the statistical significance of contribution of each of the elements of decomposition to shifting the income distribution can be measured. The idea of Fan and Ullah test is to check, whether two distributions (depicted on *Figures* 6, 7 and 8) are statistically different from each other. In my particular case difference of distributions would mean that component has not significantly contributed to changing the labour productivity distribution. Whereas, if distributions are confirmed to be the same, the particular component had a significant impact. The null hypothesis of nonparametric test, suggested by Fan and Ullah (1999) is presented as follows:

$H_0: \; f_X(\cdot) = f_Y(\cdot)$ almost everywhere, against the alternative

$H_1: \; f_X(\cdot) \neq f_Y(\cdot)$ on a set of positive measures, where

$f_X(\cdot)$ and $f_Y(\cdot)$ are estimated with kernel density estimation (explained before):

$$f_X(u) = \frac{1}{N \cdot h} \sum_{t=1}^{N} K\left(\frac{X_t - u}{h}\right) \quad \text{and} \quad f_Y(u) = \frac{1}{N \cdot h} \sum_{t=1}^{N} K\left(\frac{Y_t - u}{h}\right).$$

[20] Counterfactual distributions of output per worker of Kumar and Russell (2002) can be found in appendix on *Figures* A2, A3 and A4 with ΔEFF, $\Delta TECH$, ΔCAP, ΔCAP, ΔEFF, $\Delta TECH$ and ΔCAP, ΔEFF, $\Delta TECH$ (respectively) orderings s of introducing the components' effects.

Where N is the number of observations, $\{X_t\}_{t=1}^{N}$ and $\{Y_t\}_{t=1}^{N}$ are observed data and h is the chosen bandwidth. The statistic then will be defined as:

$$T = \frac{N \cdot h^{1/2} \cdot I_n}{\hat{\sigma}} \xrightarrow{d} N(0,1)$$

where

$$I_n = \frac{1}{N^2 \cdot h} \sum_{t=1}^{N} \sum_{\substack{s=1 \\ s \neq t}}^{N} \left[K\left(\frac{X_t - X_s}{h}\right) + K\left(\frac{Y_t - Y_s}{h}\right) - K\left(\frac{X_t - Y_s}{h}\right) - K\left(\frac{Y_t - X_s}{h}\right) \right],$$

$$\hat{\sigma}^2 = \frac{1}{N^2 \cdot h \cdot \pi^{1/2}} \sum_{t=1}^{N} \sum_{\substack{s=1 \\ s \neq t}}^{N} \left[K\left(\frac{X_t - X_s}{h}\right) + K\left(\frac{Y_t - Y_s}{h}\right) + 2 \cdot K\left(\frac{X_t - Y_s}{h}\right) \right]$$

Having performed this test[21], I found out that even the actual distributions of y_{1992} and of y_{2000} are not statistically different from each other[22]. As a result, I can not conclude significance of any of decomposed component's impact on the distribution. However, this statistical insignificance may stem from two sources: (i) I consider short time-span (only 9 years, while Kumar and Russell (2002) analysed 25 years and, furthermore, during 90's labour productivity has increased only by 8%, while over 1965-1990 – by 75%), which is very small for income distribution to change considerably, and (ii) I have a small number of observations for non-parametric test, so that test cannot reach its appropriate power. Consequently, the lack of statistical significance should not undermine the economic significance of the observed phenomenon and I would like to put forward a conjecture in this respect. During 90's the technological change was the

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[21] For test I used the MatLab code programmed by L. Simar and V. Zelenyuk (2003) and given by V. Zelenyuk

[22] $T \approx 0.2$, while critical value at 10% significance level is 1.28.

main driving force of changing the world income distribution, while capital accumulation has played the minor role. As time-span expands, the difference between distributions may become more notable and I would be able to test this conjecture.

Chapter 5

CONCLUDING REMARKS

In this paper I have studied labour productivity growth and convergence of economies during 90's. The employed methodology allows to decompose labour productivity growth into three components: efficiency change, technological change and capital accumulation.

