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Technological Change and Transition: Relative Contributions to Worldwide Growth During the 1990's

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Abstract

In this paper we use the procedures developed in the Kumar and Russell (2002) growth-accounting study to examine cross-country growth during the 1990's. Using a data set comprised of developed, newly industrialized, developing and transitional economies, we decompose the growth of output per worker into components attributable to technological catch-up, technological change and capital accumulation. In contrast to the study by Kumar and Russell (2002), which concluded that capital deepening was the major force of growth and change in the world income per worker distribution over the 1965-1990 period, our analysis shows that during the 1990's, the major force in the further divergence of the rich and the poor was due to technological change, whereas capital accumulation played a lesser role. In further contrast, we find that efficiency changes led on average to regress rather than progress. Finally, although on average we find that transitional economies performed similar to the rest of the world, our procedure was able to discover patterns within the set of transitional countries. (*JEL* O47, P27, P52)

In a recent paper, Kumar and Russell (2002), hereafter K&R, inspired, in part, by Färe, Grosskopf, Norris and Zhang (1994), employ nonparametric production-frontier methods to analyze international macroeconomic convergence. In particular, they decompose the labor productivity growth of 57 industrial, newly industrialized and developing countries into components attributable to technological catch-up (changes in efficiency), technological change and capital deepening. They find that although there is substantial evidence of efficiency improvements, with the degree of catch-up directly related to the initial distance from the frontier, that this did not contribute to convergence in income per worker across countries, since the degree of catch-up appeared not to be related to initial productivity. They also find technological change to be non-neutral and that it only had a small effect on the percentage change in output per worker across countries. In fact, they find that capital accumulation was the primary driving force for growth and bimodal international divergence in income per worker across countries in the world during the period 1965-1990.

Indeed, during their period of study, fast growing countries (e.g. the Asian Tigers) underwent heavy capital accumulation (e.g. see Mankiw, Romer and Weil 1992). Further, technological advances (shifts in the production frontier) were only seen at high capital/labor ratios. In addition, Brynjolfsson and Hitt (2000) found the effect of computers on economic growth during that time period to be negligible. However, they also found that the effect of computers on economic growth during the 1990's was quite considerable. Moreover, the OECD (2000) estimates that in the United States, information technology producing industries contributed to, on average, 35 percent of real economic growth (between 1995 and 1998). That number in Canada (between 1996 and 1997) was nearly 20 percent, while in France the information technology sectors are estimated to have contributed to 15 percent of real economic growth (in 1998).

Not only were the 1990's the time of the high-tech boom, it was also characterized by the collapse of the Soviet empire. Technological advances and the emergence of transitional economies raises a natural question: Would the results of K&R change if we examined the 1990's?

In fact, the progress of transitional economies has become a popular topic recently in economic research. This has been driven, in part, by the recent availability of data on transitional countries. Generally these studies have focused on individual countries and looked at either firm or industry level data. For example, the range of topics have varied from studies on the effects of foreign direct investment (FDI) and knowledge spillovers in Lithuania (e.g. see Javorcik 2004) to examining the law of one price on food prices in the Ukraine (e.g. see Cushman, MacDonald and Samborsky 2001). However, there is relatively little empirical study on the convergence of transitional economies (on a macro level) versus the rest of the world (e.g. see Blanchard 1997). A major reason for this is that the most popular data set on cross-country differences, the Penn World Tables (Summers and Heston 1991), until recently, only included data on a few transitional economies. However, in October of 2002, the newest version of the Penn World Tables (Mark 6.1) was released (Heston, Summers and Aten 2002) and this updated data set now includes many transitional economies with data up to the year 2000 (some of these countries did not exist before 1991). The incorporation of this updated data set opens the door for comparisons of the performance of transitional countries versus the rest of the world.

In this paper, we use a more recent and updated version of the data set used in the K&R growth-accounting study of international macroeconomic convergence to examine growth and convergence during the 1990's. The purpose for this is two-fold. First, we want to compare our results to the previous study to see if the growth pattern has changed during the last decade. Second, using this time period allows us to increase the cross-section studied and enables us to examine transitional economies and their growth rates as compared to the rest of the world.

Our results confirm the K&R finding regarding the bimodal distribution of income per worker in the world. Specifically, we find evidence of further divergence between the clubs of the rich and poor. We also confirm their finding that technological change is non-neutral, with advances in the higher capital-labor ratios countries and some evidence of technological regress for lower capital-labor ratio countries. However, contradictory to the K&R conclusion that capital accumulation alone accounts for the positive shift in the distribution of output per worker, we find that either capital accumulation or technological change can explain most of the positive shift in the mean of the distribution. Although we find that both poor and rich countries benefitted from capital accumulation, we find that rich countries benefitted more from technological change than the poor, thus causing further divergence. These advances in technology came at a cost of increased inefficiency for some economies (failure to fully implement new technologies efficiently). Interestingly, on average, rich economies suffered more from the efficiency changes than did poor countries. Finally, we find that although many transitional economies experienced losses at the beginning of the period studied, they performed (on average) more or less similar to the rest of the world.

The remainder of our paper is constructed as follows: sections 2 and 3 briefly describe the methodology and data respectively. The fourth section summarizes the results of the experiment whereas section 5 checks for robustness of the results. The final section concludes.

I Methodology

To decompose productivity growth into components attributable to changes in efficiency (technological catch-up), technological change and capital accumulation, we follow the approach of K&R[1]. We do so by first letting b and c stand for the base period and current period respectively and use the following conventional definition of the labor productivity (output per worker) index

$$\frac{y_c}{y_b} = \frac{Y_c/L_c}{Y_b/L_b}, \tag{1}$$

where Y and L represent aggregate output and labor respectively. K&R show that the growth rate of output per worker can be decomposed (into the tripartite decomposition) as

$$\frac{y_c}{y_b} = EFF \times TECH \times KACCUM, \tag{2}$$

[1] For sake of brevity, we refer readers to K&R for specific details on the methodology and the related literature.

where EFF represents efficiency change (catching-up relative to the best practice frontier), $TECH$ represents technological change (shifts in the best practice frontier) and $KACCUM$ represents capital deepening (movements along the best practice frontier). The best practice frontier is estimated, in each period, as the upper boundary of the smallest convex free disposable cone of the observed data on inputs and outputs in each period (b and c), using the data envelopment analysis (DEA) estimator (see Kneip, Park and Simar 1998 for a proof of consistency for the DEA estimator, as well as Kneip, Simar and Wilson 2003 for its limiting distribution).

II Data

Here we use the most recent and updated version of data available from the Penn World Tables (version 6.1). We focus on the period 1992 (the first year for which data on many transitional economies is available) to 2000 (the last year observed in the data set). Although the time period is significantly shorter than that used in K&R, the cross-section is increased by approximately 50 percent (28 additional countries). Specifically, in addition to OECD countries, developing and newly industrialized countries, we are also able to include transitional economies, many of which did not exist during the period considered by K&R. For aggregate output (measured in 1996 international dollars) we use real GDP (RGDPCH multiplied by POP) and employment is obtained using the real GDP per worker series (RGDPWOK). Following the literature, our capital stock is estimated using the perpetual inventory method.[2]

[2]The data used in the paper is available from the authors upon request.

III Results

A Tripartite Decomposition

Constant returns to scale allows us to construct the production frontiers in $y \times k$ space, where $y = Y/L$ and $k = K/L$ are the ratios of output and capital, respectively, to labor. Figure 1 superimposes the production frontiers for 1992 and 2000. One fact that emerges immediately from these graphs is the non-neutrality of technological change. Up to a capital/labor ratio of approximately 6000, the 1992 and 2000 frontiers are virtually coincident, but for higher levels of capitalization, the 2000 frontier shifts upwards dramatically. This is basically the same result found in K&R, indicating, not surprisingly, that almost all technological change occurs at high levels of capitalization.

Table 1 shows country specific estimates of efficiency and each of the components of the decomposition of the growth rate of output per worker from 1992 to 2000. The first two columns of numbers show the estimated efficiency in both the base period (1992) and the current period (2000) for each country. We observe that Hong Kong, Luxembourg, Paraguay, Sierra Leone, Taiwan and the United States appear on the best practice frontier in 1992, whereas Guatemala, Ireland, Luxembourg, Mauritius, and Sierra Leone are all on the best practice frontier in 2000 (of those countries, Hong Kong, Luxembourg, Paraguay, Sierra Leone and the United States also formed portions of the best practice frontiers in K&R). For Hong Kong, the key financial center of Asia, its fall from the technological frontier by about 23 percentage points is not surprising considering the Asian financial crises in the late 1990's. The fall from the frontier by the United States by about 20 percentage points can be explained by both the slowdown of the High-Tech industry in the late 1990's and the 'explosion' of productivity in Luxembourg.[3]

The next column of numbers in Table 1 shows each country's productivity growth and subsequent columns show the contributions to productivity growth of the three factors: efficiency change ($(EFF - 1) \times 100$), technological change ($(TECH - 1) \times 100$) and physical

[3]One likely explanation for Luxembourg's high productivity is that part of Luxembourg's GDP is created by residents of nearby countries (e.g. Belgium) commuting to work in Luxembourg.

capital accumulation $((KACCUM - 1) \times 100)$. Ordering of the average contributions are similar to what was found in K&R. The table suggests that capital accumulation, on average, was again the principal driving force in the *mean* growth of worldwide productivity. The second largest source, on average, was technological change, followed by efficiency change. However, here we find the average contribution of technological change is nearly 80 percent that of capital accumulation, whereas in K&R it was less than 11 percent. Further, we find the average contribution of efficiency change to be negative, suggesting that (on average) changes in efficiency during the 1990's actually lead to regress.

Table 2 reports mean changes in productivity and the three components of productivity change for several groups of countries. OECD countries experienced productivity gains above the world average[4], primarily because of faster rates of technological progress. The phenomenal growth rates of the Asian Tigers are attributable primarily to well-above-average contributions of capital accumulation, while technological change played a lesser role. Transitional economies performed more or less similar to the rest of the world on average, their slightly above average growth was due mostly to capital accumulation and to a lesser extent technological progress. The poor Latin America performance is attributable to large efficiency losses, and the abysmal African performance is attributable to a lack of technological progress and minimal capital accumulation.

Similar to K&R, we find that technological change is non-neutral and that the largest contribution from technological changes to increase labor productivity growth came with developed countries. This result appears to be driven by shifts up in the best practice frontier by Ireland at mid capital-labor ratios and Luxembourg at high capital-labor ratios. Also similar to the previous study, we find that technology change was actually negative for many developing countries. This can partly be explained by the modest implosion of the frontier at lower capital-labor ratios, caused by decreases in productivity of the best-practice frontier defining countries Paraguay and Sierra Leone, over the sample period.

[4]Note that for some large OECD economies (Austria, France, German and Italy) labor productivity growth is much lower than the OECD average. One possible explanation for this difference comes from the paradox of thrift argument (*The Economist*, 2005).

Finally, the largest labor productivity changes due to capital accumulation were observed in developing countries. The traditional Asian Tigers continued their high capitalization over this time period, but they were also accompanied by nearby China, India, Indonesia, Malaysia and Sri Lanka. Further, Mauritius, Turkey and a number of Latin American countries followed suit with similar increases in labor productivity changes due to capital deepening. At the same time, developed economies experienced relatively minor percentage increases in labor productivity due to changes in capital per worker.

B Regression Analysis

Figure 2 contains plots of the four growth rates (labor productivity and the three components) against output per worker in the base period (1992), along with fitted regression lines.[5] Panel A suggests that relatively richer countries have grown significantly faster than relatively poorer ones. This supports the view of the absence of absolute convergence in income per worker in the world (e.g. see Quah 1996 and DeLong 1998). In contrast, K&R found statistically insignificant evidence (for a smaller number of countries) of world-wide labor productivity convergence. Although unconditional convergence is subject to Barro's (1991) critique, we concentrate on Quah's criticism of absolute convergence and leave conditional convergence during the 1990's to future research.

Panel B shows that there has been a disproportionate amount of decrease in efficiency in our sample. As was shown in Table 1, we notice that some of the relatively rich economies have become less efficient, whereas many relatively poorer countries experienced efficiency improvements. This is different from K&R who noted that in their sample that efficiency did little, if anything, to lower income inequality across countries. A major explanation for this contrast is that during the 1990's some countries moved the technological frontier up so dramatically that even some of the most developed countries were not able to catch-up with it to maintain their 1992 efficiency level (e.g., Belgium, Denmark, France, Germany, Italy, Portugal and Spain). This finding goes hand in hand with the general purpose tech-

[5]Specifically, the lines are OLS fitted lines with Huber/White/Sandwich estimators for the variance. See Table 3 for further details.

nology argument, emphasizing that it takes time before newly implemented technology can be utilized 100 percent efficiently (see Helpman and Rangel 1999).

Panel C suggests that technological change contributed to productivity growth positively for many countries. Moreover, richer countries (in the base period) benefitted more from this technological change than poorer countries (the estimated coefficient is significant at any conventional level). This finding is the same as that of K&R. However, more so than in K&R, world technological progress hindered economical development in some relatively poor countries. This suggests that the technological change contributed to further divergence in income per worker amongst countries in the world.

Finally, panel D reveals that capital deepening was positive for most countries, but it appears to have an insignificant relationship with base level income per worker. In other words, although capital deepening was the major source in the *average* increase of labor productivity from 1992-2000, it does not seem to have contributed to convergence or divergence of income per worker across our sample. This is in contrast to K&R, who found that capital accumulation led to both the shift in labor productivity growth and the emergence of the bimodal distribution of output per worker. Of course, each of these interpretations are based on first-moment characterizations of the productivity distribution and are therefore vulnerable to the Quah's (1993a,b, 1996, 1997) critique.

C Analysis of Productivity Distributions

Given this critique, we now turn to an analysis of the distribution dynamics of labor productivity. A plot of the distributions of output per worker across the 85 countries in our sample in 1992 and 2000 appears in Figure 3. The solid (dashed) curve is the actual 1992 (2000) distribution of output per worker and the solid (dashed) line represents the mean value of output per worker.[6] The first thing to note is that the distribution in both periods is bimodal. This was found to be the case in 1990 in K&R and holds true for the distribution of labor productivity through the end of 2000. It also should be noted that the 'poor mode'

[6]For the estimated distributions we use a Gaussian kernel and use the Sheather and Jones (1991) method for choice of the optimal bandwidth.

remained relatively stagnant while the 'rich mode' moved further away. This is consistent with the positive and significant slope in panel A of Figure 2. In other words, the richer the country, the higher the rate of growth. Both these findings give support to the hypothesis of divergence in income per worker in the world, emphasizing the divergence between the 'peak of the rich' and the 'peak of the poor'.

We again follow the work of K&R by re-writing the tripartite decomposition of labor productivity in (2) as

$$y_c = (EFF \times TECH \times KACCUM) \times y_b. \tag{3}$$

Thus, the labor productivity distribution in the current period (2000) can be constructed by successively multiplying labor productivity in the base period (1992) by each of the three factors. This in turn allows us to construct counterfactual distributions by sequential introduction of each of these three factors. We estimate the actual and counterfactual distributions by employing nonparametric kernel methods and apply the Li-test to test formally for statistical significance of differences between the corresponding distributions (e.g. see Li 1996, Fan and Ullah 1999, and Pagan and Ullah 1999 for further details).

