Foreign Direct Investment and Convergence: A Nonparametric Production Frontier Approach

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Abstract

We decompose labor productivity growth into components attributable to technological change, technological catch-up, foreign capital deepening, domestic capital deepening, and human capital accumulation, thus separating the effects of foreign and domestic capital deepening on productivity growth and convergence. We apply nonparametric production-frontier methods to a worldwide 1980-2005 panel and find that (1) foreign capital accumulation, together with human capital accumulation, is the driving force for productivity growth and increasing international dispersion of productivity, (2) technological change is decidedly nonneutral, with most technological advancement taking place in foreign-capital-intensive countries, and (3) international polarization is brought about primarily by efficiency changes.

Key Words: Convergence, Foreign Direct Investment, Growth, Data envelopment analysis, Nonparametric.

JEL Classification: F21, F43, O47

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1 Introduction

Worldwide flows of foreign direct investment (FDI), abetted by increasing openness and integration of global capital markets, grew substantially during the last three decades, at rates well above those of global economic growth. The role that FDI plays in economic growth has been studied extensively at both the theoretical and the empirical level. In the 1960s, exogenous growth analysis of FDI treated foreign and domestic capital as identical inputs, which can therefore be aggregated to form a homogeneous input that enters the production function as a whole. MacDougall (1960), Kemp (1966), and Jones (1967), for example, maintain this assumption in their models of FDI and growth. Findlay (1978) provides the first attempt to model foreign capital and domestic capital as distinct factors of production, each with a separate rate of return. His work is inspired by earlier research of Hymer (1960), which regards FDI as a transfer of a "package" combining capital, management, and new technology.

Endogenous growth theory, pioneered by Romer (1986) and Lucas et al. (1988) in the 1980s, has emphasized the extent to which physical and human capital investment are crucial to persistent economic growth. This theory has led to extensive empirical research on the role of heterogeneous capital inputs in the growth process. Using both time-series and cross-sectional data, these studies have conducted regional and worldwide regressions using time-series or cross-sectional data. Using cross-sectional data for 46 developing countries over the period 1970-1985, Balasubramanyam et al. (1996) estimates a pooled regression of labor-productivity growth on the growth of foreign capital per capita and the growth of other inputs. Their study indicates that the elasticity of output with respect to FDI exceeds the elasticity with respect to domestic capital investment, implying that FDI is the driving force in the growth process. Borensztein et al. (1998) use seemingly unrelated regressions (SUR) to examine the inflow of FDI from OECD countries to 69 developing countries over two decades (1970-1989). The result shows that FDI contributes more to economic growth than does domestic investment, but the effect of FDI depends on the level of human capital available in the host economy. Ram and Zhang (2002) pool the data for 85 countries in the 1990s, and the regression supports the hypothesis of a positive nexus between FDI and economic growth in host countries. Makki and Somwaru (2004) test the effect of FDI on economic growth in a framework of cross-country equations, utilizing data from 66 developing countries over last three decades (1971-2000). The results suggest that FDI is a significant source of economic growth for developing countries and that its contribution is enhanced by a positive interaction with human capital, sound macroeconomic policies, and institutional stability. Much of the empirical literature on FDI-growth linkage is summarized in De Mello Jr (1997).

Two limitations of the empirical studies outlined above are evident. First, those studies are mainly model driven, requiring assumptions about the technology, the market structure, and other relevant factors of the growth process. This is a common drawback in growth-accounting studies, as outlined by Quah (1993, 1996, 1997). Quah (1997) argues that empirical convergence studies based on parametric regressions and focusing on first moments of the distribution are not adequate. Kumar and Russell (2002) (hearafter KR) develop a nonparametric (deterministic) growth-accounting method to overcome the shortcomings of the approach relying on parametric regressions. Inspired partly by Färe et al. (1994), KR suggest a tripartite decomposition of labor-productivity growth, with components attributable to technological change (expansion or contraction of the world production frontier), technological catch-up (movements toward or away from the frontier), and capital accumulation (movements along the frontier). Their Data Envelopment Analysis (DEA) approach to constructing the worldwide production frontier and its associated country-level efficiency indexes is based on Farrell (1957) and Afriat (1972). This method envelops the data in the "tightest fitting" convex cone, with the upper boundary of the set representing the "best practice" production frontier. It requires assumptions only on returns to scale of the technology and free disposability of inputs and outputs. No specification of the functional form for the technology or assumptions about market structure are needed. KR use a panel of 57 countries over the period 1965-1990, and find that both growth and increased international dispersion of productivity are driven primarily by capital deepening and that technological change is decidedly non-neutral, with all technological advancement taking place in relatively rich countries.

The principal limitation of KR is the absence of human capital in the decomposition. Henderson and Russell (2005) (hereafter HR) incorporate human capital into the analysis and develop a quadripartite decomposition, with components attributable to technological change, technological catch-up, and physical and human capital accumulation. They employ a panel of 52 countries over the period 1965-1990 and find that human capital accumulation, as well as physical capital accumulation, accounts for the growth of productivity. They credit the increased international dispersion of productivity to physical capital accumulation and the international polarization to technological catch-up.

Numerous studies applying DEA production-frontier methods to the decomposition of labor productivity growth into different components and to the analysis of growth and convergence have followed up on KR and HR. None of these studies, however, have extended the method to incorporate foreign capital as one of explainatory components. In this paper, we introduce foreign capital into the DEA growth-accounting framework and decompose labor productivity growth into components attributable to technological change, technological catch-up, foreign capital accumulation, domestic capital accumulation and human capital accumulation. This pent-partite decomposition enables separation of the effect of foreign capital from other factors that contribute to labor-productivity growth.

Another limitation of previous empirical studies of the FDI-growth linkage is sample selection bias, since these studies either focus on developing countries or evaluate the effects of FDI on developing countries and OECD countries separately. The limited time span and the exclusion of OECD countries hampers analysis of the convergence of the economies of the world as a whole. In our study, a broad worldwide panel with both developing countries and OECD countries over last two decades is employed.

The remainder of the paper is organized as follows: Section 2 describes the DEA method of constructing production frontiers and the penta-partite decomposition of the contribution of the different factors on labor productivity growth. Section 3 discusses the panel data. Section 4 summarizes the empirical results and analyzes the shifts in the productivity distributions. Section 5 concludes.

2 Methodology

2.1 Data Envelopment Analysis

We follow the HR methodology to construct the worldwide production frontier and concomitantly retrieve country-specific efficiency levels. To be specific, we use DEA to envelop the data in the smallest convex cone and identify the upper boundary of the set as the "best practice" production frontier. As capital is treated as heterogeneous, separated into foreign capital (KF) and domestic capital (KD), five macroeconomic variables are needed to define the technology: aggregate output (Y) and four aggregate inputs—KF, KD, labor (L), and human capital (H). Let $\langle Y_{jt}, KF_{jt}, KD_{jt}, L_{jt}, H_{jt} \rangle$ and $t = 1, \cdots, T$, $j = 1, \cdots, J$, represent T observations on the five variables for each of the J countries. Following the standard approach in the macroeconomics literature, human capital is assumed to be a multiplicative labor augmentation. Define $\hat{L}_{jt}$=$H_{jt}L_{jt}$ as the amount of labor input measured in efficiency units in country j at time t, so that the JT observations are $\langle Y_{jt}, KF_{jt}, KD_{jt}, \hat{L}_{jt} \rangle$, $t = 1, \cdots, T$ and $j = 1, \cdots, J$.

We adopt the "sequential production set" formulation of Diewert (1980) to preclude technological degradation (potential implosion of the frontier over time). The constant-returns-to-scale reference technology for the world at time t , using all the data up to t, is defined by

$$\mathcal{T}_t = \Big\{ \langle Y, KF, KD, \hat{L} \rangle \in \mathcal{R}^4_+ \ \Big| \ Y \leq \sum_{\tau \leq t} \sum_j z_{j\tau} Y_{j\tau} \ \wedge \ KF \geq \sum_{\tau \leq t} \sum_j z_{j\tau} KF_{j\tau} \qquad (1)$$

$$\wedge \ KD \geq \sum_{\tau \leq t} \sum_j z_{j\tau} KD_{j\tau} \ \wedge \ \hat{L} \geq \sum_{\tau \leq t} \sum_j z_{j\tau} \hat{L}_{j\tau}, \ z_{j\tau} \geq 0 \ \forall \, j, \tau \Big\},$$

where z_{jt} is the level of operation of a linear process for the jt observation. Every point in the technology set is a linear combination of observed input and output vectors or a point dominated by such a combination. The constructed technology is a polyhedral cone with piecewise linear isoquants, commonly referred to as a Farrell cone. The Farrell output-based efficiency index for country j at time t is defined by

$$E(Y_{j\tau}, KF_{j\tau}, KD_{j\tau}, \hat{L}_{j\tau}) = \min \Big\{ \lambda \ \Big| \ \langle Y_{j\tau}/\lambda, KF_{j\tau}, KD_{j\tau}, \hat{L}_{j\tau} \rangle \in \mathcal{T}_t \Big\}. \qquad (2)$$

As the index is the inverse of the maximal proportional amount that output can be expanded and remain technologically feasible, given the input quantities and the technology, it takes a value between zero and one and equals one if and only if the jt observation lies on the period t production frontier. As the aggregate output Y_{jt} is a scalar, the Farrell output-based efficiency index is the ratio of actual to potential (production frontier) output, evaluated at the actual input levels.