Nonetheless, analysis provides worthy answers to the raised questions. Overall in the world countries have got richer. The growth and divergence of labour productivity across countries noted prior 1990, persists after 1990 as well. Most remarkably, the primal driving force of growth during 90's and of bimodal divergence of countries' levels of productivity is the shift of technology frontier, rather than capital deepening, as found by Kumar and Russell (2002).

These findings are different and even may sound conflicting as compared to previous studies. But they are rather complementing due to the extensive nature of the analysis. I enriched previous growth studies via, first, including emerging economies and, second, I expand a period of examination to the 90's, which is especially marked by technological advancements.

The additional insight into understanding of growth during 90's would give the inclusion of human capital variable. In order to check the robustness of the analysis I suggest also try different methods of construction the capital stock variable, since economists have not yet come to consensus, by which methodology and which assumptions should be made for estimation of capital stock.

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APPENDIX

Table A1 (tripartite decomposition of labour productivity growth)

Period	Country	Productivity change	=	Efficiency change	Change in technology	Capital accumulation
1992\1996	Argentina	5.81	=	-7.06	15.34	-1.29
1996\2000	Argentina	-0.96	=	-25.22	33.33	-0.67
1992\2000	Argentina	4.79	=	-30.50	54.14	-2.18
1992\1996	Armenia	4.96	=	-0.58	6.29	-0.68
1996\2000	Armenia	16.44	=	2.43	15.09	-1.22
1992\2000	Armenia	22.21	=	1.83	22.29	-1.86
1992\1996	Australia	10.46	=	6.21	4.43	-0.41
1996\2000	Australia	10.65	=	-8.81	21.03	0.25
1992\2000	Australia	22.22	=	-3.14	26.08	0.08
1992\1996	Austria	4.21	=	0.72	3.27	0.19
1996\2000	Austria	10.27	=	-2.80	12.77	0.59
1992\2000	Austria	14.91	=	-2.10	16.82	0.48
1992\1996	Azerbaijan	-48.64	=	-55.54	15.51	0.01
1996\2000	Azerbaijan	29.50	=	3.18	25.51	0.00
1992\2000	Azerbaijan	-33.49	=	-54.13	44.99	0.00
1992\1996	Belgium	3.43	=	-9.62	14.09	0.30
1996\2000	Belgium	11.68	=	-9.30	22.65	0.40
1992\2000	Belgium	15.51	=	-18.02	40.35	0.40
1992\1996	Brazil	9.84	=	-3.00	17.66	-3.75
1996\2000	Brazil	1.20	=	-20.90	32.26	-3.26
1992\2000	Brazil	11.16	=	-23.28	55.83	-7.02
1992\1996	Bulgaria	-4.33	=	-4.93	0.59	0.04
1996\2000	Bulgaria	7.84	=	-2.22	10.15	0.12
1992\2000	Bulgaria	3.17	=	-7.03	10.82	0.14
1992\1996	Canada	7.13	=	0.00	6.52	0.57
1996\2000	Canada	14.28	=	-9.09	25.17	0.43
1992\2000	Canada	22.43	=	-9.09	32.66	1.51
1992\1996	Chile	22.69	=	6.16	15.24	0.28
1996\2000	Chile	6.46	=	-15.19	25.48	0.03
1992\2000	Chile	30.61	=	-9.96	43.17	1.32
1992\1996	China	47.20	=	6.00	17.71	17.97
1996\2000	China	30.49	=	-14.86	32.36	15.80
1992\2000	China	92.08	=	-9.75	55.79	36.62
1992\1996	Colombia	7.14	=	-7.28	15.55	0.00
1996\2000	Colombia	-8.14	=	-26.80	25.49	0.00
1992\2000	Colombia	-1.59	=	-32.13	44.97	0.01
1992\1996	Costa Rica	5.98	=	-4.28	10.90	-0.16
1996\2000	Costa Rica	13.75	=	-4.02	19.52	-0.83
1992\2000	Costa Rica	20.56	=	-8.13	32.31	-0.82
1992\1996	Czech Republic	12.15	=	12.21	-0.11	0.05
1996\2000	Czech Republic	-0.59	=	-9.41	9.49	0.22
1992\2000	Czech Republic	11.49	=	1.65	9.39	0.27
1992\1996	Denmark	9.91	=	11.28	-0.71	-0.52
1996\2000	Denmark	11.52	=	2.31	8.68	0.30
1992\2000	Denmark	22.57	=	13.85	7.44	0.21
1992\1996	Dominican Republic	8.68	=	2.99	5.79	-0.25
1996\2000	Dominican Republic	21.27	=	-1.38	23.18	-0.17
1992\2000	Dominican Republic	31.80	=	1.57	30.24	-0.36
1992\1996	Ecuador	-2.27	=	-15.38	15.51	-0.01
1996\2000	Ecuador	-12.68	=	-30.44	25.51	0.02
1992\2000	Ecuador	-14.65	=	-41.14	44.98	0.01