In Figures 4-6, in each panel, again the solid (dashed) curve is the actual 1992 (2000) distribution of output per worker and the solid (dashed) vertical line represents the 1992 (2000) mean value of output per worker, whereas the dotted curve is the counterfactual distribution (and the corresponding dotted line represents the counterfactual mean) isolating, sequentially, the effects of technology change, efficiency change and capital accumulation on the 1992 distribution of output per worker.

Contrary to K&R, the major source of divergence (during the nine-year period) between the rich and the poor appears to be technological change. This is inferred by comparing panel A in Figure 4 with Figure 3. One can see that the technological change effect alone appears to have constituted most of the shift of the 1992 distribution of output per worker closer towards that of the 2000 distribution. This story is backed by the Li-tests in Tables 4 and 5. These tables compare the counterfactual distributions to the distribution in the current and base periods, respectively.[7] Here we see that technological change alone can describe the significant shift in the distribution from 1992 towards that in 2000. Correspondingly, the Li-test is able to show that the counterfactual distribution incorporating technical change is significantly different from the 1992 distribution.

At the same time, according to Table 4, it appears that capital accumulation can also statistically explain the shift from 1992 to 2000 (see panel A of Figure 5). However, a different story is told by Table 5. Here we see that the counterfactual distribution, incorporating only capital deepening, is not statistically different from the distribution in the base period. In other words, we cannot identify a significant change in the base period distribution due to capital deepening alone. This paradox is a particular case of the standard statistical problem of small samples. If two objects (e.g., distributions, moments) are close enough to one another but statistically different, then a similar object 'between' them may be found to be indifferent to both objects (in a statistical sense) for a sufficiently small sample. In other words, given our sample size, it might be that the test did not have enough power to distinguish the base period distribution from the counterfactual distribution.

Further, Table 4 suggests that efficiency alone cannot explain the shift in the base period distribution towards that in 2000. This, however, does not mean that efficiency changes had an insignificant impact. On the opposite, Table 5 tells us that it did bring a significant change to the base period distribution. Unfortunately, the direction of this change was not towards the 2000 distribution. As noted previously, efficiency changes actually caused regress on average. This result corresponds to the increase in the test statistic of $f(y1992 \times EFF)$, relative to $f(y1992)$, in Table 4 and in the shifting back of the counterfactual distribution in panel A of Figure 6 (especially in the rich mode). So, however strange it sounds, efficiency deterioration has actually stimulated convergence in income per worked across countries. This is because rich countries deteriorated in terms of efficiency the most. However, these losses were more than compensated by technological progress and further capital deepening

[7] Here we use the Gaussian kernel and the Silverman (1986) adaptive (robust) rule of thumb choice for optimal bandwidth partially to avoid the large computational burden involved with the Sheather and Jones (1991) method when bootstrapping is employed.

so that income per worker still grew at a positive rate. This fact strongly supports the argument that the rich or developed countries still have room or potential for growth by improving their efficiency, i.e., improved utilization of currently deployed technologies. For example, better utilization could come from more intensive and extensive use of computers according to their power rather than their fashion and prestige.

This discussion of efficiency brings about an interesting story. Different from K&R, we have one of the three factors working against the other two. For example, although technological change and efficiency change, when considered separately, result in significant changes with respect to the base period distribution, together we are unable to distinguish them from the 1992 distribution (panel B of Figure 4). Also remarkable is the finding that considering technology change and capital deepening together introduces a significant difference not only relative to the 1992 distribution, but also relative to the distribution in 2000 (panel B of Figure 5). This is due to the fact that if there were no efficiency changes, the rich mode would be significantly further to the right than what is actually observed in 2000. This is again consistent with our previous discovery that efficiency change introduced regress in the distribution of income per worker.

Overall, we found that all three effects were important in the evolution of the distribution of income per worker in the world. We found that both capital accumulation and technological change had similar influences on the *average* increase in output per worker, but only technological change brought about a significant positive effect itself to the 1992 distribution of output per worker. Further, we identify technological change as the major source of additional divergence in the *distribution* of output per worker. Finally, efficiency change also shifted the distribution, but on average the effect introduced regress rather than progress.

D What Can We Learn from Transitional Economies

As noted in Table 2, the group of transitional countries perform on par with the average country in the sample. However, we can still learn much about them from the procedures used in this paper.

Although many of the transitional countries experienced sudden efficiency drops before and during the 1990's (especially starting with Soviet 'Perestroyka'), those who started their transitions earlier (e.g., Hungary, Poland, Slovenia) or successfully passed key economic and political reforms (e.g., China, Estonia, Latvia) managed to recover and actually increased their efficiency score over the sample. On the other hand, some countries that started their transition later or were slow on reforms (e.g. Bulgaria, Russia, Ukraine) experienced a deterioration in efficiency. These findings are consistent with past evidence and theoretical explanations given in the transitional economics literature (e.g., see Blanchard 1997). However, we were somewhat surprised to see countries like Albania, Armenia and Tajikistan improve in terms of efficiency. One possible explanation is that among these countries, Albania and Armenia were improving their economic freedom, as suggested by the 'economic freedom index' during the 1990's.[8]

It is interesting to note that the Baltic countries (see Table 2) perform differently from the rest of the world as well as from the rest of the transitional economies. Their labor productivity growth is twice as large as the average growth rate and they actually possess a positive efficiency change on average. However, the latter phenomenon is mainly driven by Estonia. The achievement of Estonia might also be explained by its high ranking in the world economic freedom index (ranked fourth in the world as of 2004).

On the other extreme we have the countries from the former USSR. During the nine years under consideration, they were only able (on average) to return to their initial level of labor productivity after plummeting during the beginning and mid 1990's. Further, during this period of transition, they lost nearly fourteen percent in terms of efficiency.

Central and Eastern European economies performed, on average, similar to the rest of the world. Thus, together with the fact that former USSR and Baltic countries compensated each others labor productivity and efficiency indices, transitional countries together performed on the same level as the rest of the world.

An alternative explanation for these highs and lows is somewhat more technical rather

[8]See `http://www.heritage.org/research/features/index/countries.cfm` for details.

than intuitive. During the sample, it was found that some transitional economies experienced sudden decreases in their total output while their stocks of capital did not fall as much (e.g., Azerbaijan, Bulgaria, Moldova, Russia, Ukraine). This would show up as a decrease in efficiency, *ceteris paribus*. A theoretical explanation for this phenomenon is given via the disorganization argument of Blanchard and Kremer (1997). Also, some transitional economies who experienced minor efficiency improvements (e.g., Armenia, Estonia, Macedonia, Poland) looked as if they made huge strides partly due to low efficiency levels in the base period.

The inclusion of transitional countries does not necessarily help us learn something new about the pattern of economic growth of the entire world, but it definitely sheds light on the pattern of various transitional countries relative to the general pattern. We have found evidence to suggest that the sources of growth associated with transitional economies is heterogeneous. Countries of Central and Eastern Europe (except for Albania, Bulgaria, Macedonia and Romania, but certainly those that later entered European Union) had patterns very similar to OECD countries (the largest source of growth being due to technological change). The countries of the former Soviet Union experienced a different pattern. Estonia was the leader, having a positive contribution from all three sources, with the largest being due to capital accumulation, as was the case for Lithuania. For Latvia, the largest source was technological change. The three Slavic countries of the former Soviet Union (Belarus, Russia and Ukraine) experienced a pattern similar to OECD countries: high contribution from (positive) technological change with a similarly high but negative efficiency change. The former Soviet Union countries of Central Asia were quite heterogeneous in their pattern of growth: for Kazakhstan, technological change was the largest source (with minimal effects from the other two components), while for Kyrgyzstan and Tadjikistan the largest sources were capital accumulation and efficiency change, respectively.

As compared to the former Soviet economies, the transition of China is unique and deserves separate attention. In fact, China's growth over the nine year period was quite impressive. Its percentage increase in labor productivity was second only to Ireland. In addition, its contribution to productivity growth from capital accumulation was the largest in the entire sample. Further, it showed a large percentage increase in efficiency. All of these results suggest that China's growth over the 1992-2000 period was far different from that of the other transitional economies.

Although it was shown that both efficiency change and capital accumulation brought about positive increases in labor productivity, the primary driving force for China was capital deepening. It is well known that FDI into China was extemely high during this time period. The China Statistical Yearbook 1999 (SSB 1999) reports that FDI flows from 1992 to 1999 increased by nearly 400 percent. In fact, China has become the largest recipient of FDI in the developing world and second globally only to the United States (since 1993). In 1997, FDI flows into China constituted 31 percent of total FDI in all developing and transitional countries (UNCTAD 1998).

These increases in FDI can also partly explain the increases in efficiency over the sample period (e.g. see Cheung and Lin 2004). FDI in China not only brought much needed capital, it also brought advanced machines, better production and human resource management, new products and marketing techniques (e.g. see Zhiqiang 2000). In addition to better practices, labor has been moving from the less efficient state-owned enterprises to the more efficient non-state-owned enterprises (e.g. see Jefferson, Rawski and Zhen 1996). Specifically, the China Statistical Yearbook 1999 (SBB 1999) reports that while the percentage of urban employment in state-owned enterprises was over 62 percent in 1990, it dropped to less than 44 percent in 1998. Capital moved in a similar fashion. The percent of capital employed in state-owned enterprises was over 66 percent in 1990, but fell to 55 percent in 1998.

Overall we find such heterogeneity in the sources of economic growth across countries to be quite intriguing. It is likely to have been caused by differences in economic policies, stages of development, success rates of transitional reforms, and the comparative advantages of each country. Here we suggest that future research should emphasize on more micro level data as well as additionally focus on country and regional case studies.

IV Robustness of the Results

As a final note, we wanted to check our results for robustness. For example, one may think that the reason our results for the 1992-2000 period are different from those of the 1965-1990 period used in K&R is because our sample includes transitional countries. Admittedly we had the same concern. Therefore, we re-ran the analysis only using countries from K&R (of which we had data for 55 of the 57 countries–with the omitted countries being the Ivory Coast, and Yugoslavia) for the period 1992-2000. In doing so, we found that our conclusions did not change (the results are given in Appendix A, available from the authors upon request).

We also checked for the presence of outliers distorting the data. One of the main criticisms of the DEA estimator is that a single decision making unit can drastically alter the shape of the frontier. Luxembourg, as noted in Table 1 and Figure 1, defined the best practice frontier for high capital/labor ratio countries in both 1992 and 2000. Further, it had a dramatic increase in productivity over that time period (thus shifting up the best practice frontier). We feared that some may believe that this observation may have driven the technological change conclusion of the paper. Therefore, we decided to re-run the results assuming that Luxembourg had no changes over the nine year period.[9] Interestingly enough, Luxembourg (1992 values) remained on the 2000 best practice frontier. However, more importantly, this experiment did not significantly change the conclusions of the paper (these results are given in Appendix B, available from the authors upon request). Having said that, the most pronounced difference came from the Li-test. In the test, it suggests the effect of efficiency change on the 1992 distribution was not significant. Even though the effect was found to be insignificant, we still find that efficiency fell for many rich countries. Here we also note that, in this experiment, the impact of capital accumulation slightly changed. In fact, in the GLS regression, the model no longer gives an insignificant positive coefficient, but it now shows some evidence (as was the case in K&R) that capital accumulation actually led to absolute convergence (p-value = 0.067). Although these checks have bought about some minor differences, we suggest that the results of this paper are robust and leave it to others

[9]Here we artifically restrict Luxembourg's GDP and capital per worker to be fixed at its 1992 level.

to experiment with other tests for robustness.

V Conclusion

As was stated in the conclusion of K&R, it must be noted that this approach has several limitations. First, the techniques used in this paper do not provide reasons for the phenomena that are measured. The approach is only able to tell us what happened. It is left to the authors and readers to give stories as to why these phenomenon occur. Also, this paper only examines three macroeconomic variables commonly used in empirical studies of convergence, however potentially important variables (e.g. natural resources) are omitted. As our goal was to compare our results to those of K&R, we chose to use the variables employed in their paper and leave the remaining variables to future research. Lastly, although we used a more recent and updated version of the data available from the Penn World Tables, we still must admit that the increased sample of countries is arbitrary and that the data are measured with considerable error. All of this information should be taken into account when assessing our results.

In spite of the above mentioned caveats, our approach was able to uncover many important findings. Specifically, using a more recent and updated version of the data set used in the K&R growth-accounting analysis of international macroeconomic convergence enabled us to increase the cross-section studied and thus to include many transitional economies. In summary, our principal conclusions are as follows:

- We confirm the K&R conclusion that the distribution of income per worker persisted to be bimodal, with evidence for further divergence between the club of the rich and the club of the poor. We also confirm their finding that technological change appears to be non-neutral.

- In contradistinction to the K&R conclusion that capital accumulation primarily accounts for the shift in the distribution and the mean productivity increase, we find that technological change constituted the major (significant) source of change in the labor productivity *distribution* towards further divergence.

- We find the effect of efficiency change contributed to regress rather than progress. Interestingly, richer countries were hurt most in terms of efficiency losses. This result suggests that efficiency deterioration of the rich contributed to convergence.

- Although on average transitional countries performed on par with the rest of the world, our procedure was able to discover patterns within the set of transitional economies: from some stagnating countries of the former USSR to booming China.

Overall, our results have shed additional and sometimes unexpected light onto world development during the era of the 1990's–a time of major structural change in the world–shaped by the collapse of the Soviet empire and the high-tech boom.