2.2 Pent-partite Decomposition of Labor Productivity

Define $y_t = Y_t/L_t$ to be labor productivity at period t and $\hat{y}_t = Y_t/\hat{L}_t$ the output per efficiency unit of labor at period t. The foreign and domestic capital per efficiency unit of labor at period t are given by $\widehat{KF}_t = KF_t/\hat{L}_t$ and $\widehat{KD}_t = KD_t/\hat{L}_t$, respectively. As the technology is characterized by constant returns to scale, the potential outputs per efficiency unit of labor in the base period (b) and the current period (c) are $\overline{y}_b(\widehat{KF}_b, \widehat{KD}_b) = \hat{y}_b/e_b$and $\overline{y}_c(\widehat{KF}_c, \widehat{KD}_c) = \hat{y}_c/e_c$, respectively, where e_b and e_c are the values of the efficiency indexes in the respective periods. Thus, the growth of output per efficiency unit of labor is

$$\frac{\hat{y}_c}{\hat{y}_b} = \frac{e_c \cdot \overline{y}_c(\widehat{KF}_c, \widehat{KD}_c)}{e_b \cdot \overline{y}_b(\widehat{KF}_b, \widehat{KD}_b)}. \qquad (3)$$

Denote $\overline{y}_b(\widehat{KF}_c, \widehat{KD}_c)$ to be the potential output per efficiency unit of labor at current capital intensity using the base-period technology and $\overline{y}_c(\widehat{KF}_b, \widehat{KD}_b)$ to be the potential output per efficiency unit of labor at base-period capital intensity using the current technology. Define $\widetilde{KF}_c = \frac{KF_c}{H_b L_c}$ as the counterfactual ratio of current-period foreign capital to labor measured in efficiency units assuming human capital were still at its base-period level, and similarly, $\widetilde{KF}_b = \frac{KF_b}{H_c L_b}$ as the counterfactual ratio of base-period foreign capital to efficient unites of labor units assuming human capital equals its current-period level. Similarly, we have the group of ratios for domestic capital: $\widetilde{KD}_c = \frac{KD_c}{H_b L_c}$ and $\widetilde{KD}_b = \frac{KD_b}{H_c L_b}$. Let $\overline{y}_b(\widetilde{KF}_c, \widetilde{KD}_c)$ be potential output per efficiency unit of labor at $\widetilde{KF}_c$ and $\widetilde{KD}_c$ using base-period technologies, and similarly, $\overline{y}_c(\widetilde{KF}_b, \widetilde{KD}_b)$ to be potential output per efficiency unit of labor at $\widetilde{KF}_b$ and $\widetilde{KD}_b$ using current technologies. Multiplying the top and bottom of (3) by $\overline{y}_b(\widetilde{KF}_c, \widetilde{KD}_c)\overline{y}_b(\widehat{KF}_b, \widetilde{KD}_c)\overline{y}_b(\widehat{KF}_c, \widehat{KD}_c)$ decomposes the growth of $\hat{y}$ to

$$\frac{y_c}{y_b} = \frac{e_c}{e_b} \cdot \frac{\overline{y}_c(\widehat{KF}_c, \widehat{KD}_c)}{\overline{y}_b(\widehat{KF}_c, \widehat{KD}_c)} \cdot \frac{\overline{y}_b(\tilde{K}F_c, \tilde{K}D_c)}{\overline{y}_b(\widehat{KF}_b, \widetilde{KD}_c)} \cdot \frac{\overline{y}_b(\widehat{KF}_b, \widetilde{KD}_c)}{\overline{y}_b(\widehat{KF}_b, \widehat{KD}_b)} \cdot \frac{\overline{y}_b(\widehat{KF}_c, \widehat{KD}_c)}{\overline{y}_b(\tilde{K}F_c, \tilde{K}D_c)}. \tag{4}$$

Multiplying the top and bottom of (3) by $\overline{y}_c(\widetilde{KF}_b, \widetilde{KD}_b)\overline{y}_c(\widehat{KF}_c, \widetilde{KD}_b)\overline{y}_c(\widehat{KF}_b, \widehat{KD}_b)$ yields an alternative decomposition:

$$\frac{y_c}{y_b} = \frac{e_c}{e_b} \cdot \frac{\overline{y}_c(\hat{K}F_b, \hat{K}D_b)}{\overline{y}_b(\hat{K}F_b, \hat{K}D_b)} \cdot \frac{\overline{y}_c(\tilde{K}F_c, \tilde{K}D_b)}{\overline{y}_c(\hat{K}F_b, \tilde{K}D_b)} \cdot \frac{\overline{y}_c(\hat{K}F_c, \tilde{K}D_c)}{\overline{y}_c(\hat{K}F_c, \hat{K}D_b)} \cdot \frac{\overline{y}_c(\hat{K}F_b, \hat{K}D_b)}{\overline{y}_c(\tilde{K}F_b, \tilde{K}D_b)} \tag{5}$$

By definition, $\hat{y}_t = Y_t/\hat{L}_t = Y_t/(H_t L_t) = (Y_t/L_t)/H_t = y_t/H_t$. The growth of labor productivity can be decomposed as

$$\frac{y_c}{y_b} = \frac{H_c}{H_b} \cdot \frac{\hat{y}_c}{\hat{y}_b}. \tag{6}$$

Combining (4) and (6), we get the pent-partite decomposition of the labor productivity:

$$\begin{aligned} \frac{y_c}{y_b} &= \frac{e_c}{e_b} \cdot \frac{\overline{y}_c(\hat{K}F_c, \hat{K}D_c)}{\overline{y}_b(\hat{K}F_c, \hat{K}D_c)} \cdot \frac{\overline{y}_b(\tilde{K}F_c, \tilde{K}D_c)}{\overline{y}_b(\hat{K}F_b, \tilde{K}D_c)} \cdot \frac{\overline{y}_b(\hat{K}F_b, \tilde{K}D_c)}{\overline{y}_b(\hat{K}F_b, \hat{K}D_b)} \cdot \left[\frac{\overline{y}_b(\hat{K}F_c, \hat{K}D_c)}{\overline{y}_b(\tilde{K}F_c, \tilde{K}D_c)} \cdot \frac{H_c}{H_b}\right] \\ &=: EFF \times TECH^c \times KFACC^b \times KDACC^b \times HACC^b. \end{aligned} \tag{7}$$

Similarly, combining (5) and (6) yields alternative pent-partite decomposition:

$$\begin{aligned} \frac{y_c}{y_b} &= \frac{e_c}{e_b} \cdot \frac{\overline{y}_c(\hat{K}F_b, \hat{K}D_b)}{\overline{y}_b(\hat{K}F_b, \hat{K}D_b)} \cdot \frac{\overline{y}_c(\tilde{K}F_c, \tilde{K}D_b)}{\overline{y}_c(\hat{K}F_b, \tilde{K}D_b)} \cdot \frac{\overline{y}_c(\hat{K}F_c, \tilde{K}D_c)}{\overline{y}_c(\hat{K}F_c, \hat{K}D_b)} \cdot \left[\frac{\overline{y}_c(\hat{K}F_b, \hat{K}D_b)}{\overline{y}_c(\tilde{K}F_b, \tilde{K}D_b)} \cdot \frac{H_c}{H_b}\right] \\ &=: EFF \times TECH^b \times KFACC^c \times KDACC^c \times HACC^c \end{aligned} \tag{8}$$

Comparing (7) with (8), we find that the two decompositions do not necessary yield the same result. The choice between (7) and (8) is indeed arbitrary, unless technological change is Hicks neutral, in which case the proportional vertical shift in the frontier is path independent. Solow (1957) employs the assumption of Hicks neutrality in his decomposition of productivity growth into components attributable to technological change and capital deepening. However, Hicks neutrality is a strong assumption, and technological change is not neutral in general. Following KR and HR, the ambiguity is resolved by adopting the "Fisher ideal" decomposition, which is used in earlier works of Caves et al. (1982) and Färe et al. (1994). The "Fisher ideal" approach is taking geometric averages of the two measures for each growth-accounting component. Multiplying both sides of (7) and (8) together and taking the square root yields

$$\begin{aligned} \frac{y_c}{y_b} &= EFF \times (TECH^b \times TECH^c)^{1/2} \times (KFACC^b \times KFACC^c)^{1/2} \\ &\quad \times (KDACC^b \times KDACC^c)^{1/2} \times (HACC^b \times HACC^c)^{1/2} \\ &=: EFF \times TECH \times KFACC \times KDACC \times HACC \end{aligned} \tag{9}$$

Thus, the growth of labor productivity between the base period and the current period is decomposed into: (I) the change in efficiency (EFF); (II) technological change ($TECH$); (III) the change of the ratio of foreign capital to other physical and human capitals ($KFACC$); (IV) the change of the ratio of domestic capital to other physical and human capitals ($KDACC$); and (V) the change of the ratio of human capital to physical capitals ($HACC$). (I) represents the change in the distance from the production frontier, (II) stands for the shift in the frontier, and (III) to (V) represent movements along the frontier. (III) deserves special attention in our study, as it separates the effect of foreign capital on the productivity growth from the other factors.

2.3 Construction of Counterfactual Potential Outputs

The calculations of shifts in the world production frontier (TECH) and movement along the frontier ($KACC$ and $HACC$) are handy in KR and HR. In these studies, the production frontiers can be reduced to $y - k$ (or $\hat{y} - \hat{k}$) space under the assumptions of constant returns to scale and labor augmentation of human capital. The empirically estimated world production frontier is always piecewise linear with kinks at efficient points. The piecewise linear function can be estimated after identifying all the efficient points in the sample data. This step is crucial to the decomposition calculation, which then is used to compute potential output levels given some counterfactual input combinations. However, this approach is impracticable in higher dimensional input-out space due to the difficulty of parameterizing the empirical production frontiers.

In our reduced model, after normalizing the labor into efficiency units, there are still two inputs ($\hat{kf}$ and $\hat{kd}$) and one output ($\hat{y}$), so that potential outputs must be constructed in a 3-D input-output space. Our approach to calculating the counterfactual potential outputs, which requires no direct estimation of the empirical production frontiers is as follows. Given any counterfactual input combination $\hat{kf}'_{jt}$ and $\hat{kd}'_{jt}$, the efficient output level $\overline{y}_{jt}(\hat{kf}'_{jt}, \hat{kd}'_{jt})$ on the frontier of technology $\mathcal{T}_t$ can be obtained by solving the following linear program:

$$\begin{aligned} \max_{\hat{y}'_{jt}, z_{11}, \ldots, z_{Jt}} \hat{y}'_{jt} \quad subject\ to\ \hat{y}'_{jt} &\leq \sum_{\tau \leq t} \sum_{j} z_{j\tau} \hat{y}_{j\tau}, \\ \hat{kf}'_{jt} &\geq \sum_{\tau \leq t} \sum_{j} z_{j\tau} \hat{kf}_{j\tau}, \\ \hat{kd}'_{jt} &\geq \sum_{\tau \leq t} \sum_{j} z_{j\tau} \hat{kd}_{j\tau}, \\ \sum_{\tau \leq t} \sum_{j} z_{j\tau} &\leq 1, \ \forall\, j, \tau. \end{aligned} \tag{10}$$

This linear programming construction can be easily extended to technologies with any dimensionality of inputs. If the input has only one dimension in reduced form, we can still use this approach to locate any (counterfactual) efficient point on the empirical production frontier, and the results would be the same as those of KR and HR.