1992\1996	Estonia	4.80	=	5.80	-1.01	0.07
1996\2000	Estonia	24.45	=	14.93	8.41	-0.12
1992\2000	Estonia	30.43	=	21.60	7.28	-0.02
1992\1996	Finland	10.14	=	11.18	-1.17	0.24
1996\2000	Finland	23.03	=	14.18	7.85	-0.10
1992\2000	Finland	35.51	=	26.95	6.76	-0.02
1992\1996	France	0.84	=	1.45	-0.72	0.11
1996\2000	France	9.52	=	0.73	8.71	0.01
1992\2000	France	10.43	=	2.19	8.22	-0.15
1992\1996	Germany	2.39	=	0.82	0.82	0.73
1996\2000	Germany	8.64	=	-3.17	10.59	1.46
1992\2000	Germany	11.24	=	-2.38	11.85	1.88
1992\1996	Greece	1.41	=	-12.11	15.51	-0.10
1996\2000	Greece	12.62	=	-10.39	25.51	0.14
1992\2000	Greece	14.22	=	-21.25	45.08	-0.04
1992\1996	Guatemala	2.57	=	-11.80	17.90	-1.36
1996\2000	Guatemala	3.00	=	-18.76	33.60	-5.10
1992\2000	Guatemala	5.65	=	-28.35	56.61	-5.85
1992\1996	Hong Kong	7.88	=	9.47	-1.50	0.05
1996\2000	Hong Kong	7.34	=	-1.04	7.88	0.55
1992\2000	Hong Kong	15.81	=	8.33	6.46	0.41
1992\1996	Hungary	4.45	=	-9.44	15.16	0.16
1996\2000	Hungary	19.04	=	-4.55	23.88	0.67
1992\2000	Hungary	24.34	=	-13.56	42.76	0.76
1992\1996	Iceland	6.37	=	-7.76	15.30	0.01
1996\2000	Iceland	16.03	=	-7.59	25.48	0.06
1992\2000	Iceland	23.41	=	-14.77	44.98	-0.12
1992\1996	Indiaonesia	21.94	=	5.55	15.52	0.01
1996\2000	Indiaonesia	-12.13	=	-29.99	25.51	0.00
1992\2000	Indiaonesia	7.15	=	-26.11	44.99	0.01
1992\1996	Ireland	19.48	=	0.00	18.52	0.80
1996\2000	Ireland	35.44	=	0.00	33.56	1.41
1992\2000	Ireland	61.82	=	0.00	58.62	2.01