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Table 1: Percentage change of tripartite decomposition indexes, 1992-2000

Country	TE_b	TE_c	Produtivity Change	$EFF-1$ $\times$ 100	$TECH-1$ $\times$ 100	$KACCUM-1$ $\times$ 100
Albania	0.62	0.75	46.06	20.90	-3.96	25.80
Argentina	0.58	0.54	9.57	-6.52	16.08	0.98
Armenia	0.23	0.29	32.89	24.78	-6.45	13.83
Australia	0.77	0.65	22.74	-15.58	31.97	10.18
Austria	0.79	0.61	16.14	-23.03	31.62	14.65
Azerbaijan	0.31	0.30	-0.31	-2.39	-7.37	10.26
Belarus	0.28	0.23	17.39	-19.82	33.50	9.66
Belgium	0.81	0.64	16.63	-21.66	31.82	12.93
Bolivia	0.57	0.62	9.22	8.07	-4.09	5.37
Brazil	0.53	0.55	16.34	3.87	3.40	8.33
Bulgaria	0.68	0.57	-12.21	-16.48	-7.33	13.42
Canada	0.81	0.68	23.72	-16.33	32.29	11.77
Chile	0.65	0.70	31.71	8.39	1.62	19.57
China	0.67	0.74	69.40	11.11	-6.14	62.43
Colombia	0.81	0.74	-6.55	-9.56	-5.22	9.01
Costa Rica	0.67	0.70	8.23	4.90	-7.54	11.59
Croatia	0.43	0.41	13.81	-3.29	12.52	4.59
Czech Republic	0.40	0.31	9.48	-22.15	31.99	6.54
Denmark	0.70	0.59	28.29	-15.38	31.59	15.22
Dominican Republic	0.75	0.97	55.25	29.13	-5.07	26.65
Ecuador	0.47	0.43	-13.46	-7.76	-8.95	3.04
Estonia	0.33	0.38	57.91	14.77	9.58	25.56
Finland	0.65	0.60	34.30	-7.74	31.43	10.75
France	0.78	0.60	12.38	-23.81	31.64	12.05
Germany	0.63	0.49	11.07	-23.30	35.96	6.51
Greece	0.64	0.51	13.25	-21.21	34.20	7.11
Guatemala	0.97	1.00	5.76	3.00	-3.40	6.30
Honduras	0.74	0.58	-10.35	-21.39	-4.15	18.98
Hong Kong	1.00	0.77	28.98	-23.08	24.69	34.48
Hungary	0.45	0.40	37.39	-10.76	26.25	21.94
Iceland	0.70	0.60	21.86	-15.48	32.69	8.66
India	0.74	0.88	42.00	18.42	-5.84	27.34
Indonesia	0.96	0.74	9.87	-22.96	-4.19	48.86
Ireland	0.91	1.00	71.44	10.00	27.34	22.39
Israel	0.80	0.63	16.25	-21.38	32.80	11.35
Italy	0.83	0.62	10.68	-25.47	31.69	12.75

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Table 1 – Continued

Country	TE_b	TE_c	Produtivity Change	$EFF-1$ × 100	$TECH-1$ × 100	$KACCUM-1$ × 100
Jamaica	0.34	0.31	-5.64	-8.64	-8.12	12.42
Japan	0.75	0.51	6.98	-31.63	33.75	16.99
Kazakhstan	0.32	0.32	11.45	-1.27	14.42	-1.35
Kenya	0.54	0.56	-5.06	3.37	-8.20	0.05
Korea, Republic of	0.77	0.65	36.56	-15.58	17.49	37.68
Kyrgyzstan	0.83	0.81	13.36	-2.44	-5.24	22.62
Latvia	0.24	0.23	44.23	-3.65	24.21	20.52
Lithuania	0.38	0.37	16.49	-3.69	5.11	15.08
Luxembourg	1.00	1.00	52.39	0.00	40.88	8.16
Macedonia	0.34	0.37	13.79	10.00	0.75	2.68
Madagascar	0.58	0.68	-3.51	16.33	-11.54	-6.23
Malawi	0.37	0.55	33.83	47.25	-10.17	1.18
Malaysia	0.75	0.76	33.92	2.29	-1.53	32.96
Mauritius	0.83	1.00	55.90	20.00	-3.82	35.08
Mexico	0.68	0.64	12.80	-5.13	6.20	11.96
Moldova	0.36	0.28	-16.85	-19.94	-3.96	8.15
Morocco	0.65	0.65	3.30	0.00	-5.68	9.53
Netherlands	0.79	0.64	15.21	-19.11	31.16	8.59
New Zealand	0.63	0.53	18.19	-15.96	32.65	6.02
Nigeria	0.65	0.46	-28.70	-29.49	-11.23	13.92
Norway	0.66	0.57	27.04	-14.20	35.88	8.98
Panama	0.57	0.51	5.14	-10.71	-4.19	22.91
Paraguay	1.00	0.78	-34.43	-22.48	-4.01	-11.88
Peru	0.32	0.36	4.47	13.00	-2.42	-5.25
Philippines	0.55	0.57	11.72	5.17	-3.84	10.47
Poland	0.27	0.28	53.35	7.12	33.38	7.33
Portugal	0.76	0.61	20.13	-20.12	19.91	25.42
Romania	0.28	0.28	4.56	0.00	-3.27	8.10
Russia	0.33	0.22	-9.26	-33.70	32.52	3.29
Sierra Leone	1.00	1.00	-4.83	0.00	-17.81	15.80
Singapore	0.76	0.71	49.94	-5.71	31.95	20.52
Slovak Republic	0.32	0.28	22.70	-10.26	31.60	3.89
Slovenia	0.46	0.44	39.58	-4.37	32.85	9.86
Spain	0.78	0.60	13.81	-22.29	33.45	9.74
Sri Lanka	0.83	0.81	18.03	-2.42	-5.20	27.59
Sweden	0.68	0.57	20.00	-16.48	31.66	9.12
Switzerland	0.68	0.50	4.32	-26.87	35.97	4.91
Syria	0.79	0.95	15.52	20.95	-5.46	1.02

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Table 1 – Continued

Country	TE_b	TE_c	Produtivity Change	$EFF-1$ $\times$ 100	$TECH-1$ $\times$ 100	$KACCUM-1$ $\times$ 100
Taiwan	1.00	0.99	45.28	-0.99	1.06	45.20
Tajikistan	0.28	0.36	27.09	28.67	-4.29	3.20
Thailand	0.53	0.46	22.83	-14.16	-5.79	51.88
Turkey	0.77	0.67	11.65	-12.75	-7.38	38.16
Ukraine	0.25	0.11	-41.99	-58.21	31.04	5.92
United Kingdom	0.78	0.64	23.41	-17.31	32.38	12.74
Uruguay	0.58	0.58	10.78	0.00	5.70	4.81
USA	1.00	0.81	21.08	-18.70	32.63	12.29
Venezuela	0.58	0.44	-17.13	-23.56	10.38	-1.79
Zambia	0.26	0.27	-10.16	2.41	-4.01	-8.61
Zimbabwe	0.36	0.36	-5.33	0.36	-3.90	-1.84
Average			14.56	-8.04	10.29	12.94

Table 2: Mean Percentage Changes of Tripartite Decomposition Indices (Country Groupings)

Country Group	Produtivity Change	$EFF - 1$ × 100	$TECH - 1$ × 100	$KACCUM - 1$ × 100
OECD[1]	21.50	-16.70	31.00	11.34
Non OECD	12.17	-4.08	3.04	13.49
Asian Tigers[2]	32.63	-16.15	21.17	30.54
Latin America	3.99	-3.64	-1.85	9.95
Africa	1.46	4.91	-8.60	5.81
Transition (all)[3]	16.32	-6.68	9.81	13.51
Non-Transition	13.87	-8.57	10.48	12.72
Baltic Countries[4]	38,44	2,12	12,68	20,31
Central and Eastern Europe[5]	21,23	-3,70	14,26	10,18
Republics of Former USSR[6]	0,99	-13,59	8,02	8,20
All countries	14.56	-8.04	10.29	12.94

[1] OECD countries by UNESCO classification as of 2004;
excluding Czech Republic, Hungary, Korea, Poland and Slovak Republic
[2] Hong Kong, Japan, Singapore, South Korea and Taiwan
[3] Albania, Armenia, Azerbaijan, Belarus, Bulgaria, China, Croatia, Czech Republic, Estonia, Hungary, Kazakhstan, Kyrgyzstan, Latvia, Lithuania, Macedonia, Moldova, Poland, Romania, Russia, Slovak Republic, Slovenia, Tajikistan, Turkey, Ukraine
[4] Estonia, Latvia, Lithuania
[5] Albania, Bulgaria, Croatia, Czech Republic, Hungary, Macedonia, Poland, Romania, Slovak Republic, Slovenia
[6] Excluding Baltic Countries

Table 3: Percentage change in output per worker and the three decomposition indexes vs. output per worker for 1992 (p-values in parentheses)

	Regression (A)	Regression (B)	Regression (C)	Regression (D)
	Productivity Change	EFF - 1 × 100	TECH - 1 × 100	KACCUM - 1 × 100
Constant	9.64	4.53	– 8.59	14.04
	(0.027)	(0.171)	(0.000)	(0.000)
Slope	0.00033	– 0.00053	0.00097	– 0.00002
	(0.016)	(0.000)	(0.000)	(0.820)

Table 4: Distribution Hypothesis Tests: Comparison to y_{2000}

H_0 : Distributions are equal H_1 : Distributions are not equal	Value of statistic	Bootstrap p-value	Conclusion of test
$g(y2000)$ vs. $f(y1992)$	1.0518	0.0788	reject H_0
$g(y2000)$ vs. $f(y1992 \times EFF)$	3.2646	0.0030	reject H_0
$g(y2000)$ vs. $f(y1992 \times TECH)$	0.2773	0.6768	fail to reject
$g(y2000)$ vs. $f(y1992 \times KACCUM)$	0.2325	0.7482	fail to reject
$g(y2000)$ vs. $f(y1992 \times EFF \times TECH)$	0.3595	0.5886	fail to reject
$g(y2000)$ vs. $f(y1992 \times EFF \times KACCUM)$	2.2103	0.0142	reject H_0
$g(y2000)$ vs. $f(y1992 \times TECH \times KACCUM)$	1.4155	0.0462	reject H_0

Table 5: Distribution Hypothesis Tests: Comparison to y_{1992}

H_0 : Distributions are equal H_1 : Distributions are not equal	Value of statistic	Bootstrap p-value	Conclusion of test
$g(y1992)$ vs. $f(y2000)$	1.0518	0.0788	reject H_0
$g(y1992)$ vs. $f(y1992 \times EFF)$	1.3763	0.0484	reject H_0
$g(y1992)$ vs. $f(y1992 \times TECH)$	2.3486	0.0122	reject H_0
$g(y1992)$ vs. $f(y1992 \times KACCUM)$	0.5133	0.4240	fail to reject
$g(y1992)$ vs. $f(y1992 \times EFF \times TECH)$	0.3157	0.6552	fail to reject
$g(y1992)$ vs. $f(y1992 \times EFF \times KACCUM)$	0.2140	0.7586	fail to reject
$g(y1992)$ vs. $f(y1992 \times TECH \times KACCUM)$	3.3722	0.0032	reject H_0

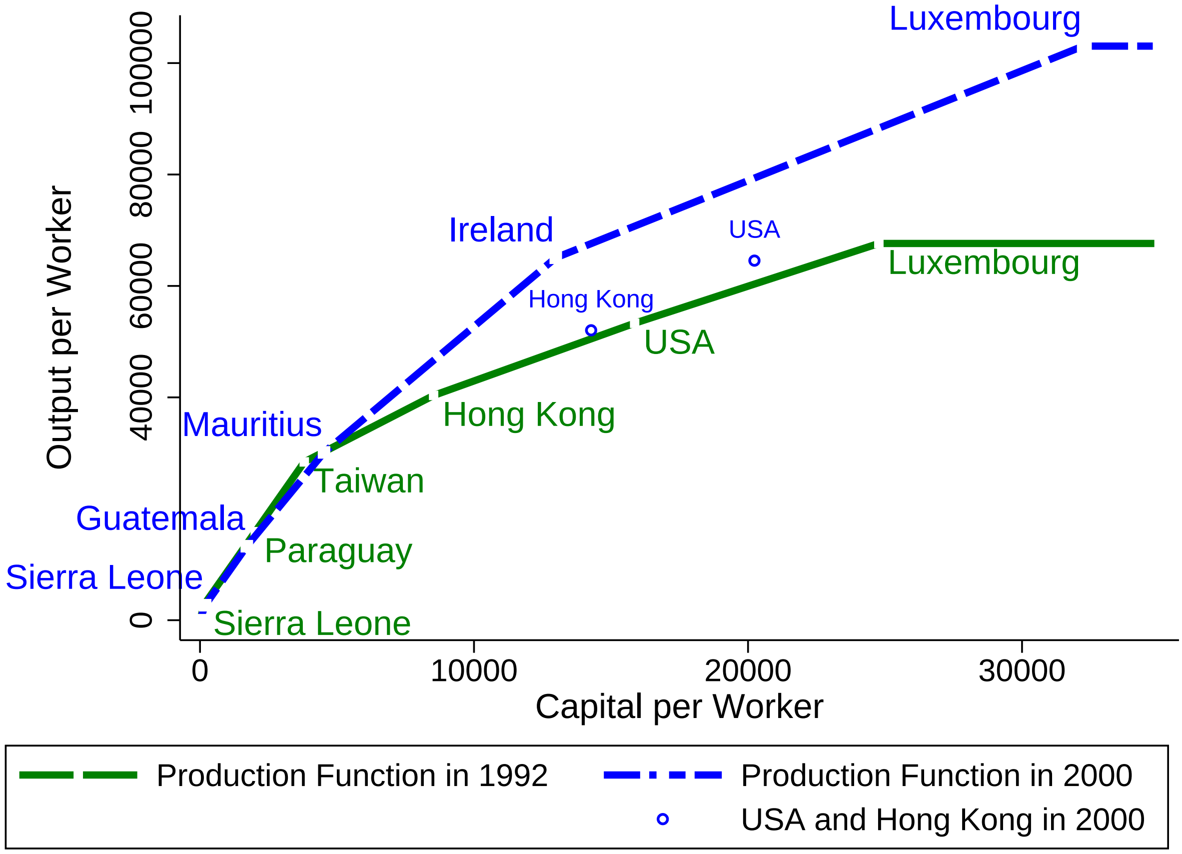
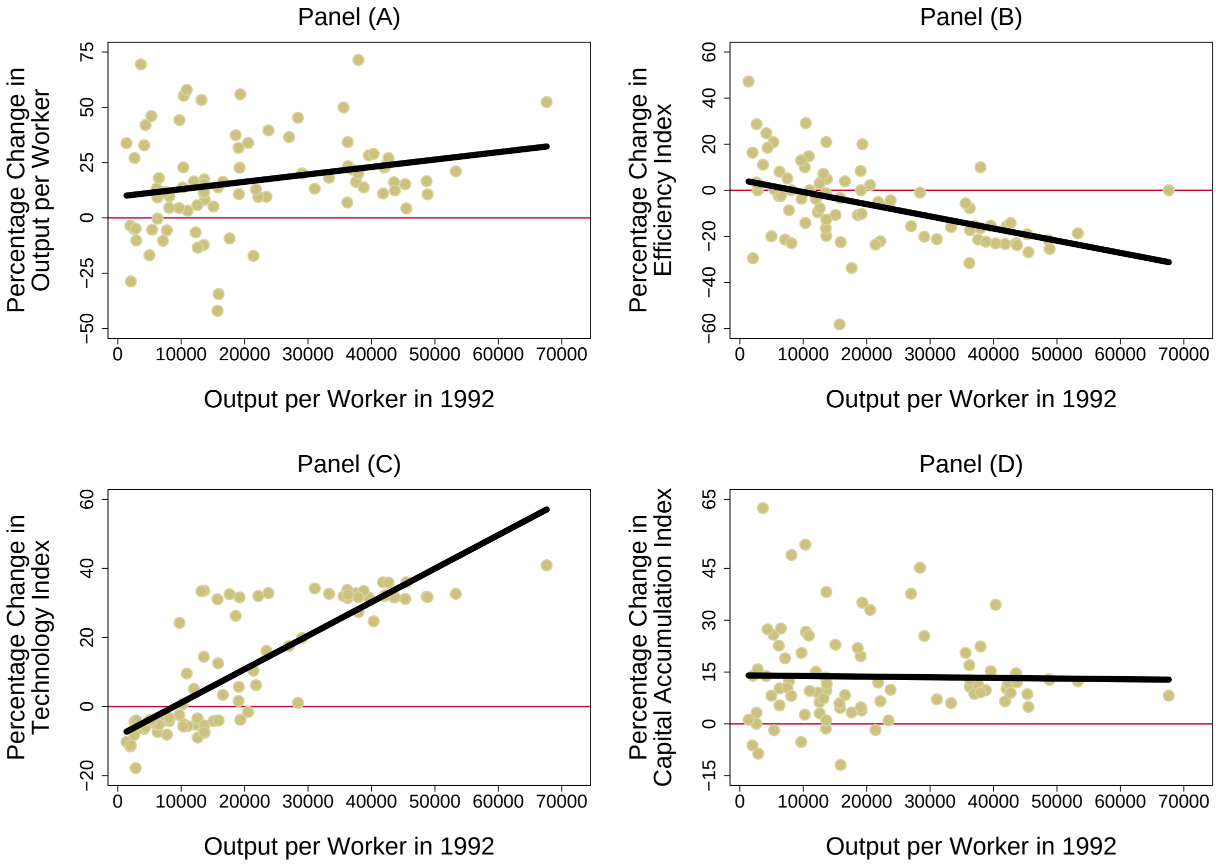
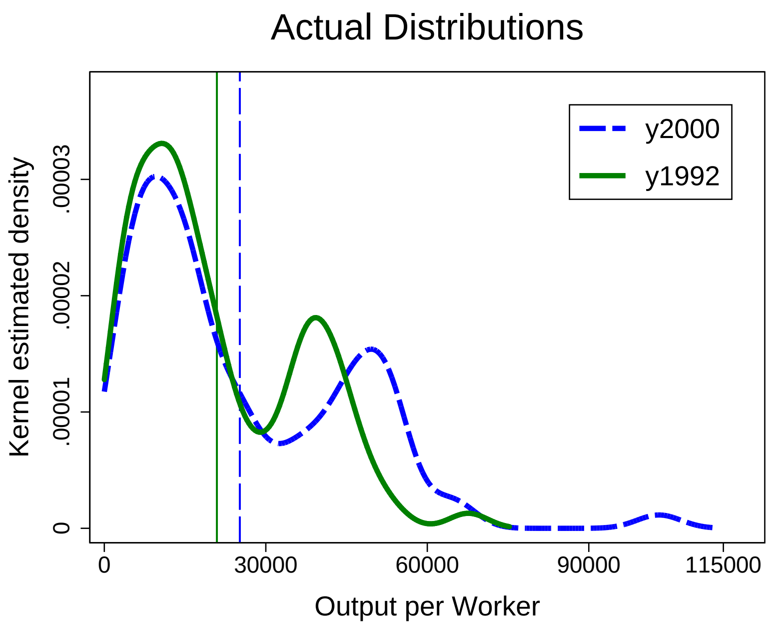