3 Data

The panel data of FDI stocks are derived from the annual World Investment Report by the United Nations Conference on Trade and Development (UNCTAD). Our period of interest is 1980-2005, during which FDI experienced striking expansion. The raw data are measured in current US Dollars, which are subject to great volatility due to variations in exchange rates. For better intercountry comparisons, we convert raw data to be those measured in purchasing-power-parity (PPP) adjusted international dollars. The pricing index employed in the conversion is Price Level of Investment (PI) from the Penn World Table (PWT)(version 6.3), which is defined as the PPP over investment divided by the exchange rate times 100.

The database employed for output, aggregate investment and labor is the PWT (version 6.3) (Heston et al. (2009)), which provides a panel across 79 countries over our period of interest. The number of workers is computed as RGDPCH∗POP/RGDPWOK, where RGDPCH is per capita GDP by chain rule, POP is the population and RGDPWOK is real GDP per worker. The aggregate output in international dollars is obtained by RGDPCH∗POP. Real aggregate investment is calculated as RGDPL∗POP∗KI, where RGDPL is the real GDP by Laspeyres rule, and KI is the investment share of real GDP. The data for real aggregate investment are employed in longer period, from 1965 to 2005.

The Perpetual Inventory Method (PIM) is used to construct the domestic capital stock. We adopt a single depreciation rate (δ) of 7% as in Caselli and Feyrer (2007). Country j's initial domestic capital stock (KD_{j0}) is estimated as

$$KD_{i0} = ID_{j0}/(g+\delta),\ j = 1, \cdots, J, \tag{11}$$

where ID_0^i is country j's value of gross domestic investment flow in 1970, and g is its geometric average growth rate of gross domestic investment in the first five years that the data are available. The gross domestic investment is constructed by substracting foreign investment from aggregate investment, where the data on foreign investment flow are from UNCTAD and the data of aggregate investment are from PWT (version 6.3). As our period of interest begins in 1980, it minimizes the bias arising from the choice of the initial value of the aggregate capital stock. Country j's aggregate capital stocks in the following sample period can be obtained recursively by

$$KD_{jt} = (1-\delta)KD_{j(t-1)} + ID_{jt},\ t = 1, \cdots, T;\ j = 1, \cdots, J. \tag{12}$$

For human capital, we adopt the Cohen and Soto (2007) education data, a panel of years of schooling across 96 countries in the 1960-2010 period.[1] The calculation of return to education is based on Psacharopoulos (1994), which is adopted by Hall and Jones (1999) and HR. Denote ϵ_{jt} to be the average number of years of education of the adult population in country j at time t. Thus, the total labor in efficiency units in country j at time t can be calculated as

$$\hat{L}_{jt} = H_{jt}L_{jt} = h(\epsilon_{jt})L_{jt} = e^{\phi(\epsilon_{jt})}L_{jt}, \tag{13}$$

where $h(0) = 1$ and ϕ is a piecewise linear function intercepting the origin. Its slope is 0.134 for the first four years' education, 0.101 for the next four years' and 0.068 for all years' education above eight. The rate of return to education is the slope of the function ϕ:

$$\frac{\partial \ln h(\epsilon_{jt})}{\partial \epsilon_{jt}} = \phi'(\epsilon_{jt}). \tag{14}$$

Thus, we have constructed a panel of four input (output) variables across 79 countries, which is a good representation of the world's economy. Table 1 shows the distribution of our sample countries. Our panel data set contain 21 OECD countries, which constitute more than half of the world's real GDP and inflows of FDI. This data set also reflects the first attempt to include China in a worldwide growth-accounting panel, which has also been excluded from previous inter-country studies due to its incomplete record of foreign capital stocks.

[1] The education data were computed for the beginning of each decade from 1960 to 2000, and is accompanied by a projection for 2010.

Table 1: Sample Country Distributions

Country Group		Number	Percentage	Percentage of FDI inflows (2005)
OECD		21	26.6%	57.4%
Non OECD	Africa	27	34.2	5.3
	Asia	11	13.9	28.5
	Latin America	19	24.1	8.8

4 Empirical Results

4.1 Production Frontier and Efficiency

Constant returns to scale and labor augmentation of human capital allow us to construct the production frontiers in 3-D ($\hat{y} - \hat{kf} - \hat{kd}$) space. One merit of our model is that we allow economies to perform below the worldwide production frontier. Figure 1 superimposes the production frontier surfaces for 1980 and 2005. Thirteen countries are identified on the 1980 production frontier, while the remaining economies in the sample are inefficient and produce below their potential output levels. The first thing to note is the non-neutrality of technological change. Up to a foreign-capital-to-labor ratio of approximately 900 (Jordan in 1980) , the 1980 and 2005 production frontiers are coincident, but for higher foreign capital intensities, the 2005 frontier shifts upward dramatically. Similarly, the 2005 frontier is also coincident with frontiers in other previous years (1985-2000) at low foreign capital intensity, indicating that almost all technological change occurs at high levels of foreign capitalization. Our result emphasizes the role foreign capital plays in technological change, while the result found in HR does not further disaggregate the effect of capital input. Ireland may be the most forceful story among all the countries. It enjoys 37% improvement in efficiency from 1980 to 2005 and defines the frontier for high foreign-capital-to-labor countries in 2005. A similar finding is found in Margaritis et al. (2007) and they explain the result by Ireland's impressive performance in the high-tech manufacturing sector. FDI inflows into Ireland increase continuously throughout the 1990s, mainly to high-tech computer and pharmaceutical companies, and peaked in 2000. The decline in FDI inflows to Ireland started in 2001 due to the dot-com bubble burst, but Ireland's foreign capital stock in 2005 still ranked as the second highest in the world.

Table 2 lists the efficiency scores of each of the 79 countries in our sample for 1980 and 2005. For comparison purposes, we report the efficiency levels using our model and the HR model, respectively. Table 2 shows that efficient countries identified by HR model are nested in our model in both 1980 and 2005. The efficient economies (Greece, Mozambique, Netherlands, South Africa,

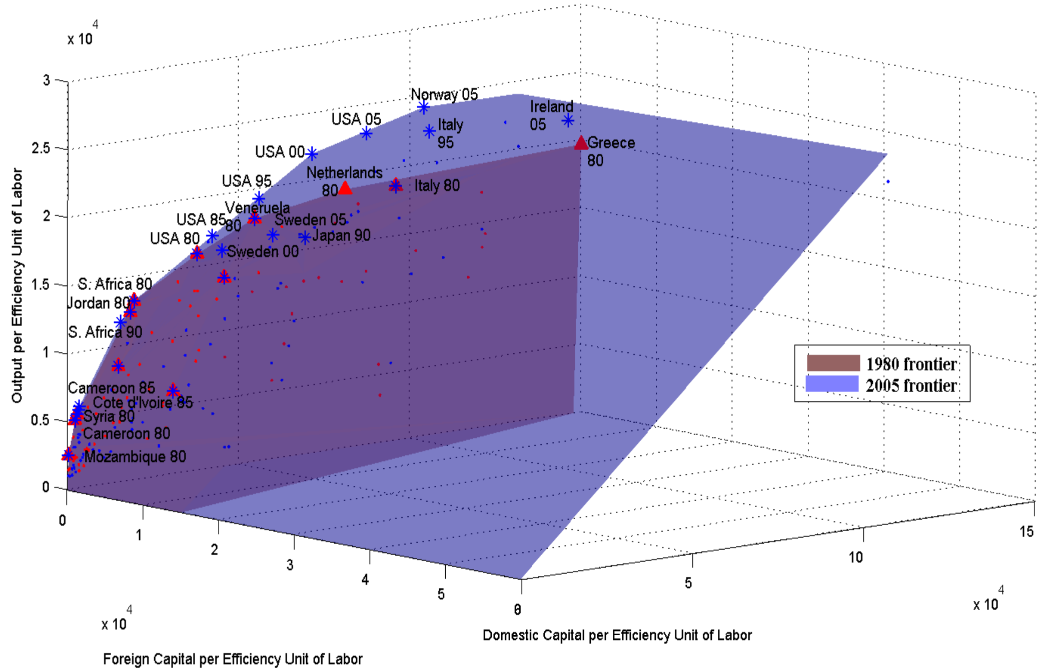


Figure 1: World Production Frontiers, 1980 and 2005

Syria, United States and Venezuela) in 1980 under the HR model are also on the empirical frontier constructed by our model, while 6 efficient countries in 1980 under our model run below the frontier constructed by HR model. A similar result is found in 2000, but the efficiency scores for 2000 with and without capital disaggregation are almost identical (up to rounding error), since the efficiencies of non-nested efficient countries in our model are very close to 1 in HR model.