1992\1996	Israel	9.68	=	10.93	0.80	-1.91
1996\2000	Israel	1.37	=	-9.41	13.02	-1.00
1992\2000	Israel	11.19	=	0.50	14.11	-3.04
1992\1996	Italy	2.51	=	-11.25	15.44	0.06
1996\2000	Italy	7.13	=	-14.89	25.86	0.01
1992\2000	Italy	9.82	=	-24.47	45.22	0.13
1992\1996	Jamaica	-3.09	=	-2.51	-0.37	-0.22
1996\2000	Jamaica	-6.65	=	-13.94	8.87	-0.37
1992\2000	Jamaica	-9.53	=	-16.10	8.48	-0.60
1992\1996	Japan	3.36	=	-10.85	15.42	0.46
1996\2000	Japan	2.25	=	-18.35	25.49	-0.20
1992\2000	Japan	5.68	=	-27.22	45.09	0.08
1992\1996	Kazakhstan	-24.95	=	-27.60	3.83	-0.15
1996\2000	Kazakhstan	16.41	=	3.03	13.23	-0.21
1992\2000	Kazakhstan	-12.63	=	-25.41	17.56	-0.36
1992\1996	Kenya	-2.03	=	-4.70	6.06	-3.07
1996\2000	Kenya	-7.16	=	-24.61	25.22	-1.65
1992\2000	Kenya	-9.04	=	-28.15	32.34	-4.35
1992\1996	Korea, Republic of	21.29	=	5.09	15.48	-0.06
1996\2000	Korea, Republic of	11.27	=	-11.37	25.64	-0.08
1992\2000	Korea, Republic of	34.96	=	-6.86	44.86	0.02
1992\1996	Kyrgyzstan	-34.16	=	-42.74	17.71	-2.31
1996\2000	Kyrgyzstan	13.26	=	-9.82	32.37	-5.13
1992\2000	Kyrgyzstan	-25.43	=	-48.36	55.81	-7.32
1992\1996	Lithuania	-16.14	=	-30.21	18.45	1.45
1996\2000	Lithuania	14.72	=	-15.13	34.07	0.82
1992\2000	Lithuania	-3.80	=	-40.78	56.59	3.73
1992\1996	Luxembourg	15.51	=	0.00	14.47	0.91
1996\2000	Luxembourg	25.52	=	0.00	24.00	1.23
1992\2000	Luxembourg	44.99	=	0.00	42.44	1.79
1992\1996	Madagascar	-5.77	=	-16.50	14.46	-1.41
1996\2000	Madagascar	3.64	=	-11.77	21.23	-3.11