Figure 1: 1992 and 2000 World Production Functions



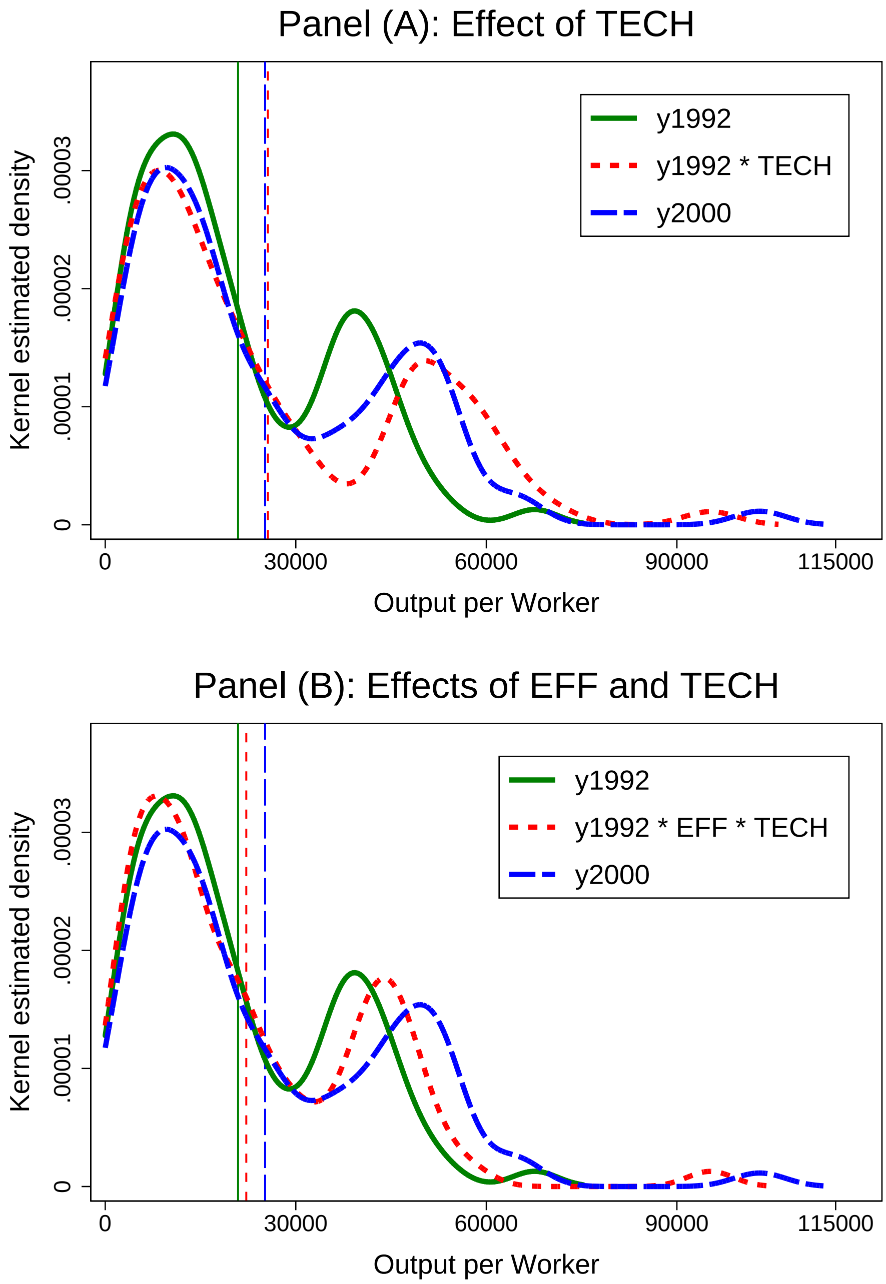
Note: *Each panel contains a GLS regression line.*

Figure 2: Percentage change in output per worker and three decomposition indexes, plotted against output per worker in 1992



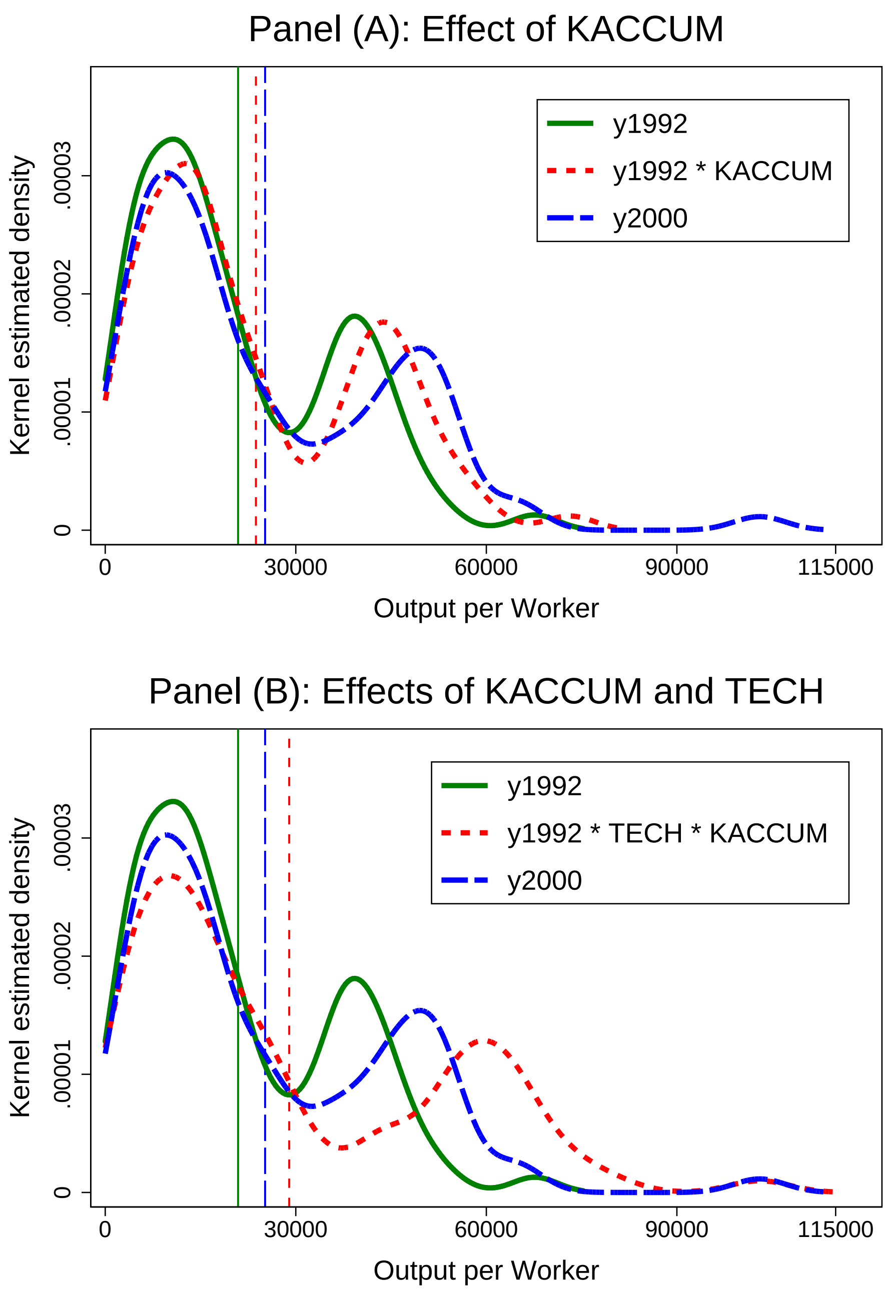
Note: In the panel, the solid curve is the actual 1992 distribution and the solid vertical line represents the 1992 mean value. The dashed curve is the actual 2000 distribution and the dashed vertical line represents the 2000 mean value.

Figure 3: Actual 1992 and 2000 Output per Worker Distributions



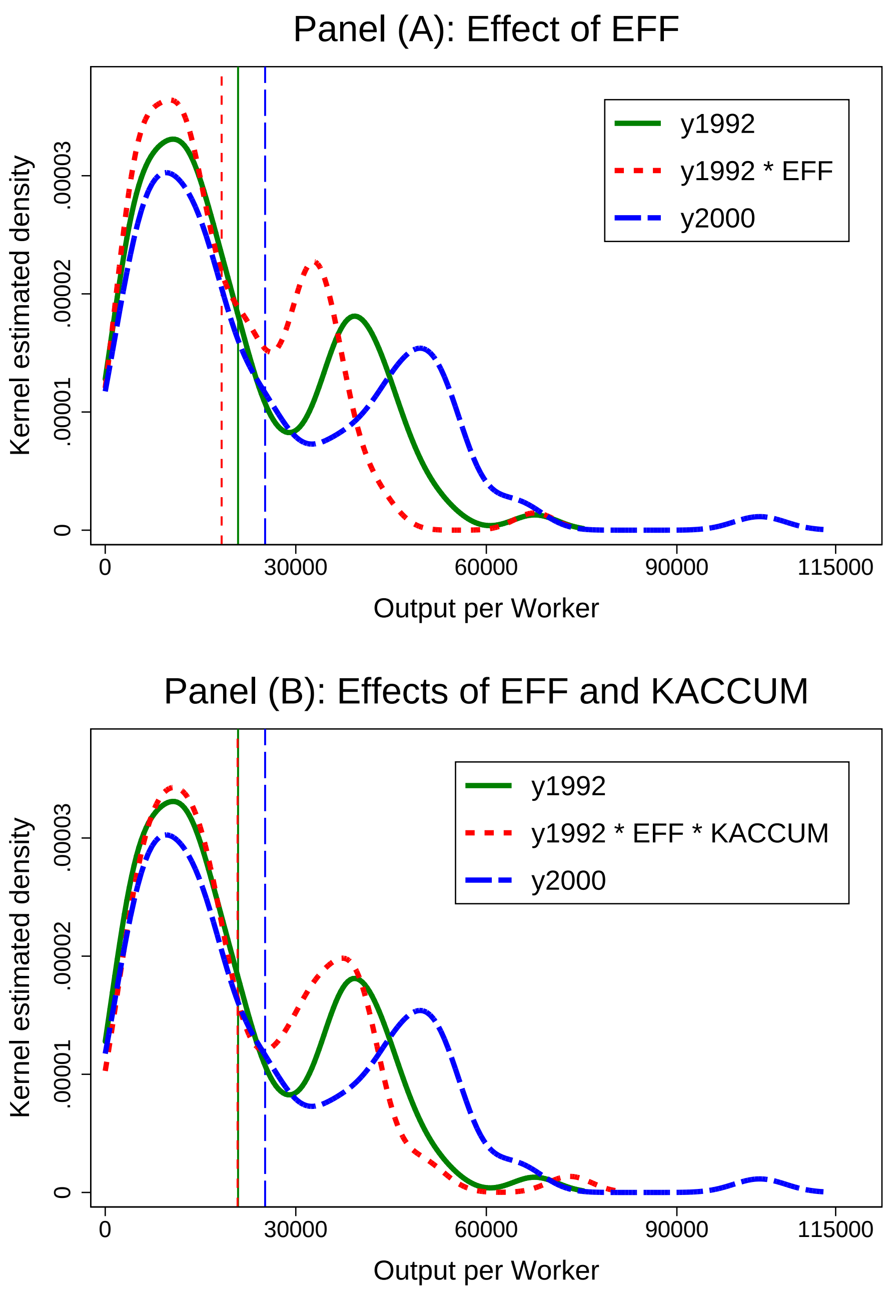
Note: In each panel, the solid curve is the actual 1992 distribution and the solid vertical line represents the 1992 mean value. The dashed curve is the actual 2000 distribution and the dashed vertical line represents the 2000 mean value. The dotted curves in each panel are the counterfactual distributions isolating, sequentially, the effects of technological change and efficiency change on the 1992 distribution, and the dotted vertical line represents the respective counterfactual mean.

Figure 4: Counterfactual Distributions of Output per Worker. Sequence of introducing effects of decomposition: TECH, EFF



Note: In each panel, the solid curve is the actual 1992 distribution and the solid vertical line represents the 1992 mean value. The dashed curve is the actual 2000 distribution and the dashed vertical line represents the 2000 mean value. The dotted curves in each panel are the counterfactual distributions isolating, sequentially, the effects of capital accumulation and technological change on the 1992 distribution, and the dotted vertical line represents the respective counterfactual mean.

Figure 5: Counterfactual Distributions of Output per Worker. Sequence of introducing effects of decomposition: KACCUM, TECH



Note: In each panel, the solid curve is the actual 1992 distribution and the solid vertical line represents the 1992 mean value. The dashed curve is the actual 2000 distribution and the dashed vertical line represents the 2000 mean value. The dotted curves in each panel are the counterfactual distributions isolating, sequentially, the effects of efficiency change and capital accumulation on the 1992 distribution, and the dotted vertical line represents the respective counterfactual mean.