Table 2: Efficiency Indexes for 79 Countries, 1980 and 2005
(Heterogeneous Vs. Homogeneous Capital)

	Heterogeneous Capital		Homogeneous Capital (HR Model)	
Country	1980	2005	1980	2005
Algeria	0.75	0.38	0.73	0.34
Angola	0.49	0.38	0.35	0.38
Argentina	1.00	0.64	0.82	0.63
Australia	0.85	0.78	0.84	0.78
Austria	0.96	0.88	0.93	0.85
Bangladesh	0.47	0.33	0.43	0.28
Brazil	0.84	0.53	0.84	0.53
Burkina Faso	0.66	0.49	0.43	0.36
Burundi	0.66	0.32	0.66	0.31

continued

TABLE 2
CONTINUED

Country	Heterogeneous Capital 1980	Heterogeneous Capital 2005	Homogeneous Capital (HR Model) 1980	Homogeneous Capital (HR Model) 2005
Cameroon	1.00	0.65	0.91	0.64
Canada	0.97	0.81	0.96	0.79
Central African Rep.	0.56	0.24	0.39	0.22
Chile	0.59	0.61	0.58	0.60
China	0.48	0.34	0.21	0.32
Colombia	1.00	0.52	0.74	0.50
Costa Rica	0.72	0.49	0.71	0.49
Côte d'Ivoire	0.92	0.67	0.80	0.67
Denmark	0.78	0.87	0.78	0.84
Ecuador	0.46	0.33	0.46	0.33
Egypt	0.70	0.74	0.63	0.71
El Salvador	0.48	0.42	0.48	0.41
Ethiopia	0.57	0.39	0.42	0.37
Fiji	0.67	0.45	0.66	0.44
Finland	0.78	0.80	0.68	0.79
France	0.93	0.90	0.93	0.89
Germany	0.77	0.78	0.77	0.78
Ghana	0.36	0.39	0.28	0.37
Greece	1.00	0.88	1.00	0.77
Guatemala	0.66	0.41	0.65	0.39
Guyana	0.19	0.11	0.18	0.10
Haiti	0.53	0.29	0.41	0.22
Honduras	1.00	0.28	0.40	0.28
India	0.92	0.43	0.36	0.34
Indonesia	0.45	0.32	0.37	0.30
Iran	0.71	0.71	0.68	0.64
Ireland	0.73	1.00	0.73	1.00
Italy	1.00	0.96	0.97	0.85
Jamaica	0.31	0.28	0.31	0.27
Japan	0.96	0.86	0.68	0.72
Jordan	1.00	0.56	0.99	0.50
Kenya	0.48	0.35	0.40	0.32
Korea, Rep. of	0.49	0.58	0.37	0.50
Madagascar	0.56	0.47	0.48	0.46
Malawi	0.27	0.32	0.24	0.29
Malaysia	0.63	0.65	0.63	0.65
Mali	0.48	0.69	0.44	0.67
Mauritius	0.88	0.99	0.62	0.95
Morocco	0.82	0.57	0.76	0.56
Mozambique	1.00	0.71	1.00	0.70
Netherlands	1.00	0.89	1.00	0.84

continued

TABLE 2
CONTINUED

Country	Heterogeneous Capital 1980	Heterogeneous Capital 2005	Homogeneous Capital (HR Model) 1980	Homogeneous Capital (HR Model) 2005
New Zealand	0.76	0.71	0.75	0.71
Nicaragua	0.32	0.17	0.32	0.17
Niger	0.45	0.39	0.37	0.33
Nigeria	0.74	0.57	0.64	0.52
Norway	0.88	1.00	0.88	1.00
Panama	0.51	0.45	0.50	0.44
Paraguay	0.82	0.38	0.67	0.38
Peru	0.53	0.35	0.51	0.34
Philippines	0.55	0.30	0.38	0.29
Portugal	0.69	0.63	0.69	0.59
Senegal	0.87	0.59	0.79	0.54
Sierra Leone	0.49	0.35	0.48	0.35
Singapore	0.75	0.92	0.75	0.92
South Africa	1.00	0.96	1.00	0.90
Spain	0.92	0.85	0.88	0.81
Sudan	0.81	0.25	0.39	0.25
Sweden	0.95	1.00	0.83	0.99
Syria	1.00	0.62	1.00	0.61
Tanzania	0.37	0.28	0.37	0.27
Thailand	0.31	0.29	0.24	0.29
Trinidad and Tobago	0.69	0.63	0.69	0.61
Tunisia	0.60	0.80	0.59	0.79
Turkey	0.60	0.55	0.54	0.54
United Kingdom	0.72	0.90	0.72	0.90
U.S.A.	1.00	1.00	1.00	0.97
Uruguay	0.71	0.56	0.66	0.55
Venezuela	1.00	0.69	1.00	0.68
Zambia	0.27	0.26	0.21	0.25
Zimbabwe	0.69	0.11	0.48	0.11
Mean	**0.70**	**0.57**	**0.63**	**0.54**

We are primarily interested in comparisons of efficiency measurement with and without the disaggregation of capital stock in the technology. Assuming that foreign capital is reasonably well measured, an improvement in efficiency when foreign and domestic capital are separated and incorporated into the measurement of efficiency indicates that some of the measured inefficiency in the HR model should have been attributed to the misspecification of capital input. A similar interpretation applies to a decrease in efficiency scores.

Table 2 reports that the mean efficiency score in 1980 is increased from 0.63 to 0.70 by the disaggregation of capital input, which suggests that a good deal of the of dispersion of 1980 efficiency in HR is attributable to misspecification of capital input. The separation of foreign and domestic capital moves economies toward the frontier, closing the gap by about 18% on average. The biggest efficiency improvements emanating from the heterogenous capital inputs in 1980 occur in the economies with foreign-capital-to-labor ratio less than 10: India, Honduras, China,Sudan, and Burkina Faso. The effect of separating capital input into the 2005 calculations is less pronounced. The average improvement in efficiency is around 5%, with the most notable move occurring in Haiti and India. Japan, with the lowest foreign capital per efficient unit of labor among OECD countries, shows substantial movement toward the empirical frontier under our model as compared to that of HR: by 40% in 1980 and by 20% in 2005.

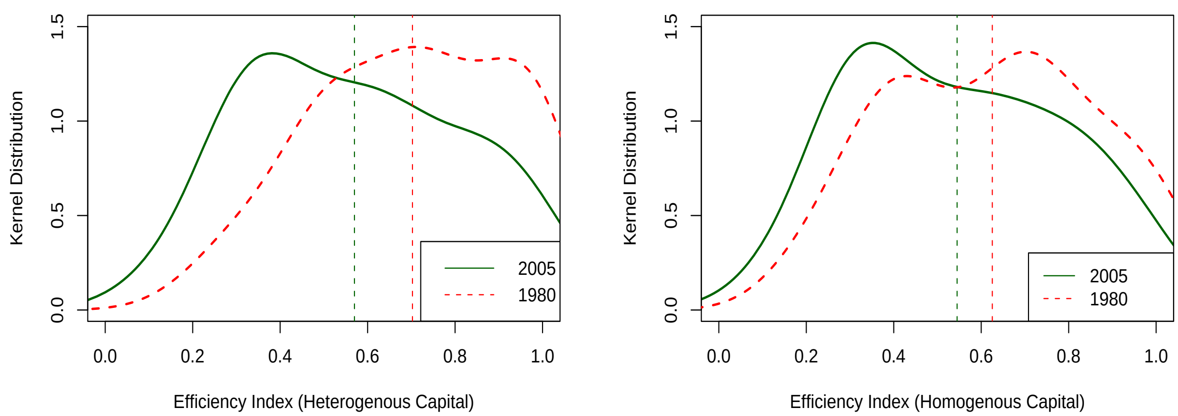


Figure 2: Distributions of Efficiency Indexes, 1980 and 2005
(Heterogeneous Vs. Homogenous Capital)

The mean efficiency index declines over time in both our model and HR model. Figure 2 plots the distributions of the efficiency index under our model in 1980 and 2005 on the left and under the HR model on the right. Both graphs suggest that the large mass in the middle of the distribution shifted away from the frontier. Such backward shifting is more prominent in our model, which is in accordance with the fact that the set of efficient economies in our model nests that in the HR model.

4.2 Pent-partite Decomposition

Table 3 shows each of the components of the relevant decomposition of productivity growth from 1980 to 2005, both with and without separation of the capital input. The first row for each country shows the country's productivity growth and the contributions to productivity growth of the five factors, efficiency change ($[EFF-1]\times 100$), technological change ($[TECH-1]\times 100$), foreign capital accumulation ($[KFACC-1]\times 100$), domestic capital accumulation ($[KDACC-1]\times 100$), and human capital accumulation ($[HACC-1]\times 100$). The second row for each country shows the contributions to productivity growth in the HR model, with foreign capital and domestic capital aggregating to total capital in the decomposition. Table 3 suggests that the ordering of average contributions is similar between HR and our model. The means of efficiency change, human capital accumulation, and human capital accumulation are not substantially different for the two models. In our heterogenous capital model, foreign capital accumulation not only is the principal driving force in the mean growth of worldwide productivity, but also contributes more than twice as much as does domestic capital accumulation on productivity growth.

Table 3: Percentage Change of Pent-partite Decomposition Indexes, 1980-2005
(Heterogeneous Vs. Homogeneous Capital)

<table>
<tr><th>Country</th><th>Productivity Change</th><th>$EFF-1$ $\times 100$</th><th>$TECH-1$ $\times 100$</th><th>$KFACC-1$ $\times 100$</th><th>$KDACC-1$ $\times 100$</th><th>$HACC-1$ $\times 100$</th></tr>
<tr><td>Algeria</td><td>-26.3%</td><td>-49.3</td><td>2.6</td><td>4.4</td><td>3.4</td><td>40.4</td></tr>
<tr><td></td><td></td><td>-53.4</td><td>27.2</td><td colspan="2">-8.2</td><td>35.5</td></tr>
<tr><td>Angola</td><td>45.4</td><td>-22.2</td><td>3.8</td><td>49.9</td><td>7.0</td><td>12.2</td></tr>
<tr><td></td><td></td><td>9.1</td><td>5.4</td><td colspan="2">9.5</td><td>15.5</td></tr>
<tr><td>Argentina</td><td>-10.4</td><td>-36.3</td><td>5.3</td><td>33.8</td><td>-3.8</td><td>3.7</td></tr>
<tr><td></td><td></td><td>-23.7</td><td>11.1</td><td colspan="2">0.1</td><td>5.5</td></tr>
<tr><td>Australia</td><td>51.8</td><td>-7.5</td><td>15.2</td><td>5.7</td><td>26.7</td><td>6.2</td></tr>
<tr><td></td><td></td><td>-7.4</td><td>16.8</td><td colspan="2">31.9</td><td>6.4</td></tr>
<tr><td>Austria</td><td>35.4</td><td>-8.0</td><td>14.7</td><td>15.1</td><td>0.9</td><td>10.4</td></tr>
<tr><td></td><td></td><td>-8.7</td><td>31.0</td><td colspan="2">4.3</td><td>8.5</td></tr>
<tr><td>Bangladesh</td><td>41.2</td><td>-30.9</td><td>2.4</td><td>8.8</td><td>62.4</td><td>13.0</td></tr>
<tr><td></td><td></td><td>-33.1</td><td>0.4</td><td colspan="2">89.4</td><td>11.1</td></tr>
<tr><td>Brazil</td><td>-22.2</td><td>-36.5</td><td>1.9</td><td>4.2</td><td>-8.4</td><td>25.9</td></tr>
<tr><td></td><td></td><td>-36.4</td><td>5.0</td><td colspan="2">7.3</td><td>25.7</td></tr>
<tr><td>Burkina Faso</td><td>32.6</td><td>-25.6</td><td>0.0</td><td>36.3</td><td>21.2</td><td>7.9</td></tr>
<tr><td></td><td></td><td>-15.0</td><td>0.2</td><td colspan="2">45.8</td><td>6.7</td></tr>
<tr><td>Burundi</td><td>-21.5</td><td>-52.3</td><td>0.0</td><td>10.7</td><td>41.5</td><td>4.9</td></tr>
<tr><td></td><td></td><td>-53.9</td><td>0.0</td><td colspan="2">63.1</td><td>4.3</td></tr>
<tr><td>Cameroon</td><td>-8.2</td><td>-35.1</td><td>1.8</td><td>13.4</td><td>9.2</td><td>12.3</td></tr>
<tr><td></td><td></td><td>-29.6</td><td>0.1</td><td colspan="2">15.4</td><td>13.0</td></tr>
<tr><td>Canada</td><td>43.8</td><td>-17.0</td><td>14.2</td><td>3.2</td><td>34.5</td><td>9.2</td></tr>
<tr><td></td><td></td><td>-17.6</td><td>14.4</td><td colspan="2">40.1</td><td>8.8</td></tr>
<tr><td>Central African</td><td>-32.2</td><td>-56.8</td><td>0.4</td><td>36.4</td><td>0.2</td><td>14.2</td></tr>
<tr><td>Republic</td><td></td><td>-42.7</td><td>0.1</td><td colspan="2">1.1</td><td>16.8</td></tr>
<tr><td>Chile</td><td>73.6</td><td>4.1</td><td>15.8</td><td>4.9</td><td>25.9</td><td>9.1</td></tr>
<tr><td></td><td></td><td>3.2</td><td>16.2</td><td colspan="2">32.7</td><td>9.1</td></tr>
</table>