1992\2000	Madagascar	-2.33	=	-26.32	38.66	-4.40
1992\1996	Malaysia	28.88	=	-1.89	18.16	11.17
1996\2000	Malaysia	0.88	=	-25.92	33.52	1.99
1992\2000	Malaysia	30.01	=	-27.32	57.69	13.44
1992\1996	Mauritius	12.94	=	14.08	-1.79	0.80
1996\2000	Mauritius	13.40	=	6.11	6.83	0.04
1992\2000	Mauritius	28.07	=	21.05	4.91	0.85
1992\1996	Mexico	-6.41	=	-7.86	2.63	-1.03
1996\2000	Mexico	12.42	=	-2.91	16.50	-0.61
1992\2000	Mexico	5.22	=	-10.53	19.43	-1.53
1992\1996	Moldova	-36.70	=	-46.92	17.68	1.34
1996\2000	Moldova	-7.43	=	-27.83	32.38	-3.11
1992\2000	Moldova	-41.40	=	-61.69	55.78	-1.81
1992\1996	Morocco	3.97	=	-2.55	7.99	-1.21
1996\2000	Morocco	-3.52	=	-23.71	27.42	-0.76
1992\2000	Morocco	0.31	=	-25.65	37.78	-2.08
1992\1996	Netherlands	6.79	=	6.20	0.39	0.17
1996\2000	Netherlands	13.58	=	3.20	9.48	0.53
1992\2000	Netherlands	21.29	=	9.60	9.93	0.67
1992\1996	New Zealand	11.90	=	7.91	4.72	-0.98
1996\2000	New Zealand	4.99	=	-13.24	20.81	0.16
1992\2000	New Zealand	17.49	=	-6.37	26.18	-0.55
1992\1996	Nigeria	-2.11	=	-9.67	9.40	-0.94
1996\2000	Nigeria	-1.11	=	-22.68	28.36	-0.36
1992\2000	Nigeria	-3.20	=	-30.16	40.44	-1.31
1992\1996	Norway	13.71	=	11.81	1.50	0.19
1996\2000	Norway	7.02	=	-3.05	10.63	-0.21
1992\2000	Norway	21.70	=	8.40	12.32	-0.04
1992\1996	Paraguay	1.48	=	-12.14	15.51	0.00
1996\2000	Paraguay	-9.91	=	-28.21	25.50	-0.01
1992\2000	Paraguay	-8.57	=	-36.92	44.97	-0.01
1992\1996	Peru	16.52	=	5.22	17.72	-5.93
1996\2000	Peru	-1.30	=	-21.97	32.37	-4.44
1992\2000	Peru	15.01	=	-17.89	55.73	-10.05
1992\1996	Philippines	6.01	=	4.27	2.96	-1.26
1996\2000	Philippines	0.46	=	-13.54	17.45	-1.07
1992\2000	Philippines	6.50	=	-9.85	20.81	-2.21
1992\1996	Poland	21.15	=	12.19	8.62	-0.58
1996\2000	Poland	18.21	=	-7.26	27.43	0.03
1992\2000	Poland	43.21	=	4.05	38.30	-0.47
1992\1996	Portugal	4.17	=	-9.77	15.37	0.07
1996\2000	Portugal	14.05	=	-9.07	25.45	-0.02
1992\2000	Portugal	18.81	=	-17.95	45.02	-0.15
1992\1996	Romania	16.46	=	0.80	15.52	0.01
1996\2000	Romania	-11.48	=	-29.47	25.51	0.00
1992\2000	Romania	3.09	=	-28.91	45.00	0.00
1992\1996	Russia	-25.94	=	-24.46	-1.82	-0.14
1996\2000	Russia	9.55	=	2.31	7.36	-0.27
1992\2000	Russia	-18.87	=	-22.71	5.43	-0.43
1992\1996	Sierra Leone	-11.87	=	-9.82	-2.26	-0.01
1996\2000	Sierra Leone	-28.56	=	-33.17	6.99	-0.09
1992\2000	Sierra Leone	-37.04	=	-39.73	4.56	-0.09
1992\1996	Singapore	29.75	=	22.40	5.14	0.83
1996\2000	Singapore	18.73	=	-2.34	20.21	1.14
1992\2000	Singapore	54.05	=	19.53	25.85	2.41
1992\1996	Slovak Republic	10.01	=	9.12	0.99	-0.17
1996\2000	Slovak Republic	9.71	=	-0.58	10.41	-0.06
1992\2000	Slovak Republic	20.70	=	8.49	11.58	-0.30
1992\1996	Slovenia	15.70	=	2.50	11.50	1.23
1996\2000	Slovenia	18.37	=	-5.29	21.66	2.73
1992\2000	Slovenia	36.95	=	-2.92	36.05	3.69
1992\1996	Spain	2.16	=	-11.78	15.61	0.18
1996\2000	Spain	11.15	=	-11.34	25.36	0.01
1992\2000	Spain	13.55	=	-21.79	45.03	0.11
1992\1996	Sri Lanka	13.60	=	9.51	2.47	1.24