Figure 6: Counterfactual Distributions of Output per Worker. Sequence of introducing effects of decomposition: EFF, KACCUM

Appendix A: Results for K&R Sample

Table 6: Percentage change of tripartite decomposition indexes, 1992-2000

Country	TE_b	TE_c	Produtivity Change	$EFF-1$ × 100	$TECH-1$ × 100	$KACCUM-1$ × 100
Argentina	0.58	0.54	9.57	-6.52	16.08	0.98
Australia	0.77	0.65	22.74	-15.58	31.97	10.18
Austria	0.79	0.61	16.14	-23.03	31.62	14.65
Belgium	0.81	0.64	16.63	-21.66	31.82	12.93
Bolivia	0.57	0.62	9.22	8.07	-4.09	5.37
Canada	0.81	0.68	23.72	-16.33	32.29	11.77
Chile	0.65	0.70	31.71	8.39	1.62	19.57
Colombia	0.81	0.74	-6.55	-9.56	-5.22	9.01
Denmark	0.70	0.59	28.29	-15.38	31.59	15.22
Dominican Republic	0.75	0.97	55.25	29.13	-5.07	26.65
Ecuador	0.47	0.43	-13.46	-7.76	-8.95	3.04
Finland	0.65	0.60	34.30	-7.74	31.43	10.75
France	0.78	0.60	12.38	-23.81	31.64	12.05
Germany	0.63	0.49	11.07	-23.30	35.96	6.51
Greece	0.64	0.51	13.25	-21.21	34.20	7.11
Guatemala	0.97	1.00	5.76	3.00	-3.40	6.30
Honduras	0.74	0.58	-10.35	-21.39	-4.15	18.98
Hong Kong	1.00	0.77	28.98	-23.08	24.69	34.48
Iceland	0.70	0.60	21.86	-15.48	32.69	8.66
India	0.74	0.88	42.00	18.42	-5.84	27.34
Ireland	0.91	1.00	71.44	10.00	27.34	22.39
Israel	0.80	0.63	16.25	-21.38	32.80	11.35
Italy	0.83	0.62	10.68	-25.47	31.69	12.75
Jamaica	0.34	0.31	-5.64	-8.64	-8.12	12.42
Japan	0.75	0.51	6.98	-31.63	33.75	16.99
Kenya	0.54	0.56	-5.06	3.37	-8.20	0.05
Korea, Republic of	0.77	0.65	36.56	-15.58	17.49	37.68
Luxembourg	1.00	1.00	52.39	0.00	40.88	8.16
Madagascar	0.58	0.68	-3.51	16.33	-11.54	-6.23
Malawi	0.37	0.55	33.83	47.25	-10.17	1.18
Mauritius	0.83	1.00	55.90	20.00	-3.82	35.08
Mexico	0.68	0.64	12.80	-5.13	6.20	11.96
Morocco	0.65	0.65	3.30	0.00	-5.68	9.53
Netherlands	0.79	0.64	15.21	-19.11	31.16	8.59

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Table 6 – Continued

Country	TE$_b$	TE$_c$	Produtivity Change	$EFF-1$ × 100	$TECH-1$ × 100	$KACCUM-1$ × 100
New Zealand	0.63	0.53	18.19	-15.96	32.65	6.02
Nigeria	0.65	0.46	-28.70	-29.49	-11.23	13.92
Norway	0.66	0.57	27.04	-14.20	35.88	8.98
Panama	0.57	0.51	5.14	-10.71	-4.19	22.91
Paraguay	1.00	0.78	-34.43	-22.48	-4.01	-11.88
Peru	0.32	0.36	4.47	13.00	-2.42	-5.25
Philippines	0.55	0.57	11.72	5.17	-3.84	10.47
Portugal	0.76	0.61	20.13	-20.12	19.91	25.42
Sierra Leone	1.00	1.00	-4.83	0.00	-17.81	15.80
Spain	0.78	0.60	13.81	-22.29	33.45	9.74
Sri Lanka	0.83	0.81	18.03	-2.42	-5.20	27.59
Sweden	0.68	0.57	20.00	-16.48	31.66	9.12
Switzerland	0.68	0.50	4.32	-26.87	35.97	4.91
Syria	0.79	0.95	15.52	20.95	-5.46	1.02
Taiwan	1.00	0.99	45.28	-0.99	1.06	45.20
Thailand	0.53	0.46	22.83	-14.16	-5.79	51.88
Turkey	0.77	0.67	11.65	-12.75	-7.38	38.16
United Kingdom	0.78	0.64	23.41	-17.31	32.38	12.74
USA	1.00	0.81	21.08	-18.70	32.63	12.29
Zambia	0.26	0.27	-10.16	2.41	-4.01	-8.61
Zimbabwe	0.36	0.36	-5.33	0.36	-3.90	-1.84
Average			13.77	-8.89	10.87	12.62

Table 7: Mean Percentage Changes of
Tripartite Decomposition Indices (Country Groupings)

Country Group	Produtivity Change	$EFF - 1$ × 100	$TECH - 1$ × 100	$KACCUM - 1$ × 100
OECD[1]	20,85	-17,38	31,11	11,57
Non OECD	5,92	-0,34	-4,25	11,00
Asian Tigers[2]	28,63	-18,58	18,62	33,17
Latin America	2,76	-2,52	-2,92	8,58
Africa	1.46	4.91	-8.60	5.81
All countries	13,77	-8,89	10,87	12,62

[1] OECD countries by UNESCO classification as of 2004;
excluding Czech Republic, Hungary, Korea, Poland and Slovak Republic

[2] Hong Kong, Japan, South Korea and Taiwan

Table 8: Percentage change in output per worker and the three decomposition indexs vs. 1992 output per worker (p-values in parentheses)

	Regression (A)	Regression (B)	Regression (C)	Regression (D)
	Productivity Change	EFF - 1 × 100	TECH - 1 × 100	KACCUM - 1 × 100
Constant	3.69	5.60	– 13.79	12.36
	(0.454)	(0.203)	(0.000)	(0.001)
Slope	0.00047	– 0.00053	0.00105	0.00004
	(0.001)	(0.000)	(0.000)	(0.664)

Table 9: Distribution Hypothesis Tests: Comparison to y_{2000}

H_0 : Distributions are equal H_1 : Distributions are not equal	Value of statistic	Bootstrap p-value	Conclusion of test
$g(y2000)$ vs. $f(y1992)$	1.5122	0.0502	reject H_0
$g(y2000)$ vs. $f(y1992 \times EFF)$	6.0254	0.0004	reject H_0
$g(y2000)$ vs. $f(y1992 \times TECH)$	0.5921	0.3350	fail to reject
$g(y2000)$ vs. $f(y1992 \times KACCUM)$	0.2022	0.7858	fail to reject
$g(y2000)$ vs. $f(y1992 \times EFF \times TECH)$	0.4688	0.4776	fail to reject
$g(y2000)$ vs. $f(y1992 \times EFF \times KACCUM)$	3.6541	0.0028	reject H_0
$g(y2000)$ vs. $f(y1992 \times TECH \times KACCUM)$	2.2877	0.0188	reject H_0

Table 10: Distribution Hypothesis Tests: Comparison to y_{1992}

H_0 : Distributions are equal H_1 : Distributions are not equal	Value of statistic	Bootstrap p-value	Conclusion of test
$g(y1992)$ vs. $f(y2000)$	1.5122	0.0550	reject H_0
$g(y1992)$ vs. $f(y1992 \times EFF)$	2.3339	0.0174	reject H_0
$g(y1992)$ vs. $f(y1992 \times TECH)$	3.7560	0.0024	reject H_0
$g(y1992)$ vs. $f(y1992 \times KACCUM)$	0.6752	0.2768	fail to reject
$g(y1992)$ vs. $f(y1992 \times EFF \times TECH)$	0.3346	0.6426	fail to reject
$g(y1992)$ vs. $f(y1992 \times EFF \times KACCUM)$	0.4443	0.5112	fail to reject
$g(y1992)$ vs. $f(y1992 \times TECH \times KACCUM)$	5.7034	0.0002	reject H_0

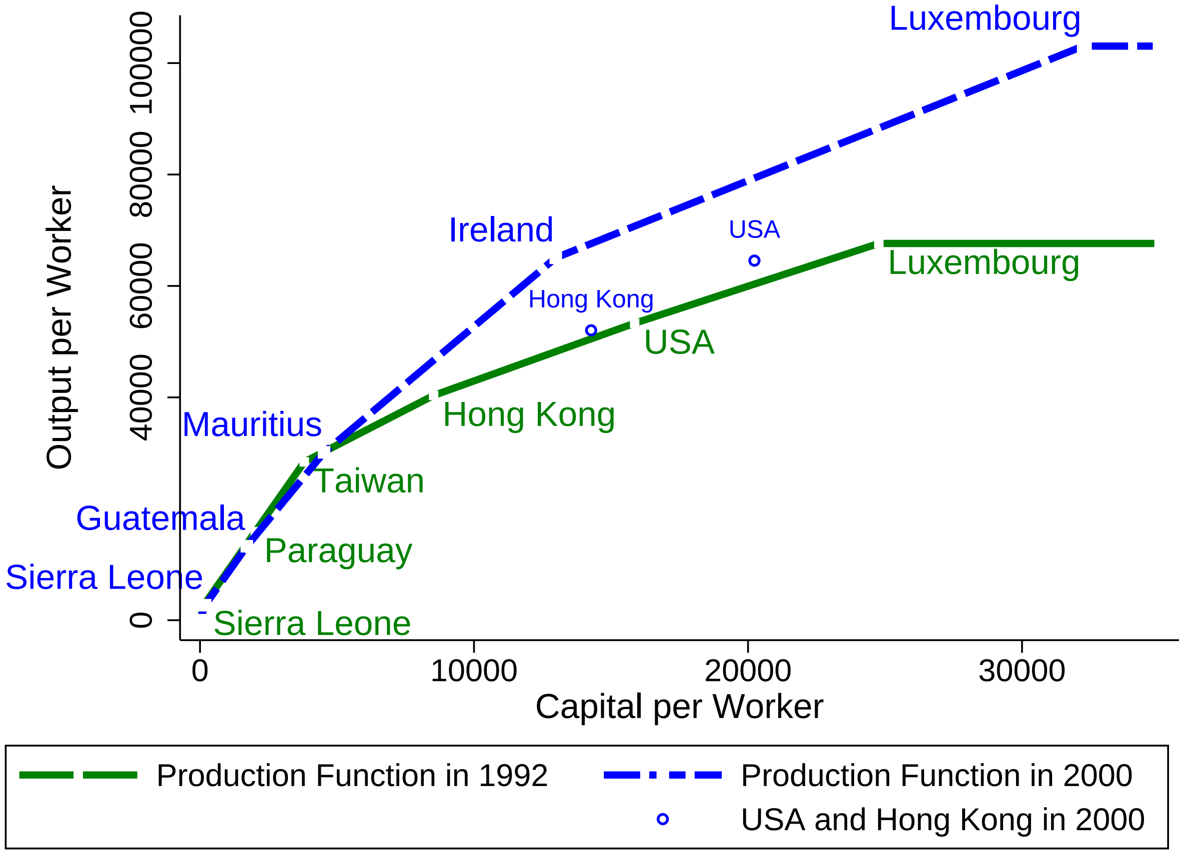
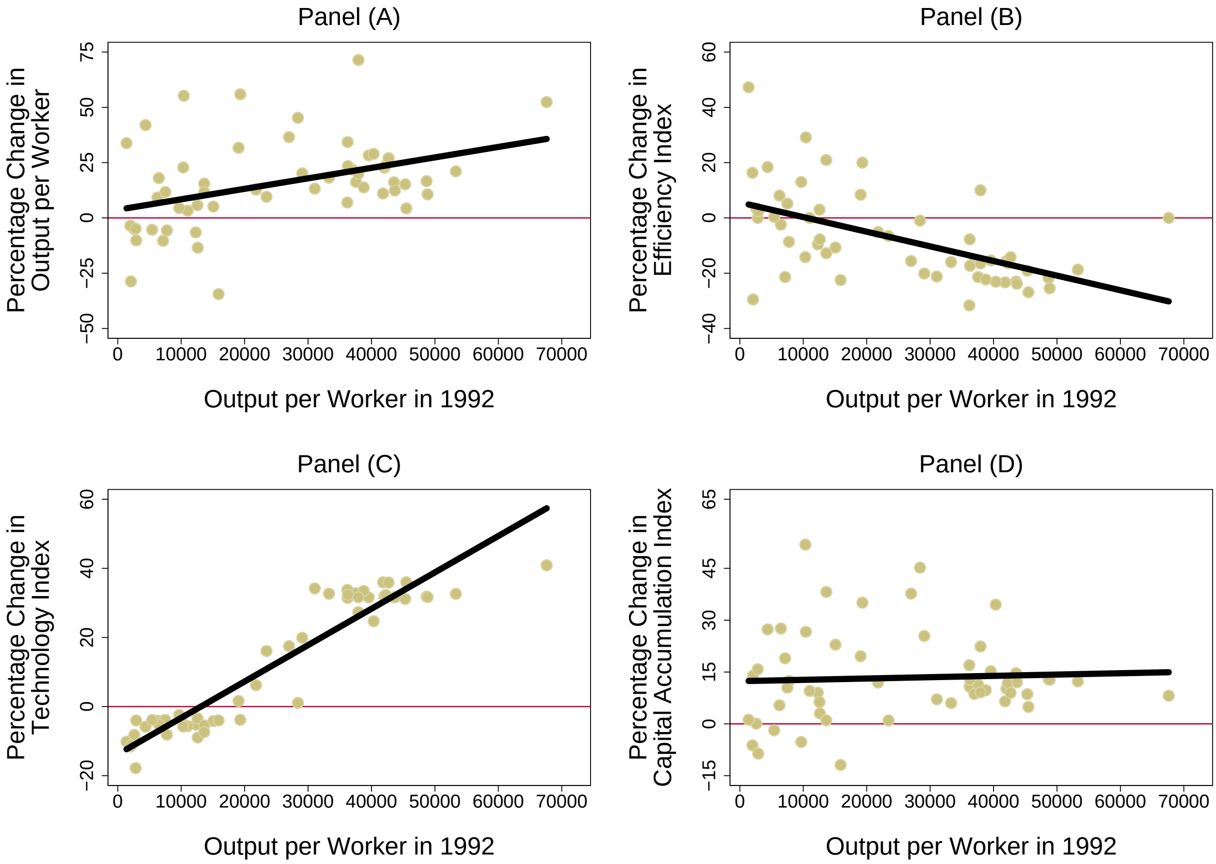
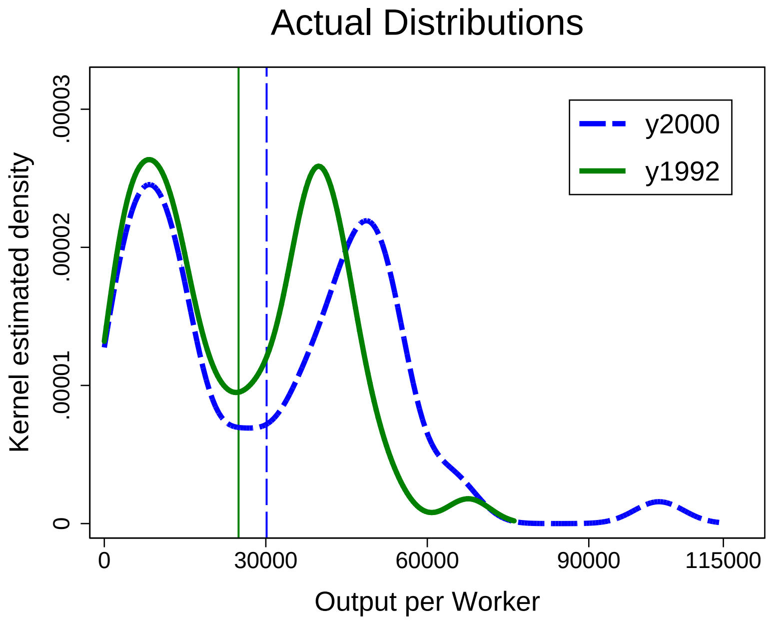