continued

TABLE 3
CONTINUED

Country	Productivity Change	$EFF - 1$ ×100	$TECH - 1$ ×100	$KFACC - 1$ ×100	$KDACC - 1$ ×100	$HACC - 1$ ×100
China	393.8	-29.8	0.7	285.4	59.9	13.3
		50.3	3.9	173.0		15.9
Colombia	-8.7	-48.4	0.0	39.2	12.7	12.8
		-32.6	0.8	19.5		12.4
Costa Rica	4.3	-31.9	11.7	4.3	11.2	18.2
		-31.8	16.1	13.1		16.5
Côte d'Ivoire	-11.4	-27.4	2.8	13.3	-11.5	18.3
		-16.6	0.3	-11.1		19.1
Denmark	66.6	11.3	10.8	8.7	16.5	6.6
		8.1	13.6	26.5		7.3
Ecuador	-26.3	-27.7	3.3	4.1	-18.4	16.1
		-28.5	12.1	-18.6		13.1
Egypt	112.9	5.5	5.0	17.2	30.6	25.6
		13.5	0.8	47.9		25.8
El Salvador	0.3	-13.2	3.3	12.9	-9.2	9.2
		-14.0	9.5	-5.1		12.3
Ethiopia	-16.8	-31.6	0.0	17.1	-7.9	12.8
		-12.5	0.0	-12.6		8.8
Fiji	1.0	-32.2	0.6	2.2	30.3	11.1
		-33.1	0.5	34.5		11.6
Finland	71.4	2.9	14.2	26.9	3.5	11.1
		16.5	21.9	9.3		10.4
France	41.2	-3.4	14.5	10.5	6.2	8.7
		-4.2	22.4	11.4		8.2
Germany	33.3	0.2	10.5	7.6	4.6	7.0
		0.2	16.9	7.3		6.1
Ghana	13.8	9.8	0.0	15.5	-15.1	5.5
		28.7	0.1	-17.3		6.7
Greece	23.2	-12.1	12.8	6.9	-0.8	17.1
		-22.9	37.0	-1.4		18.3
Guatemala	-11.0	-37.3	8.9	5.7	0.0	23.3
		-39.7	22.5	0.7		19.7
Guyana	-34.0	-44.0	5.4	11.2	-13.3	16.0
		-42.9	21.7	-15.4		12.2
Haiti	-31.4	-45.8	0.4	3.6	7.2	13.6
		-45.5	0.9	12.1		11.3
Honduras	-9.6	-71.6	3.4	173.0	5.3	7.1
		-32.1	7.8	12.9		9.4
India	123.9	-53.0	1.5	227.3	25.6	14.2
		-3.9	0.4	92.0		20.9
Indonesia	72.2	-29.1	5.4	19.0	59.7	21.2
		-18.1	1.3	63.7		26.8

continued

TABLE 3
CONTINUED

<table>
<tr><th>Country</th><th>Productivity Change</th><th>$EFF - 1$ ×100</th><th>$TECH - 1$ ×100</th><th>$KFACC - 1$ ×100</th><th>$KDACC - 1$ ×100</th><th>$HACC - 1$ ×100</th></tr>
<tr><td>Iran</td><td>39.7</td><td>0.5</td><td>0.4</td><td>1.6</td><td>-4.0</td><td>42.1</td></tr>
<tr><td></td><td></td><td>-6.1</td><td>24.9</td><td colspan="2">-12.2</td><td>35.5</td></tr>
<tr><td>Ireland</td><td>111.9</td><td>36.9</td><td>38.8</td><td>1.7</td><td>2.2</td><td>7.3</td></tr>
<tr><td></td><td></td><td>37.8</td><td>37.6</td><td colspan="2">3.5</td><td>8.0</td></tr>
<tr><td>Italy</td><td>45.7</td><td>-3.7</td><td>10.4</td><td>16.8</td><td>0.2</td><td>17.1</td></tr>
<tr><td></td><td></td><td>-12.5</td><td>36.8</td><td colspan="2">6.8</td><td>14.0</td></tr>
<tr><td>Jamaica</td><td>30.0</td><td>-10.2</td><td>19.1</td><td>8.2</td><td>0.4</td><td>12.0</td></tr>
<tr><td></td><td></td><td>-13.6</td><td>31.7</td><td colspan="2">2.9</td><td>11.0</td></tr>
<tr><td>Japan</td><td>46.7</td><td>-9.7</td><td>2.0</td><td>47.6</td><td>1.2</td><td>6.7</td></tr>
<tr><td></td><td></td><td>5.3</td><td>23.0</td><td colspan="2">5.1</td><td>7.8</td></tr>
<tr><td>Jordan</td><td>-43.1</td><td>-43.9</td><td>0.0</td><td>0.0</td><td>-6.8</td><td>8.9</td></tr>
<tr><td></td><td></td><td>-49.7</td><td>0.7</td><td colspan="2">4.0</td><td>8.2</td></tr>
<tr><td>Kenya</td><td>-6.8</td><td>-27.4</td><td>1.8</td><td>8.6</td><td>-1.8</td><td>18.1</td></tr>
<tr><td></td><td></td><td>-18.8</td><td>0.3</td><td colspan="2">-2.1</td><td>16.9</td></tr>
<tr><td>Korea, Rep. of</td><td>209.5</td><td>18.4</td><td>8.9</td><td>40.7</td><td>47.6</td><td>15.5</td></tr>
<tr><td></td><td></td><td>35.6</td><td>20.4</td><td colspan="2">60.0</td><td>18.5</td></tr>
<tr><td>Madagascar</td><td>-14.0</td><td>-15.6</td><td>0.0</td><td>4.5</td><td>-14.4</td><td>13.9</td></tr>
<tr><td></td><td></td><td>-4.3</td><td>0.0</td><td colspan="2">-19.7</td><td>11.9</td></tr>
<tr><td>Malawi</td><td>29.7</td><td>17.7</td><td>0.6</td><td>4.3</td><td>-14.4</td><td>22.7</td></tr>
<tr><td></td><td></td><td>23.6</td><td>0.2</td><td colspan="2">-14.7</td><td>22.8</td></tr>
<tr><td>Malaysia</td><td>133.2</td><td>3.4</td><td>8.5</td><td>0.6</td><td>71.6</td><td>20.4</td></tr>
<tr><td></td><td></td><td>3.5</td><td>7.8</td><td colspan="2">73.4</td><td>20.5</td></tr>
<tr><td>Mali</td><td>79.0</td><td>41.6</td><td>2.0</td><td>6.7</td><td>10.7</td><td>4.9</td></tr>
<tr><td></td><td></td><td>53.5</td><td>0.1</td><td colspan="2">11.1</td><td>4.9</td></tr>
<tr><td>Mauritius</td><td>146.2</td><td>12.4</td><td>2.9</td><td>31.3</td><td>43.8</td><td>12.8</td></tr>
<tr><td></td><td></td><td>53.2</td><td>5.5</td><td colspan="2">33.3</td><td>14.2</td></tr>
<tr><td>Morocco</td><td>7.4</td><td>-30.8</td><td>4.7</td><td>4.4</td><td>15.2</td><td>23.3</td></tr>
<tr><td></td><td></td><td>-25.9</td><td>3.5</td><td colspan="2">13.2</td><td>23.7</td></tr>
<tr><td>Mozambique</td><td>46.2</td><td>-29.3</td><td>0.0</td><td>38.7</td><td>43.8</td><td>3.7</td></tr>
<tr><td></td><td></td><td>-30.3</td><td>0.0</td><td colspan="2">102.8</td><td>3.3</td></tr>
<tr><td>Netherlands</td><td>13.6</td><td>-11.2</td><td>15.9</td><td>11.0</td><td>-7.3</td><td>7.3</td></tr>
<tr><td></td><td></td><td>-15.5</td><td>25.4</td><td colspan="2">0.5</td><td>6.7</td></tr>
<tr><td>New Zealand</td><td>26.1</td><td>-6.0</td><td>11.7</td><td>6.6</td><td>4.8</td><td>7.4</td></tr>
<tr><td></td><td></td><td>-6.1</td><td>11.9</td><td colspan="2">11.2</td><td>7.9</td></tr>
<tr><td>Nicaragua</td><td>-43.3</td><td>-46.5</td><td>2.4</td><td>8.2</td><td>-21.0</td><td>21.2</td></tr>
<tr><td></td><td></td><td>-46.8</td><td>10.1</td><td colspan="2">-18.6</td><td>19.0</td></tr>
<tr><td>Niger</td><td>-20.8</td><td>-13.7</td><td>0.5</td><td>-4.2</td><td>-10.5</td><td>6.7</td></tr>
<tr><td></td><td></td><td>-10.8</td><td>0.5</td><td colspan="2">-16.6</td><td>6.1</td></tr>
<tr><td>Nigeria</td><td>15.7</td><td>-22.0</td><td>0.1</td><td>18.4</td><td>-4.0</td><td>30.3</td></tr>
<tr><td></td><td></td><td>-17.6</td><td>0.3</td><td colspan="2">10.4</td><td>26.7</td></tr>
<tr><td>Norway</td><td>72.1</td><td>13.1</td><td>20.5</td><td>9.1</td><td>5.6</td><td>9.6</td></tr>
<tr><td></td><td></td><td>13.2</td><td>29.7</td><td colspan="2">7.7</td><td>8.9</td></tr>
</table>