1996\2000	Sri Lanka	12.32	=	-2.96	15.33	0.36
1992\2000	Sri Lanka	27.59	=	6.27	18.41	1.40
1992\1996	Sweden	4.98	=	5.42	-0.30	-0.12
1996\2000	Sweden	14.19	=	3.75	9.61	0.41
1992\2000	Sweden	19.88	=	9.38	9.37	0.22
1992\1996	Switzerland	-2.51	=	0.00	-1.50	-1.03
1996\2000	Switzerland	6.73	=	0.00	7.26	-0.50
1992\2000	Switzerland	4.05	=	0.00	5.18	-1.08
1992\1996	Tajikistan	-56.44	=	-56.16	-0.34	-0.30
1996\2000	Tajikistan	10.13	=	1.77	8.80	-0.54
1992\2000	Tajikistan	-52.03	=	-55.39	8.45	-0.85
1992\1996	Thailand	28.81	=	19.05	1.89	6.19
1996\2000	Thailand	-8.13	=	-20.01	12.60	2.00
1992\2000	Thailand	18.34	=	-4.77	15.80	7.32
1992\1996	Ukraine	-46.70	=	-51.37	8.02	1.46
1996\2000	Ukraine	2.37	=	-19.19	26.14	0.42
1992\2000	Ukraine	-45.44	=	-60.70	36.34	1.82
1992\1996	United Kingdom	12.12	=	-4.00	16.20	0.51
1996\2000	United Kingdom	10.86	=	-17.22	33.03	0.67
1992\2000	United Kingdom	24.30	=	-20.53	54.96	0.94
1992\1996	United States	7.44	=	0.00	6.69	0.71
1996\2000	United States	11.09	=	-11.50	25.28	0.20
1992\2000	United States	19.36	=	-11.50	33.47	1.06
1992\1996	Uruguay	9.40	=	6.39	3.15	-0.31
1996\2000	Uruguay	0.35	=	-14.61	17.56	-0.03
1992\2000	Uruguay	9.79	=	-9.15	21.38	-0.43
1992\1996	Venezuela	-10.20	=	-22.30	15.57	0.00
1996\2000	Venezuela	-8.23	=	-26.85	25.47	-0.01
1992\2000	Venezuela	-17.59	=	-43.16	44.98	0.01
1992\1996	Zambia	-10.28	=	-22.33	15.52	0.00
1996\2000	Zambia	-3.95	=	-23.47	25.51	0.00
1992\2000	Zambia	-13.83	=	-40.57	44.99	0.00
1992\1996	Zimbabwe	12.84	=	3.68	11.51	-2.40
1996\2000	Zimbabwe	-7.51	=	-28.51	30.92	-1.17
1992\2000	Zimbabwe	4.37	=	-25.88	46.30	-3.75