Figure 7: 1992 and 2000 World Production Functions



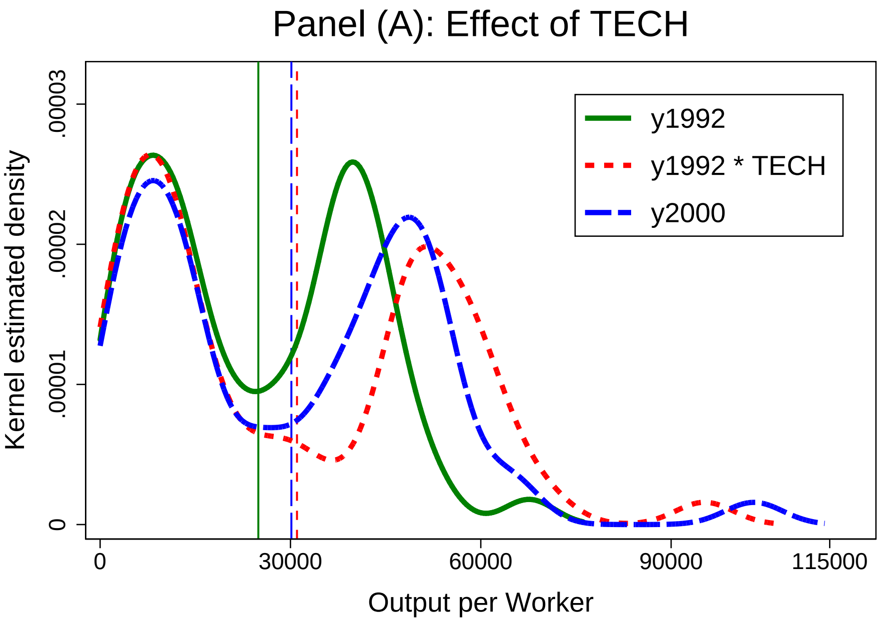
Note: *Each panel contains a GLS regression line.*

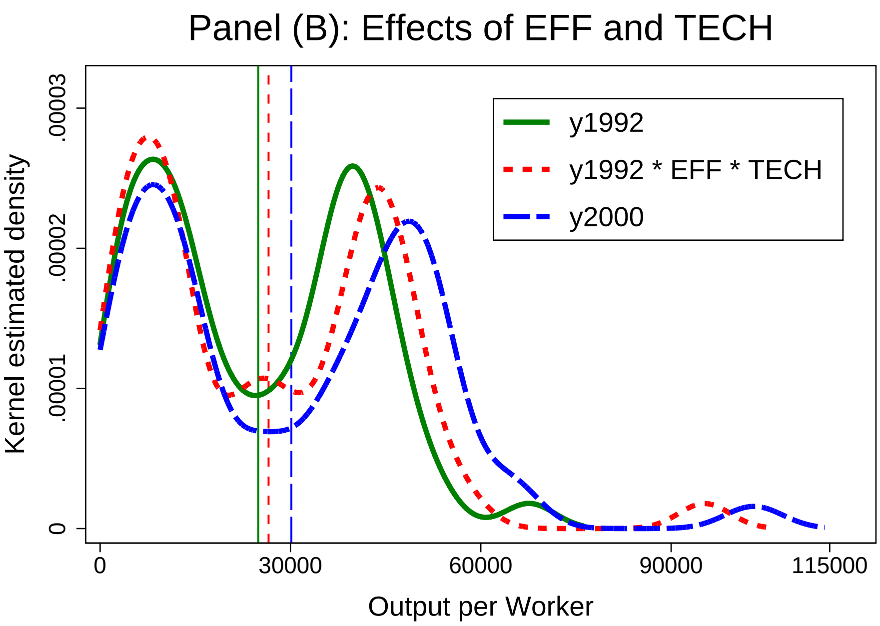
Figure 8: Percentage change in output per worker and three decomposition indexes, plotted against output per worker in 1992



Note: In panel solid vertical line represents sample mean values of output per worker for 1992; longdashed – for 2000.

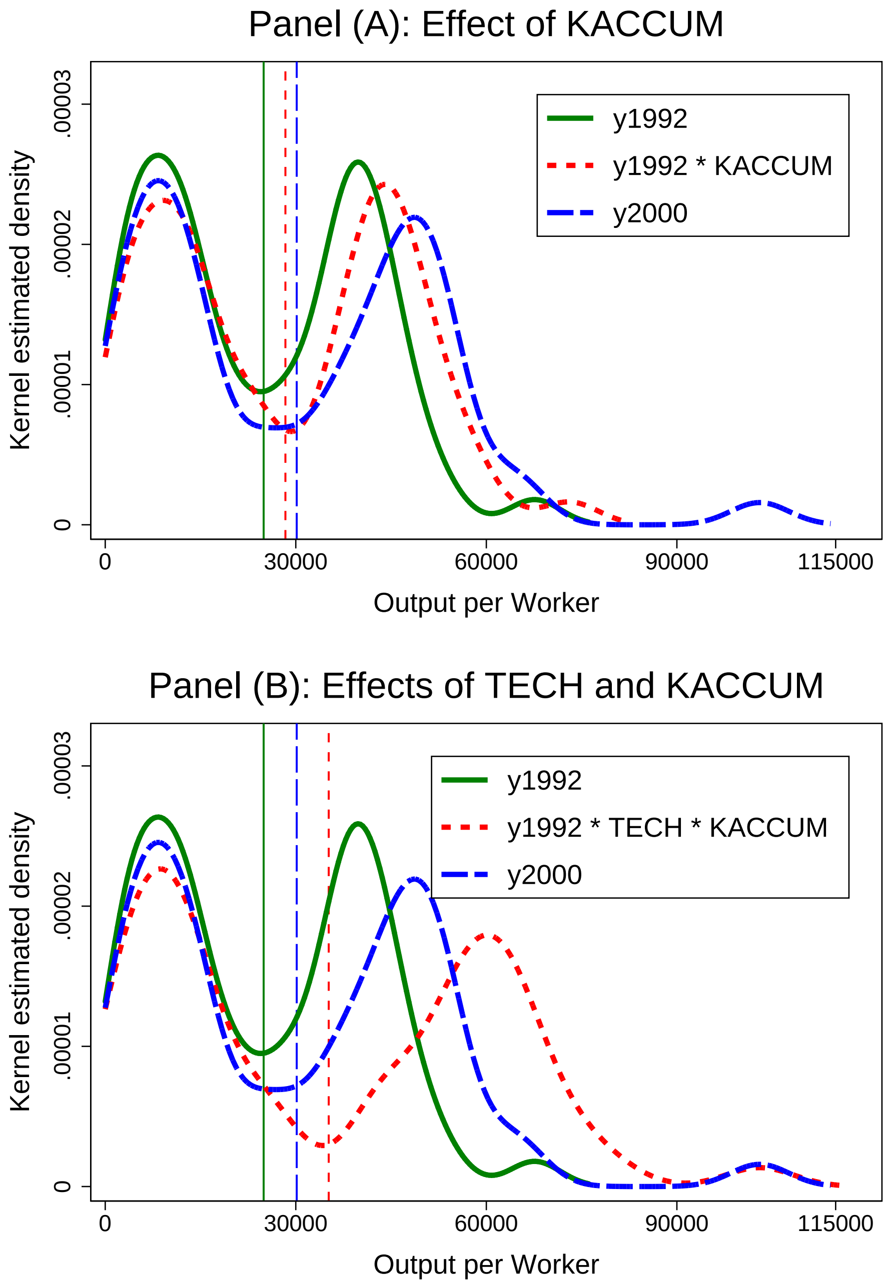
Figure 9: Actual 1992 and 2000 Output per Worker Distributions





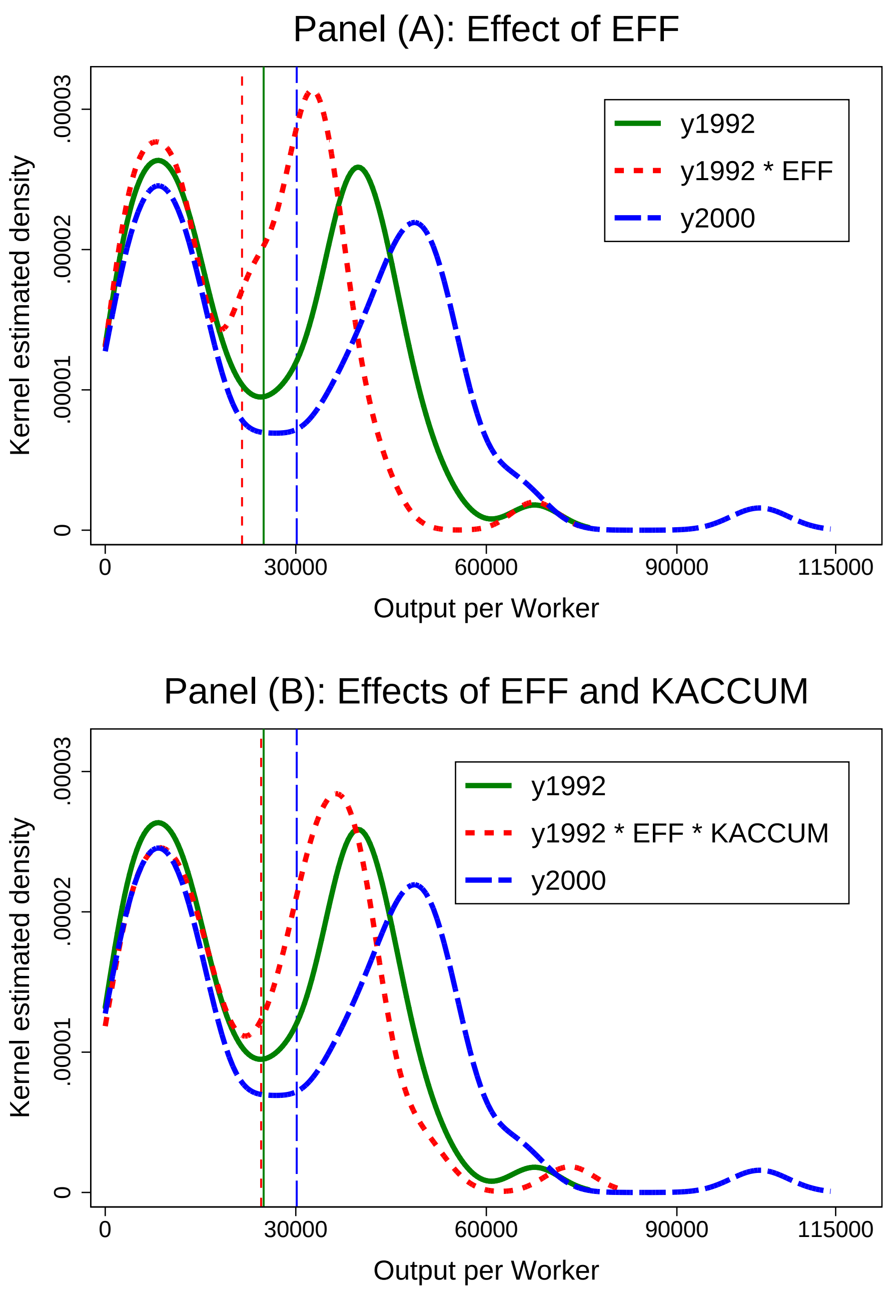
Note: In each panel, the solid curve is the actual 1992 distribution and the solid vertical line represents the 1992 mean value. The dashed curve is the actual 2000 distribution and the dashed vertical line represents the 2000 mean value. The dotted curves in each panel are the counterfactual distributions isolating, sequentially, the effects of technological change and efficiency change on the 1992 distribution, and the dotted vertical line represents the respective counterfactual mean.

Figure 10: Counterfactual Distributions of Output per Worker. Sequence of introducing effects of decomposition: TECH, EFF



Note: In each panel, the solid curve is the actual 1992 distribution and the solid vertical line represents the 1992 mean value. The dashed curve is the actual 2000 distribution and the dashed vertical line represents the 2000 mean value. The dotted curves in each panel are the counterfactual distributions isolating, sequentially, the effects of capital accumulation and technological change on the 1992 distribution, and the dotted vertical line represents the respective counterfactual mean.

Figure 11: Counterfactual Distributions of Output per Worker. Sequence of introducing effects of decomposition: KACCUM, TECH



Note: In each panel, the solid curve is the actual 1992 distribution and the solid vertical line represents the 1992 mean value. The dashed curve is the actual 2000 distribution and the dashed vertical line represents the 2000 mean value. The dotted curves in each panel are the counterfactual distributions isolating, sequentially, the effects of efficiency change and capital accumulation on the 1992 distribution, and the dotted vertical line represents the respective counterfactual mean.