continued

TABLE 3
CONTINUED

<table>
<tr><th>Country</th><th>Productivity
Change</th><th>$EFF-1$
×100</th><th>$TECH-1$
×100</th><th>$KFACC-1$
×100</th><th>$KDACC-1$
×100</th><th>$HACC-1$
×100</th></tr>
<tr><td>Panama</td><td>13.0</td><td>-11.1</td><td>3.9</td><td>0.0</td><td>10.8</td><td>10.3</td></tr>
<tr><td></td><td></td><td>-12.9</td><td>3.1</td><td colspan="2">12.7</td><td>11.6</td></tr>
<tr><td>Paraguay</td><td>-24.0</td><td>-53.5</td><td>5.1</td><td>22.1</td><td>18.6</td><td>7.5</td></tr>
<tr><td></td><td></td><td>-43.3</td><td>0.9</td><td colspan="2">24.1</td><td>7.0</td></tr>
<tr><td>Peru</td><td>-33.0</td><td>-34.7</td><td>0.1</td><td>20.5</td><td>-22.6</td><td>10.0</td></tr>
<tr><td></td><td></td><td>-32.2</td><td>4.6</td><td colspan="2">-16.4</td><td>13.0</td></tr>
<tr><td>Philippines</td><td>3.3</td><td>-45.7</td><td>2.5</td><td>45.6</td><td>17.5</td><td>8.6</td></tr>
<tr><td></td><td></td><td>-23.6</td><td>0.5</td><td colspan="2">20.8</td><td>11.4</td></tr>
<tr><td>Portugal</td><td>49.7</td><td>-8.6</td><td>17.1</td><td>10.1</td><td>8.6</td><td>17.0</td></tr>
<tr><td></td><td></td><td>-13.6</td><td>31.3</td><td colspan="2">15.1</td><td>14.6</td></tr>
<tr><td>Senegal</td><td>-2.5</td><td>-31.2</td><td>0.3</td><td>1.1</td><td>24.2</td><td>12.7</td></tr>
<tr><td></td><td></td><td>-31.1</td><td>0.0</td><td colspan="2">26.2</td><td>12.2</td></tr>
<tr><td>Sierra Leone</td><td>-37.6</td><td>-29.4</td><td>3.5</td><td>-0.3</td><td>-23.2</td><td>11.5</td></tr>
<tr><td></td><td></td><td>-27.3</td><td>0.8</td><td colspan="2">-24.0</td><td>12.0</td></tr>
<tr><td>Singapore</td><td>152.1</td><td>23.5</td><td>30.6</td><td>4.5</td><td>8.0</td><td>38.5</td></tr>
<tr><td></td><td></td><td>23.6</td><td>36.1</td><td colspan="2">11.1</td><td>34.8</td></tr>
<tr><td>South Africa</td><td>4.5</td><td>-3.8</td><td>0.0</td><td>0.1</td><td>-2.8</td><td>11.6</td></tr>
<tr><td></td><td></td><td>-10.3</td><td>0.5</td><td colspan="2">2.6</td><td>12.9</td></tr>
<tr><td>Spain</td><td>50.6</td><td>-7.8</td><td>15.2</td><td>20.6</td><td>0.0</td><td>17.5</td></tr>
<tr><td></td><td></td><td>-8.4</td><td>38.6</td><td colspan="2">1.7</td><td>16.7</td></tr>
<tr><td>Sudan</td><td>73.3</td><td>-69.1</td><td>4.3</td><td>214.7</td><td>58.7</td><td>7.8</td></tr>
<tr><td></td><td></td><td>-37.1</td><td>5.1</td><td colspan="2">142.6</td><td>8.1</td></tr>
<tr><td>Sweden</td><td>58.9</td><td>5.0</td><td>9.7</td><td>22.9</td><td>7.7</td><td>4.1</td></tr>
<tr><td></td><td></td><td>18.8</td><td>9.4</td><td colspan="2">16.5</td><td>5.0</td></tr>
<tr><td>Syria</td><td>-14.2</td><td>-38.3</td><td>0.0</td><td>0.1</td><td>17.2</td><td>18.5</td></tr>
<tr><td></td><td></td><td>-39.1</td><td>0.0</td><td colspan="2">18.6</td><td>18.7</td></tr>
<tr><td>Tanzania</td><td>28.2</td><td>-24.5</td><td>0.0</td><td>7.0</td><td>41.2</td><td>12.3</td></tr>
<tr><td></td><td></td><td>-25.2</td><td>0.0</td><td colspan="2">54.3</td><td>11.1</td></tr>
<tr><td>Thailand</td><td>152.5</td><td>-4.7</td><td>6.9</td><td>38.3</td><td>42.4</td><td>25.7</td></tr>
<tr><td></td><td></td><td>20.0</td><td>11.3</td><td colspan="2">43.5</td><td>31.8</td></tr>
<tr><td>Trinidad & Tobago</td><td>22.4</td><td>-8.9</td><td>22.8</td><td>7.2</td><td>-3.5</td><td>5.8</td></tr>
<tr><td></td><td></td><td>-11.4</td><td>28.5</td><td colspan="2">1.3</td><td>6.1</td></tr>
<tr><td>Tunisia</td><td>68.5</td><td>34.2</td><td>14.0</td><td>2.7</td><td>-7.6</td><td>16.1</td></tr>
<tr><td></td><td></td><td>33.9</td><td>15.0</td><td colspan="2">-4.5</td><td>14.7</td></tr>
<tr><td>Turkey</td><td>98.2</td><td>-7.9</td><td>11.0</td><td>0.6</td><td>69.1</td><td>13.9</td></tr>
<tr><td></td><td></td><td>1.1</td><td>5.2</td><td colspan="2">63.6</td><td>13.9</td></tr>
<tr><td>U.S.A.</td><td>60.5</td><td>0.0</td><td>11.4</td><td>9.5</td><td>25.7</td><td>4.7</td></tr>
<tr><td></td><td></td><td>-3.3</td><td>18.0</td><td colspan="2">32.7</td><td>5.9</td></tr>
<tr><td>United Kingdom</td><td>76.2</td><td>24.8</td><td>11.0</td><td>7.4</td><td>7.2</td><td>10.5</td></tr>
<tr><td></td><td></td><td>24.6</td><td>10.7</td><td colspan="2">15.8</td><td>10.3</td></tr>
<tr><td>Uruguay</td><td>6.9</td><td>-21.0</td><td>3.6</td><td>11.3</td><td>8.0</td><td>8.6</td></tr>
<tr><td></td><td></td><td>-16.5</td><td>6.7</td><td colspan="2">8.1</td><td>10.9</td></tr>
</table>

continued

TABLE 3
CONTINUED

<table>
<tr><th>Country</th><th>Productivity Change</th><th>$EFF - 1$ ×100</th><th>$TECH - 1$ ×100</th><th>$KFACC - 1$ ×100</th><th>$KDACC - 1$ ×100</th><th>$HACC - 1$ ×100</th></tr>
<tr><td>Venezuela</td><td>-35.8</td><td>-31.0</td><td>3.7</td><td>18.2</td><td>-25.8</td><td>2.3</td></tr>
<tr><td></td><td></td><td>-31.9</td><td>10.2</td><td colspan="2">-16.9</td><td>3.0</td></tr>
<tr><td>Zambia</td><td>-12.9</td><td>-4.3</td><td>0.0</td><td>30.9</td><td>-34.8</td><td>6.7</td></tr>
<tr><td></td><td></td><td>18.4</td><td>1.7</td><td colspan="2">-33.1</td><td>8.2</td></tr>
<tr><td>Zimbabwe</td><td>-57.1</td><td>-84.3</td><td>5.2</td><td>28.2</td><td>69.3</td><td>19.9</td></tr>
<tr><td></td><td></td><td>-78.0</td><td>5.4</td><td colspan="2">55.8</td><td>18.6</td></tr>
<tr><td>Mean</td><td>33.4</td><td>-18.2</td><td>6.7</td><td>24.4</td><td>11.2</td><td>13.6</td></tr>
<tr><td></td><td></td><td>-11.5</td><td>10.8</td><td colspan="2">18.9</td><td>13.5</td></tr>
</table>

Table 4 reports mean changes in productivity and the five growth-accounting components for seven groups of countries. The OECD and original EU formation (EU-15) countries experienced significant productivity gains, above the world average, primarily because of faster rates of technological progress and positive efficiency gains. * Japan, Korea and Singapore.