Table A2 (effects of components growth)

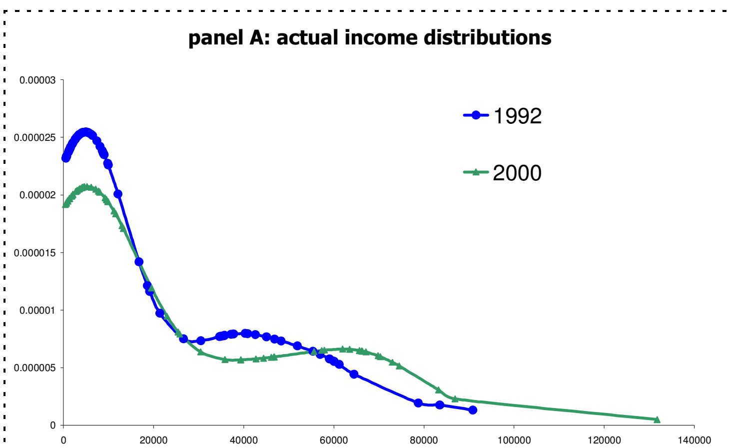
Regression (A)		
	constant	*slope*
	4.04	0.0003
p-value	0.33	0.003

Regression (B)		
	constant	*slope*
	-22.35	0.0003
p-value	0.00	0.000

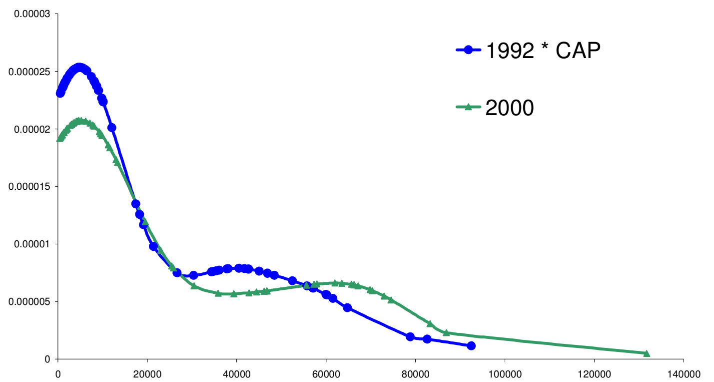
Regression (C)		
	constant	*slope*
	35.08	-0.0001
p-value	0.00	0.09

Regression (D)		
	constant	*slope*
	0.22	0.000002
p-value	0.83	0.9

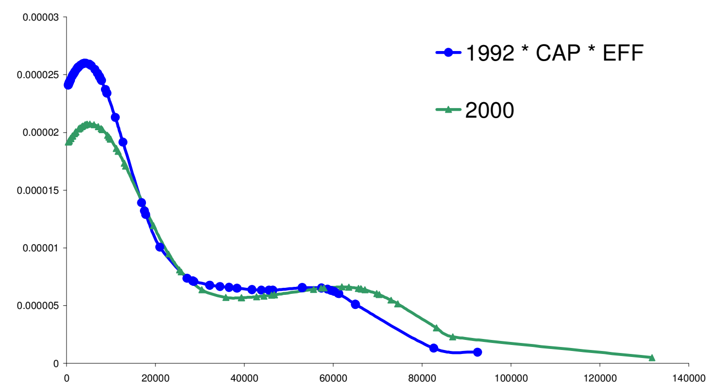
Figure A1 *(*counterfactual distributions of output per worker, ΔCAP, ΔEFF, $\Delta TECH$ order*)*



panel B: effect of capital deepening



panel C: effect of efficiency change



panel D: effect of technological change

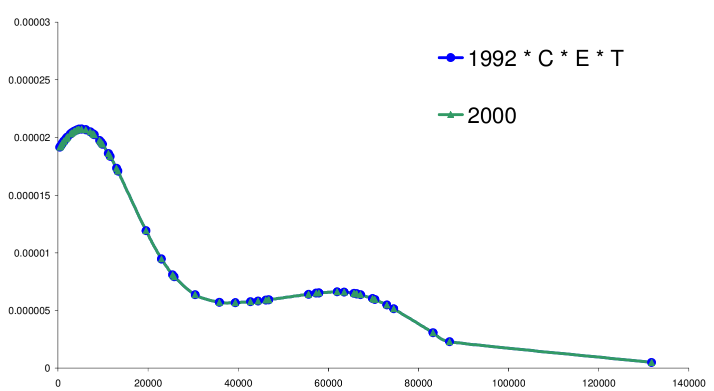


Figure A2 (Kumar and Russell (2002): counterfactual distributions of output per worker, ΔEFF, $\Delta TECH$, ΔCAP order)