Figure 12: Counterfactual Distributions of Output per Worker. Sequence of introducing effects of decomposition: EFF, KACCUM

Appendix B: Results for the entire sample with Luxembourg 'frozen' at the 1992 level

Table 11: Percentage change of tripartite decomposition indexes, 1992-2000

Country	TE_b	TE_c	Produtivity Change	$EFF-1$ $\times$ 100	$TECH-1$ $\times$ 100	$KACCUM-1$ $\times$ 100
Albania	0.62	0.75	46.06	20.90	-3.96	25.80
Argentina	0.58	0.54	9.57	-6.52	16.08	0.98
Armenia	0.23	0.29	32.89	24.78	-6.45	13.83
Australia	0.77	0.78	22.74	0.78	15.39	5.55
Austria	0.79	0.75	16.14	-4.51	12.03	8.57
Azerbaijan	0.31	0.30	-0.31	-2.39	-7.37	10.26
Belarus	0.28	0.24	17.39	-14.15	29.01	5.98
Belgium	0.81	0.84	16.63	3.36	5.54	6.92
Bolivia	0.57	0.62	9.22	8.07	-4.09	5.37
Brazil	0.53	0.55	16.34	3.87	3.40	8.33
Bulgaria	0.68	0.57	-12.21	-16.48	-7.33	13.42
Canada	0.81	0.79	23.72	-3.15	19.54	6.87
Chile	0.65	0.70	31.71	8.39	1.62	19.57
China	0.67	0.74	69.40	11.11	-6.14	62.43
Colombia	0.81	0.74	-6.55	-9.56	-5.22	9.01
Costa Rica	0.67	0.70	8.23	4.90	-7.54	11.59
Croatia	0.43	0.41	13.81	-3.29	12.52	4.59
Czech Republic	0.40	0.36	9.48	-8.00	14.52	3.91
Denmark	0.70	0.75	28.29	7.52	9.73	8.74
Dominican Republic	0.75	0.97	55.25	29.13	-5.07	26.65
Ecuador	0.47	0.43	-13.46	-7.76	-8.95	3.04
Estonia	0.33	0.38	57.91	14.77	9.58	25.56
Finland	0.65	0.73	34.30	13.14	12.11	5.88
France	0.78	0.74	12.38	-5.88	11.96	6.65
Germany	0.63	0.68	11.07	8.22	0.94	1.68
Greece	0.64	0.54	13.25	-16.13	29.76	4.06
Guatemala	0.97	1.00	5.76	3.00	-3.40	6.30
Honduras	0.74	0.58	-10.35	-21.39	-4.15	18.98
Hong Kong	1.00	0.79	28.98	-20.63	22.75	32.40
Hungary	0.45	0.40	37.39	-10.76	26.25	21.94
Iceland	0.70	0.68	21.86	-3.40	20.12	5.03
India	0.74	0.88	42.00	18.42	-5.84	27.34
Indonesia	0.96	0.74	9.87	-22.96	-4.19	48.86

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Table 11 – Continued

Country	TE_b	TE_c	Produtivity Change	$EFF-1$ × 100	$TECH-1$ × 100	$KACCUM-1$ × 100
Ireland	0.91	1.00	71.44	10.00	27.34	22.39
Israel	0.80	0.67	16.25	-16.67	28.99	8.15
Italy	0.83	0.80	10.68	-4.00	7.32	7.42
Jamaica	0.34	0.31	-5.64	-8.64	-8.12	12.42
Japan	0.75	0.58	6.98	-21.64	24.58	9.58
Kazakhstan	0.36	0.32	11.45	-13.29	14.33	12.42
Kenya	0.54	0.56	-5.06	3.37	-8.20	0.05
Korea, Republic of	0.77	0.65	36.56	-15.58	17.49	37.68
Kyrgyzstan	0.83	0.81	13.36	-2.44	-5.24	22.62
Latvia	0.24	0.23	44.23	-3.65	24.21	20.52
Lithuania	0.38	0.37	16.49	-3.69	5.11	15.08
Luxembourg	1.00	1.00	0.00	0.00	0.00	0.00
Macedonia	0.34	0.37	13.79	10.00	0.75	2.68
Madagascar	0.58	0.68	-3.51	16.33	-11.54	-6.23
Malawi	0.37	0.55	33.83	47.25	-10.17	1.18
Malaysia	0.75	0.76	33.92	2.29	-1.53	32.96
Mauritius	0.83	1.00	55.90	20.00	-3.82	35.08
Mexico	0.68	0.64	12.80	-5.13	6.20	11.96
Moldova	0.36	0.28	-16.85	-19.94	-3.96	8.15
Morocco	0.65	0.65	3.30	0.00	-5.68	9.53
Netherlands	0.79	0.78	15.21	-0.78	10.74	4.86
New Zealand	0.63	0.60	18.19	-5.95	21.45	3.47
Nigeria	0.65	0.46	-28.70	-29.49	-11.23	13.92
Norway	0.66	0.80	27.04	20.80	1.97	3.14
Panama	0.57	0.51	5.14	-10.71	-4.19	22.91
Paraguay	1.00	0.78	-34.43	-22.48	-4.01	-11.88
Peru	0.32	0.36	4.47	13.00	-2.42	-5.25
Philippines	0.55	0.57	11.72	5.17	-3.84	10.47
Poland	0.27	0.31	53.35	15.69	26.94	4.42
Portugal	0.76	0.61	20.13	-20.12	19.91	25.42
Romania	0.28	0.28	4.56	0.00	-3.27	8.10
Russia	0.33	0.24	-9.26	-27.25	22.46	1.86
Sierra Leone	1.00	1.00	-4.83	0.00	-17.81	15.80
Singapore	0.76	0.81	49.94	6.45	24.18	13.43
Slovak Republic	0.32	0.35	22.70	10.92	8.25	2.19
Slovenia	0.46	0.50	39.58	9.50	20.70	5.60
Spain	0.78	0.67	13.81	-13.42	24.59	5.51
Sri Lanka	0.83	0.81	18.03	-2.42	-5.20	27.59

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Table 11 – Continued

Country	TE_b	TE_c	Produtivity Change	$EFF-1$ × 100	$TECH-1$ × 100	$KACCUM-1$ × 100
Sweden	0.68	0.68	20.00	0.00	13.95	5.30
Switzerland	0.68	0.70	4.32	3.52	0.34	0.44
Syria	0.79	0.95	15.52	20.95	-5.46	1.02
Taiwan	1.00	0.99	45.28	-0.99	1.06	45.20
Tajikistan	0.28	0.36	27.09	28.67	-4.29	3.20
Thailand	0.53	0.46	22.83	-14.16	-5.79	51.88
Turkey	0.77	0.67	11.65	-12.75	-7.38	38.16
Ukraine	0.25	0.14	-41.99	-46.28	4.39	3.44
United Kingdom	0.78	0.68	23.41	-11.64	28.07	9.06
Uruguay	0.58	0.58	10.78	0.00	5.70	4.81
USA	1.00	0.97	21.08	-2.91	16.72	6.85
Venezuela	0.58	0.44	-17.13	-23.56	10.38	-1.79
Zambia	0.26	0.27	-10.16	2.41	-4.01	-8.61
Zimbabwe	0.36	0.36	-5.33	0.36	-3.90	-1.84
Average			13.99	-2.44	4.82	11.46

Table 12: Mean Percentage Changes of
Tripartite Decomposition Indices (Country Groupings)

Country Group	Produtivity Change	$EFF - 1$ × 100	$TECH - 1$ × 100	$KACCUM - 1$ × 100
OECD[1]	19,29	-1,72	13,38	7,06
Non OECD	12,17	-2,36	1,48	13,20
Asian Tigers[2]	32,63	-11,16	17,66	26,89
Latin America	2,98	-2,98	-1,61	7,88
Africa	1.46	4.91	-8.60	5.81
Transition (all)[3]	16.32	-3,22	6,10	13,28
Non-Transition	13,09	-2,13	-2,13	4,33
Baltic Countries[4]	38,44	2,12	12,68	20,31
Central and Eastern Europe[5]	21,23	2,17	8,87	8,99
Republics of Former USSR[6]	0,99	-10,84	4,00	8,91
All countries	14.56	-2,44	4,82	11,46

[1] OECD countries by UNESCO classification as of 2004;
excluding Czech Republic, Hungary, Korea, Poland and Slovak Republic
[2] Hong Kong, Japan, Singapore, South Korea and Taiwan
[3] Albania, Armenia, Azerbaijan, Belarus, Bulgaria, China, Croatia, Czech Republic, Estonia, Hungary, Kazakhstan, Kyrgyzstan, Latvia, Lithuania, Macedonia, Moldova, Poland, Romania, Russia, Slovak Republic, Slovenia, Tajikistan, Turkey, Ukraine
[4] Estonia, Latvia, Lithuania
[5] Albania, Bulgaria, Croatia, Czech Republic, Hungary, Macedonia, Poland, Romania, Slovak Republic, Slovenia
[6] Excluding Baltic Countries

Table 13: Percentage change in output per worker and the three decomposition indexs vs. 1992 output per worker (p-values in parentheses)

	Regression (A)	Regression (B)	Regression (C)	Regression (D)
	Productivity Change	EFF - 1 × 100	TECH - 1 × 100	KACCUM - 1 × 100
Constant	11.63	1.37	– 4.22	15.40
	(0.009)	(0.660)	(0.027)	(0.000)
Slope	0.0002	– 0.0001	0.0005	– 0.0002
	(0.137)	(0.197)	(0.000)	(0.067)

Table 14: Distribution Hypothesis Tests: Comparison to y_{2000}

H_0 : Distributions are equal H_1 : Distributions are not equal	Value of statistic	Bootstrap p-value	Conclusion of test
$g(y2000)$ vs. $f(y1992)$	1.1003	0.0726	reject H_0
$g(y2000)$ vs. $f(y1992 \times EFF)$	0.7493	0.1814	fail to reject H_0
$g(y2000)$ vs. $f(y1992 \times TECH)$	0.0885	0.9004	fail to reject
$g(y2000)$ vs. $f(y1992 \times KACCUM)$	0.5981	0.3344	fail to reject
$g(y2000)$ vs. $f(y1992 \times EFF \times TECH)$	0.1215	0.8540	fail to reject
$g(y2000)$ vs. $f(y1992 \times EFF \times KACCUM)$	0.3401	0.6096	fail to reject H_0
$g(y2000)$ vs. $f(y1992 \times TECH \times KACCUM)$	0.0069	0.9914	fail to reject H_0

Table 15: Distribution Hypothesis Tests: Comparison to y_{1992}

H_0 : Distributions are equal H_1 : Distributions are not equal	Value of statistic	Bootstrap p-value	Conclusion of test
$g(y1992)$ vs. $f(y2000)$	1.1003	0.0898	reject H_0
$g(y1992)$ vs. $f(y1992 \times EFF)$	0.1062	0.8842	fail to reject H_0
$g(y1992)$ vs. $f(y1992 \times TECH)$	1.0754	0.0838	reject H_0
$g(y1992)$ vs. $f(y1992 \times KACCUM)$	0.2558	0.7180	fail to reject
$g(y1992)$ vs. $f(y1992 \times EFF \times TECH)$	0.7159	0.2200	fail to reject
$g(y1992)$ vs. $f(y1992 \times EFF \times KACCUM)$	0.1968	0.7746	fail to reject
$g(y1992)$ vs. $f(y1992 \times TECH \times KACCUM)$	1.8739	0.0288	reject H_0

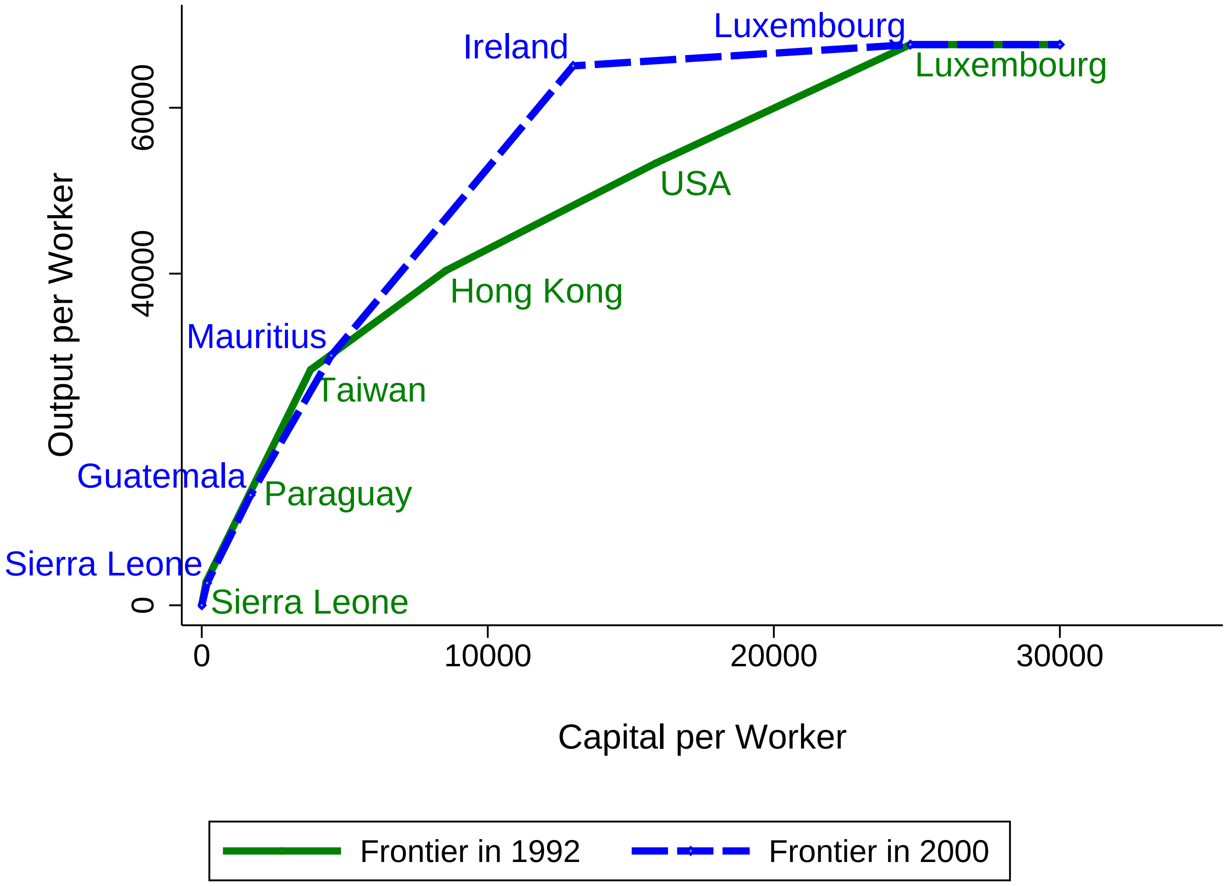
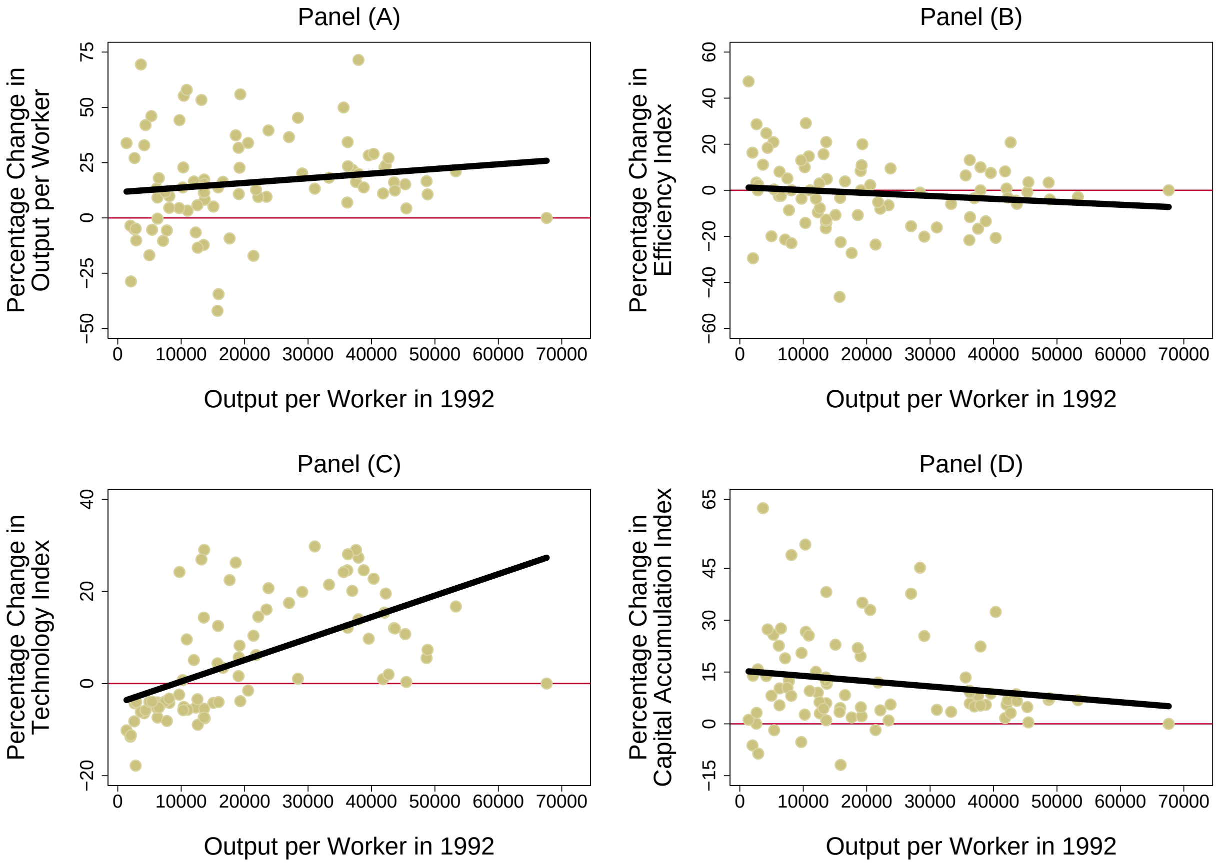
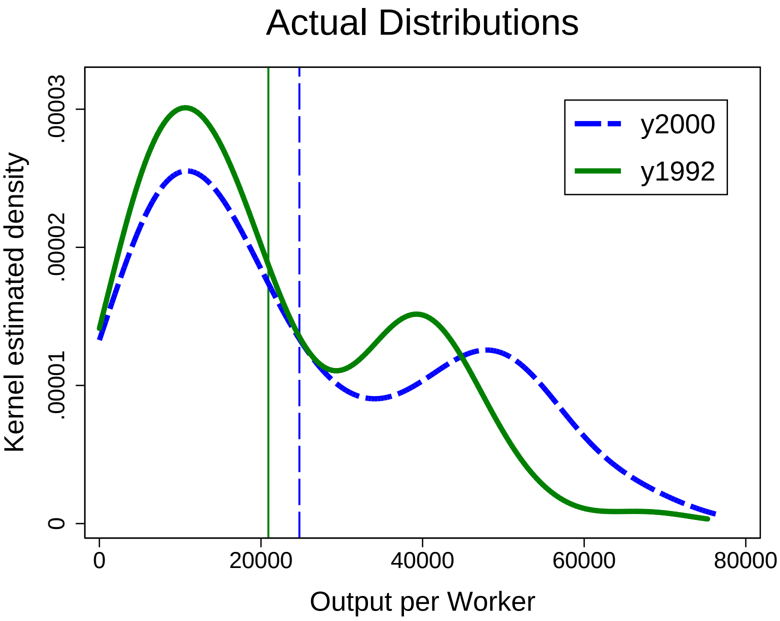