Table 4: Mean Percentage Changes of the Pent-partite Decomposition Indices
(Country Groupings)

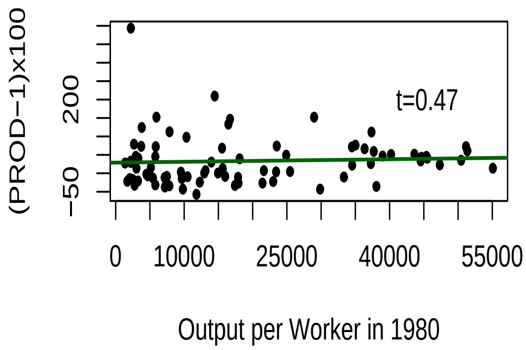
<table>
<tr><th>Country Group</th><th>Productivity Change</th><th>$EFF - 1$ ×100</th><th>$TECH - 1$ ×100</th><th>$KFACC - 1$ ×100</th><th>$KDACC - 1$ ×100</th><th>$HACC - 1$ ×100</th></tr>
<tr><td>OECD</td><td>61.3</td><td>0.5</td><td>13.8</td><td>13.8</td><td>12.6</td><td>10.2</td></tr>
<tr><td></td><td></td><td>1.9</td><td>22.5</td><td colspan="2">17.6</td><td>10.1</td></tr>
<tr><td>EU 15</td><td>52.1</td><td>2.0</td><td>15.1</td><td>12.8</td><td>3.8</td><td>10.9</td></tr>
<tr><td></td><td></td><td>1.5</td><td>25.6</td><td colspan="2">9.0</td><td>10.3</td></tr>
<tr><td>Asian Tigers*</td><td>136.1</td><td>10.7</td><td>13.8</td><td>30.9</td><td>18.9</td><td>20.3</td></tr>
<tr><td></td><td></td><td>21.5</td><td>26.5</td><td colspan="2">25.4</td><td>20.4</td></tr>
<tr><td>Non-OECD</td><td>23.3</td><td>-25.0</td><td>4.1</td><td>28.2</td><td>10.7</td><td>14.8</td></tr>
<tr><td></td><td></td><td>-16.3</td><td>6.6</td><td colspan="2">19.4</td><td>14.8</td></tr>
<tr><td>Asia</td><td>95.9</td><td>-22.6</td><td>5.3</td><td>57.4</td><td>32.1</td><td>20.4</td></tr>
<tr><td></td><td></td><td>-6.9</td><td>7.9</td><td colspan="2">52.5</td><td>21.4</td></tr>
<tr><td>Africa</td><td>16.1</td><td>-20.9</td><td>2.1</td><td>22.6</td><td>9.8</td><td>14.4</td></tr>
<tr><td></td><td></td><td>-11.3</td><td>2.7</td><td colspan="2">17.5</td><td>14.1</td></tr>
<tr><td>Latin America</td><td>-7.3</td><td>-31.9</td><td>6.3</td><td>20.7</td><td>-1.4</td><td>12.3</td></tr>
<tr><td></td><td></td><td>-28.0</td><td>11.5</td><td colspan="2">2.2</td><td>12.0</td></tr>
<tr><td>All Countries</td><td>33.4</td><td>-18.2</td><td>6.7</td><td>24.4</td><td>11.2</td><td>13.6</td></tr>
<tr><td></td><td></td><td>-11.5</td><td>10.8</td><td colspan="2">18.9</td><td>13.5</td></tr>
</table>

The miraculous growth rates of the Asian Tigers, which are more than fivefold that of the world average, are attributable primarily to predominant contributions of efficiency gains in Singapore and prominent foreign capital deepening in Japan and Korea. The neighboring Asian economies, especially China and India, also experienced large increases in productivity growth from 1980 to 2005. The HR model credits their productivity growth mostly to the aggregate capital accumulation, but the results from our model suggest that the phenomenal contribution from foreign capital accumulation overwhelms that from domestic capital accumulation. As the production frontier remained the same at low foreign-capital-to-labor ratios, the extraordinary foreign capital deepening of the remaining Asian countries moved further away from the world frontier, which led to huge falls in efficiency. Actually, the remaining Asian economies and Latin America are the two groups that suffer the biggest efficiency losses over time.

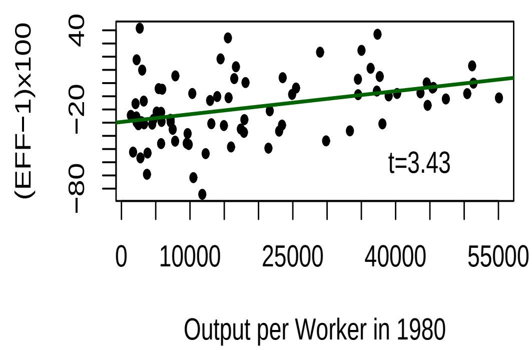
Latin America is the only group that experienced a negative average growth rate of labor productivity. The HR model explains its poor performance by the collapse in efficiency and a lack of capital accumulation. Our results concur with HR regarding the contribution of the deterioration in efficiency but finds that foreign capital accumulation is not so anemic, and in fact is close to the average over this period. It is interesting to note that domestic capital accumulation for Latin American countries was actually slightly negative, suggesting that gross domestic investment was not sufficient to replace depreciated domestic capital.

The HR model and ours both attribute the weak African performance to a lack of technological progress and big falls in efficiency but have different conclusions on the role of capital accumulation. The rate of capital accumulation is close to the world average under the HR model, while our decomposition suggests well-above-average contributions of foreign capital accumulation and a lack of domestic capital accumulation.

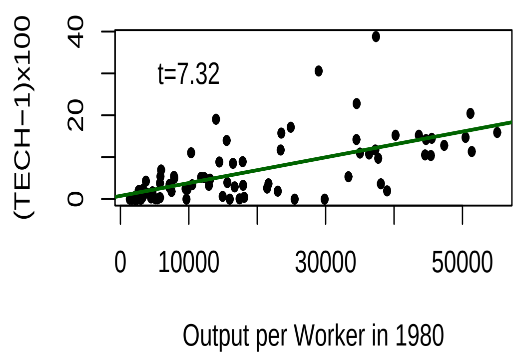
Figure 3 contains plots of the five growth rates (of labor productivity and its four components) against output per worker in 1980, along with GLS regression lines. The positive but statistically insignificant slope of the regression slope coefficient in Figure 3a suggests (at least) that there is no absolute convergence in income per worker in the world. The statistically significant positive regression slope coefficients in Figure 3b and Figure 3c indicate that relatively wealthy countries have benefited more from technological catch-up and technological change than have less-developed countries. Figure 3d reveals that, while foreign capital accumulation has contributed positively to growth for most countries, the pattern is very dissimilar to that of overall productivity growth, with some striking examples of foreign capital accumulation for low-income countries. The negative regression slope coefficient is statistically significant, indicating that the international pattern of foreign capital accumulation may have been the primary driving force to convergence. Figure 3e and Figure 3f evince a wide dispersion of contributions of domestic and human capital



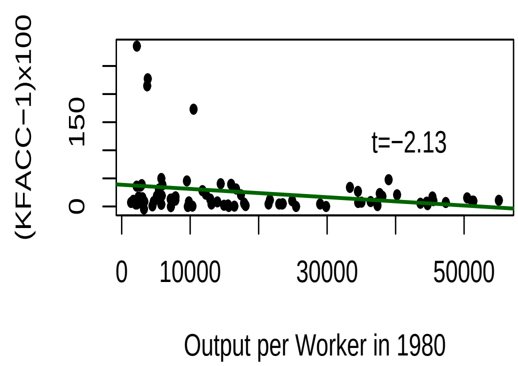
(a) Productivity Growth vs. Output per Worker



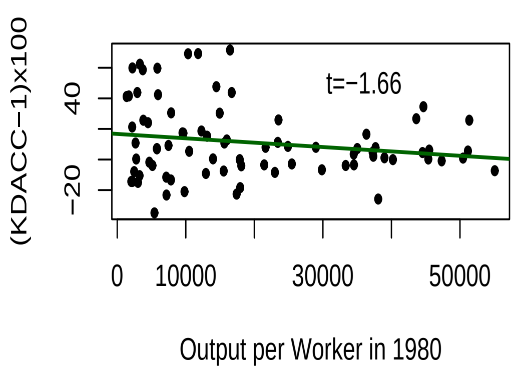
(b) Efficiency Growth vs. Output per Worker



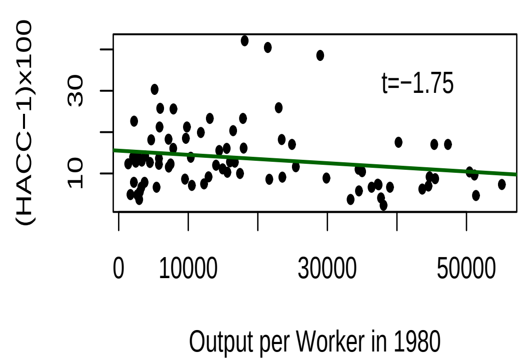
(c) Technological Growth vs. Output per Worker



(d) Foreign Capital Growth vs. Output per Worker



(e) Domestic Capital Growth vs. Output per Worker



(f) Human Capital Growth vs. Output per Worker

Figure 3: Percentage Change in Output per Worker and Five Decomposition Idexes (Plot against 1980 Output per Worker)

accumulation, but the slopes are statistically insignificant, suggesting that domestic capital and human capital deepening have done little to contribute to convergence. Each of these interpretations is based on first-moment characterizations of the productivity distribution and is therefore vulnerable to the Quah (1993, 1996, 1997) critique. Given this critique, we place more emphasis on the analysis of the distribution dynamics of labor productivity in the next sub-section.

4.3 Analysis of Productivity Distributions

Figure 4 plots the distributions of putout per worker across the 79 countries in our sample in 1980 and 2005. The dashed (solid) curve is the estimated 1980 (2005) distribution of outout per worker. One fact that emerges immediately from Figure 4 is that the distributions in both periods are bi-modal, with the ”poor mode” remaining relatively stagnant while the ”rich mode” moved further away. The ”rich mode” emerged in 1980 and became more apparent over the 25-year period. The increased distance between the two modes is consistent with the finding from Figure 4, supporting the view that relatively richer countries have grown faster than relatively poor ones.

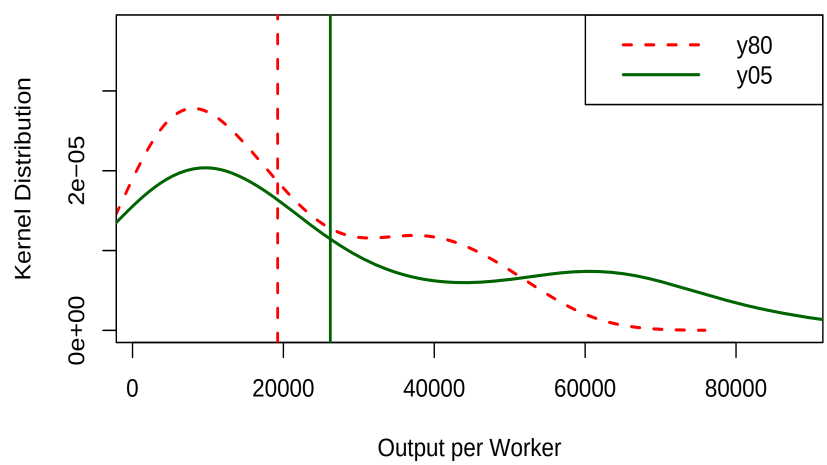


Figure 4: Distributions of Output per Worker, 1980 and 2005

We employ two statistical tests for changes in the distribution: the calibrated Silverman test for multimodality and a nonparametric test to for the statistical significance of differences between actual and counterfactual distributions. Following HR, for the latter we choose the test proposed by Li (1996) and further studied by Fan and Ullah (1999) to test the null hypothesis, $\mathbf{H}_0 : f(x) = g(x)$ for all x, against the alternative, $\mathbf{H}_1 : f(x) \neq g(x)$ for some x.