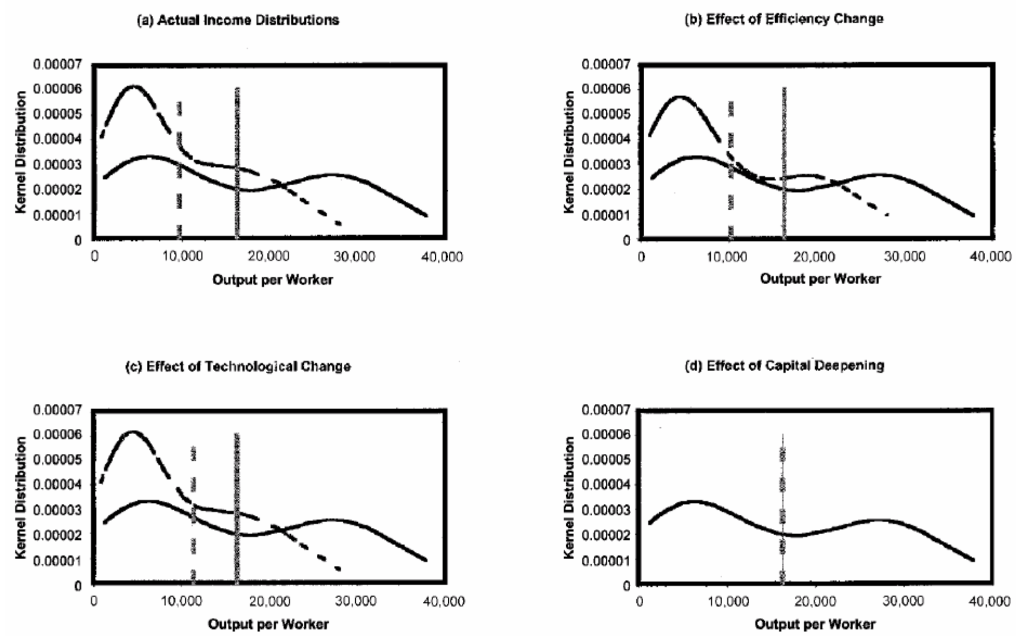


Figure A3 (Kumar and Russell (2002): counterfactual distributions of output per worker, ΔCAP, ΔEFF, $\Delta TECH$ order)

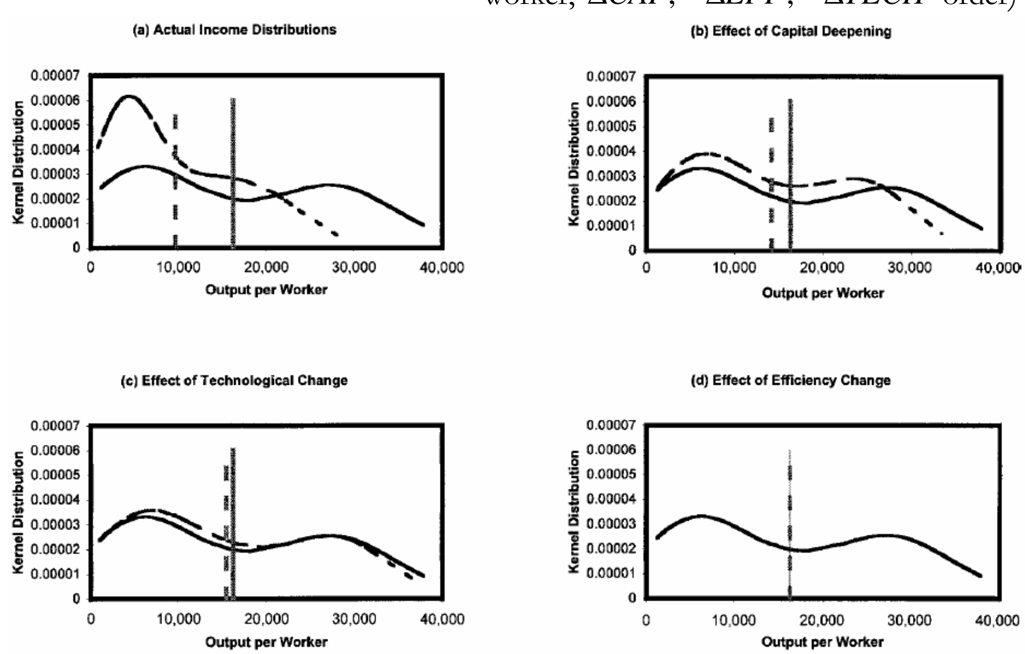


Figure A4 (Kumar and Russell (2002): counterfactual distributions of output per worker, ΔCAP, ΔEFF, $\Delta TECH$ order)