Figure 13: 1992 and 2000 World Production Functions



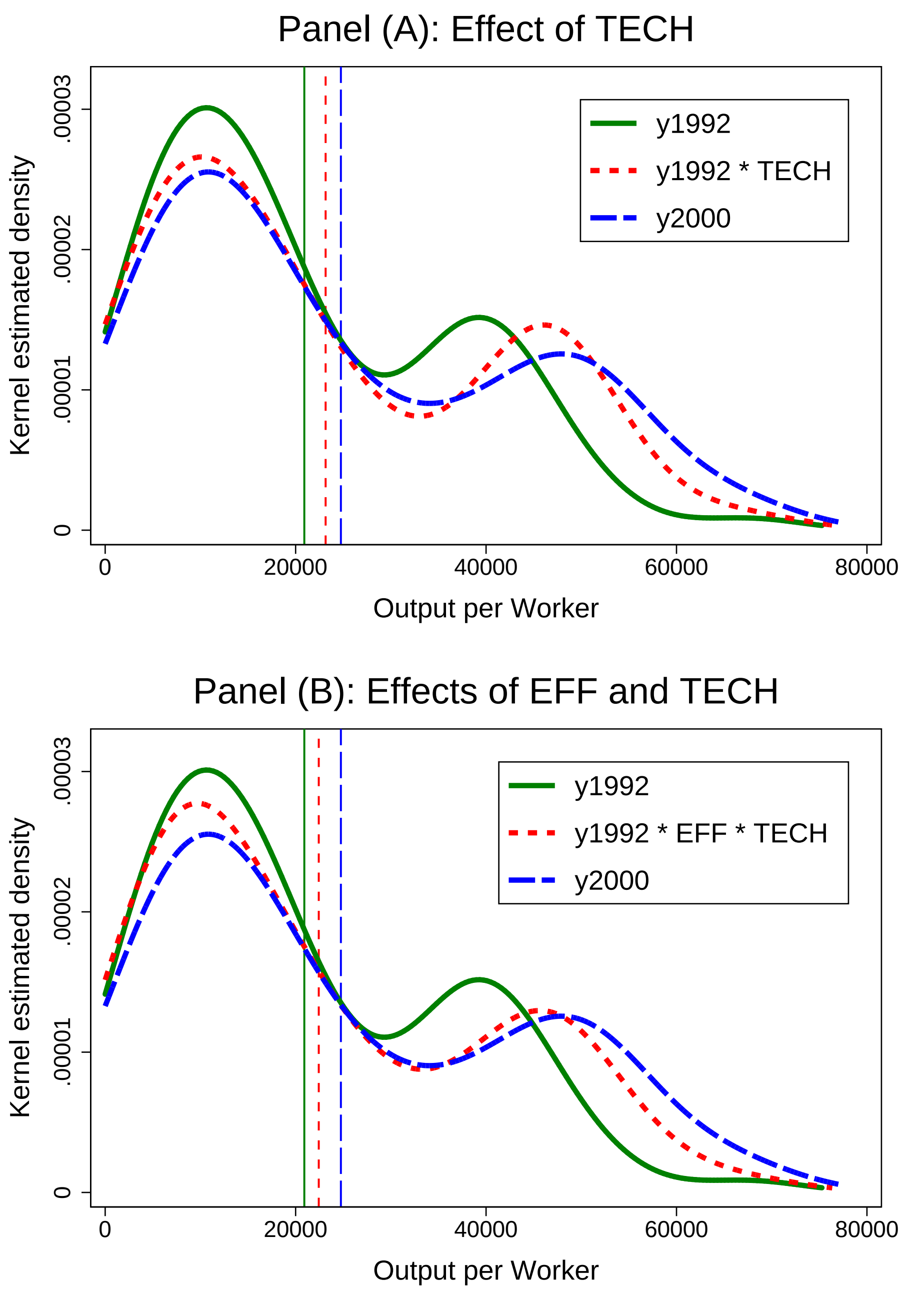
Note: *Each panel contains a GLS regression line.*

Figure 14: Percentage change in output per worker and three decomposition indexes, plotted against output per worker in 1992



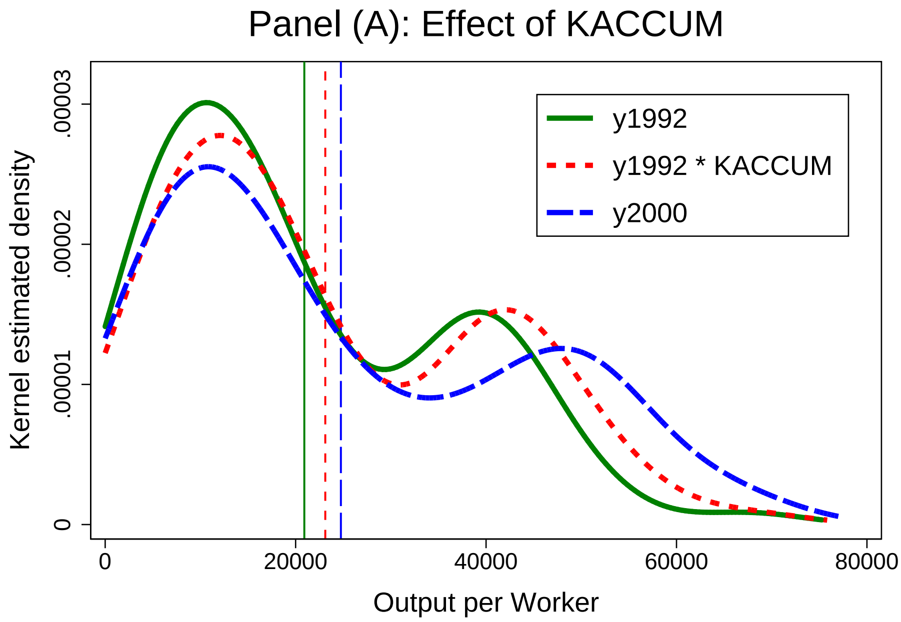
Note: In panel solid vertical line represents sample mean values of output per worker for 1992; longdashed – for 2000.

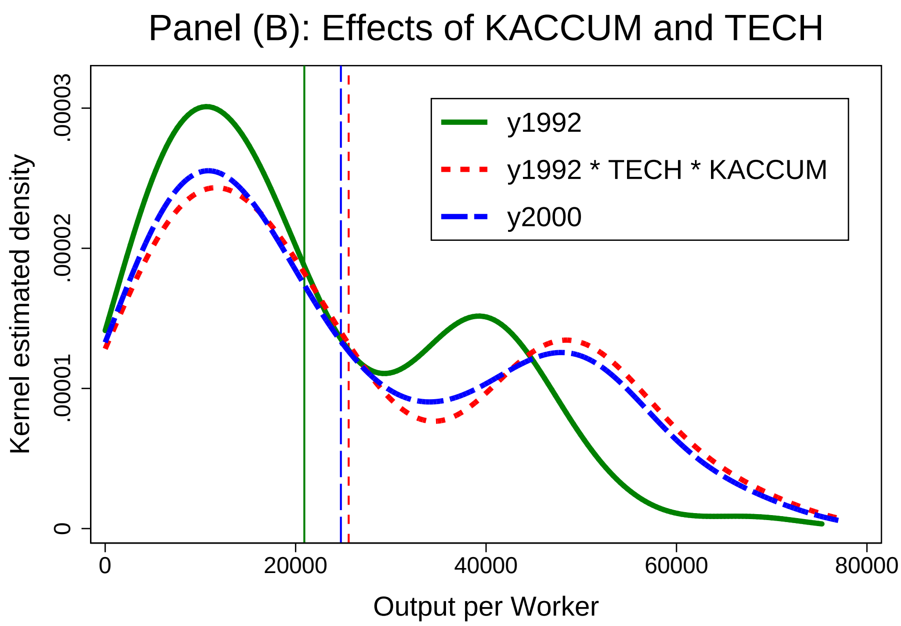
Figure 15: Actual 1992 and 2000 Output per Worker Distributions



Note: In each panel, the solid curve is the actual 1992 distribution and the solid vertical line represents the 1992 mean value. The dashed curve is the actual 2000 distribution and the dashed vertical line represents the 2000 mean value. The dotted curves in each panel are the counterfactual distributions isolating, sequentially, the effects of technological change and efficiency change on the 1992 distribution, and the dotted vertical line represents the respective counterfactual mean.

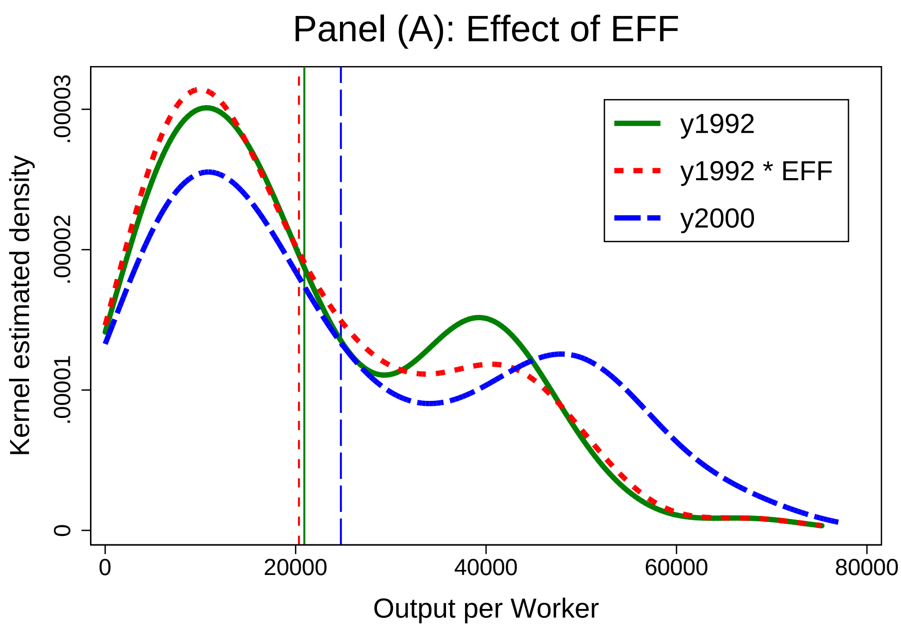
Figure 16: Counterfactual Distributions of Output per Worker. Sequence of introducing effects of decomposition: TECH, EFF

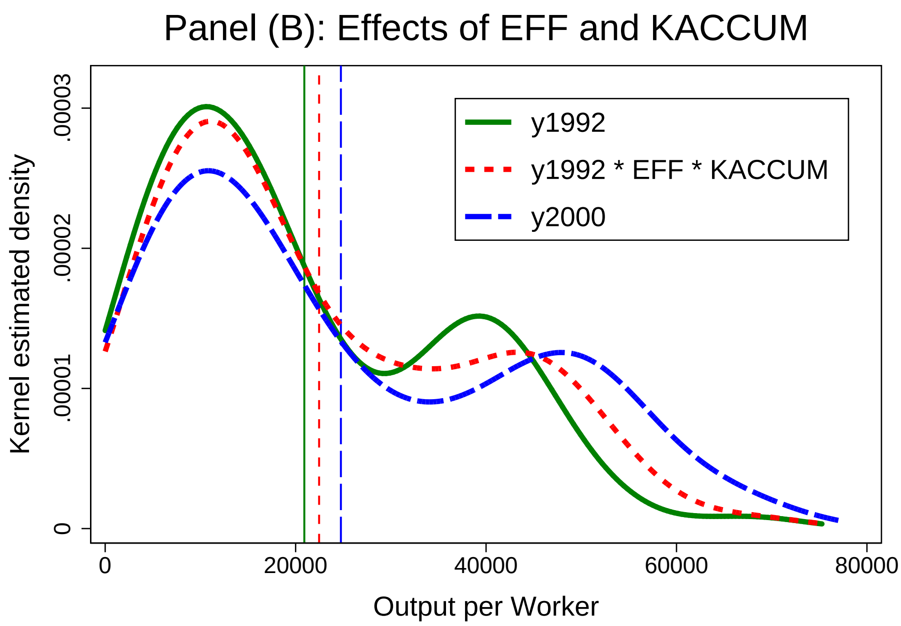




Note: In each panel, the solid curve is the actual 1992 distribution and the solid vertical line represents the 1992 mean value. The dashed curve is the actual 2000 distribution and the dashed vertical line represents the 2000 mean value. The dotted curves in each panel are the counterfactual distributions isolating, sequentially, the effects of capital accumulation and technological change on the 1992 distribution, and the dotted vertical line represents the respective counterfactual mean.

Figure 17: Counterfactual Distributions of Output per Worker. Sequence of introducing effects of decomposition: KACCUM, TECH





Note: In each panel, the solid curve is the actual 1992 distribution and the solid vertical line represents the 1992 mean value. The dashed curve is the actual 2000 distribution and the dashed vertical line represents the 2000 mean value. The dotted curves in each panel are the counterfactual distributions isolating, sequentially, the effects of efficiency change and capital accumulation on the 1992 distribution, and the dotted vertical line represents the respective counterfactual mean.

Figure 18: Counterfactual Distributions of Output per Worker. Sequence of introducing effects of decomposition: EFF, KACCUM