Table 5: Modality Tests (p-values)

	Null Hypothesis (H_0)	H_0: One Mode H_A: More than One Mode	Conclusion of testing H_0
1	$f(y_{80})$	0.044	Reject
2	$f(y_{05})$	0.001	Reject
3	$f(y_{80} \times EFF)$	0.003	Reject
4	$f(y_{80} \times TECH)$	0.034	Reject
5	$f(y_{80} \times KFACC)$	0.018	Reject
6	$f(y_{80} \times KDACC)$	0.762	Fail to reject
7	$f(y_{80} \times HACC)$	0.223	Fail to reject
8	$f(y_{80} \times EFF \times TECH)$	0.003	Reject
9	$f(y_{80} \times EFF \times KFACC)$	0.001	Reject
10	$f(y_{80} \times EFF \times KDACC)$	0.016	Reject
11	$f(y_{80} \times EFF \times HACC)$	0.005	Reject
12	$f(y_{80} \times TECH \times KFACC)$	0.002	Reject
13	$f(y_{80} \times TECH \times KDACC)$	0.355	Fail to reject
14	$f(y_{80} \times TECH \times HACC)$	0.587	Fail to reject
15	$f(y_{80} \times KFACC \times KDACC)$	0.148	Fail to reject
16	$f(y_{80} \times KFACC \times HACC)$	0.276	Fail to reject
17	$f(y_{80} \times KDACC \times HACC)$	0.841	Fail to reject
18	$f(y_{80} \times EFF \times TECH \times KFACC)$	0.002	Reject
19	$f(y_{80} \times EFF \times TECH \times KDACC)$	0.009	Reject
20	$f(y_{80} \times EFF \times TECH \times HACC)$	0.012	Reject
21	$f(y_{80} \times EFF \times KFACC \times KDACC)$	0.002	Reject
22	$f(y_{80} \times EFF \times KFACC \times HACC)$	0.001	Reject
23	$f(y_{80} \times EFF \times KDACC \times HACC)$	0.009	Reject
24	$f(y_{80} \times TECH \times KFACC \times KDACC)$	0.079	Fail to reject
25	$f(y_{80} \times TECH \times KFACC \times HACC)$	0.026	Reject
26	$f(y_{80} \times TECH \times KDACC \times HACC)$	0.616	Fail to reject
27	$f(y_{80} \times KFACC \times KDACC \times HACC)$	0.175	Fail to reject
28	$f(y_{80} \times EFF \times TECH \times KFACC \times KDACC)$	0.002	Reject
29	$f(y_{80} \times EFF \times TECH \times KFACC \times HACC)$	0.002	Reject
30	$f(y_{80} \times EFF \times TECH \times KDACC \times HACC)$	0.026	Reject
31	$f(y_{80} \times EFF \times KFACC \times KDACC \times HACC)$	0.000	Reject
32	$f(y_{80} \times TECH \times KFACC \times KDACC \times HACC)$	0.091	Reject

Table 5 reports the results of calibrated Silverman test for multimodality of the counterfactual distributions by successive introduction of the five growth-accounting components. The rejection of null hypothesis of the first and second tests at the 5% level, suggesting bimodality in both 1980 and 2005, is consistent with the finding from Figure 4. Note that the first test fails to reject the null hypothesis at the 1% level, indicating that the ”poor mode” had emerged but was not very apparent in 1980. Table 6 and Table 7 summarize the Fan-Li-Ullah test results for comparisons of the counterfactual distributions and the actual 1980 and 2005 distribution, respectively. The first test in each tables rejects the hypothesis that the actual 1980 and 2005 productivity distributions are identical at the 5% level, which reinforces the results of the multimodality test and reflects the significantly increased international dispersion of labor productivity.

Table 6: Distribution Hypothesis Tests
(comparison year, 2005)

	Distribution	Bootstrap p-value	Conclusion of testing H_0
1	$f(y_{05}) = g(y_{80})$	0.039	Reject
2	$f(y_{05}) = g(y_{80} \times EFF)$	0.019	Reject
3	$f(y_{05}) = g(y_{80} \times TECH)$	0.208	Fail to reject
4	$f(y_{05}) = g(y_{80} \times KFACC)$	0.065	Fail to reject
5	$f(y_{05}) = g(y_{80} \times KDACC)$	0.074	Fail to reject
6	$f(y_{05}) = g(y_{80} \times HACC)$	0.058	Fail to reject
7	$f(y_{05}) = g(y_{80} \times EFF \times TECH)$	0.027	Reject
8	$f(y_{05}) = g(y_{80} \times EFF \times KFACC)$	0.045	Reject
9	$f(y_{05}) = g(y_{80} \times EFF \times KDACC)$	0.037	Reject
10	$f(y_{05}) = g(y_{80} \times EFF \times HACC)$	0.034	Reject
11	$f(y_{05}) = g(y_{80} \times TECH \times KFACC)$	0.206	Fail to reject
12	$f(y_{05}) = g(y_{80} \times TECH \times KDACC)$	0.331	Fail to reject
13	$f(y_{05}) = g(y_{80} \times TECH \times HACC)$	0.651	Fail to reject
14	$f(y_{05}) = g(y_{80} \times KFACC \times KDACC)$	0.046	Reject
15	$f(y_{05}) = g(y_{80} \times KFACC \times HACC)$	0.082	Fail to reject
16	$f(y_{05}) = g(y_{80} \times KDACC \times HACC)$	0.058	Fail to reject
17	$f(y_{05}) = g(y_{80} \times EFF \times TECH \times KFACC)$	0.075	Fail to reject
18	$f(y_{05}) = g(y_{80} \times EFF \times TECH \times KDACC)$	0.035	Reject
19	$f(y_{05}) = g(y_{80} \times EFF \times TECH \times HACC)$	0.127	Fail to reject
20	$f(y_{05}) = g(y_{80} \times EFF \times KFACC \times KDACC)$	0.018	Reject
21	$f(y_{05}) = g(y_{80} \times EFF \times KFACC \times HACC)$	0.075	Fail to reject
22	$f(y_{05}) = g(y_{80} \times EFF \times KDACC \times HACC)$	0.034	Reject
23	$f(y_{05}) = g(y_{80} \times TECH \times KFACC \times KDACC)$	0.108	Fail to reject
24	$f(y_{05}) = g(y_{80} \times TECH \times KFACC \times HACC)$	0.126	Fail to reject
25	$f(y_{05}) = g(y_{80} \times TECH \times KDACC \times HACC)$	0.293	Fail to reject
26	$f(y_{05}) = g(y_{80} \times KFACC \times KDACC \times HACC)$	0.032	Reject
27	$f(y_{05}) = g(y_{80} \times EFF \times TECH \times KFACC \times KDACC)$	0.219	Fail to reject
28	$f(y_{05}) = g(y_{80} \times EFF \times TECH \times KFACC \times HACC)$	0.747	Fail to reject
29	$f(y_{05}) = g(y_{80} \times EFF \times TECH \times KDACC \times HACC)$	0.310	Fail to reject
30	$f(y_{05}) = g(y_{80} \times EFF \times KFACC \times KDACC \times HACC)$	0.069	Fail to reject
31	$f(y_{05}) = g(y_{80} \times TECH \times KFACC \times KDACC \times HACC)$	0.044	Reject

Table 7: Distribution Hypothesis Tests
(comparison year, 1980)

	Distribution	Bootstrap p-value	Conclusion of testing H_0
1	$f(y_{05}) = g(y_{80})$	0.039	Reject
2	$f(y_{80}) = g(y_{80} \times EFF)$	0.614	Fail to reject
3	$f(y_{80}) = g(y_{80} \times TECH)$	0.856	Fail to reject
4	$f(y_{80}) = g(y_{80} \times KFACC)$	0.453	Fail to reject
5	$f(y_{80}) = g(y_{80} \times KDACC)$	0.954	Fail to reject
6	$f(y_{80}) = g(y_{80} \times HACC)$	0.952	Fail to reject
7	$f(y_{80}) = g(y_{80} \times EFF \times TECH)$	0.183	Fail to reject
8	$f(y_{80}) = g(y_{80} \times EFF \times KFACC)$	0.597	Fail to reject
9	$f(y_{80}) = g(y_{80} \times EFF \times KDACC)$	0.720	Fail to reject
10	$f(y_{80}) = g(y_{80} \times EFF \times HACC)$	0.496	Fail to reject
11	$f(y_{80}) = g(y_{80} \times TECH \times KFACC)$	0.076	Fail to reject
12	$f(y_{80}) = g(y_{80} \times TECH \times KDACC)$	0.828	Fail to reject
13	$f(y_{80}) = g(y_{80} \times TECH \times HACC)$	0.491	Fail to reject
14	$f(y_{80}) = g(y_{80} \times KFACC \times KDACC)$	0.158	Fail to reject
15	$f(y_{80}) = g(y_{80} \times KFACC \times HACC)$	0.117	Fail to reject
16	$f(y_{80}) = g(y_{80} \times KDACC \times HACC)$	0.560	Fail to reject
17	$f(y_{80}) = g(y_{80} \times EFF \times TECH \times KFACC)$	0.075	Fail to reject
18	$f(y_{80}) = g(y_{80} \times EFF \times TECH \times KDACC)$	0.259	Fail to reject
19	$f(y_{80}) = g(y_{80} \times EFF \times TECH \times HACC)$	0.129	Fail to reject
20	$f(y_{80}) = g(y_{80} \times EFF \times KFACC \times KDACC)$	0.351	Fail to reject
21	$f(y_{80}) = g(y_{80} \times EFF \times KFACC \times HACC)$	0.106	Fail to reject
22	$f(y_{80}) = g(y_{80} \times EFF \times KDACC \times HACC)$	0.479	Fail to reject
23	$f(y_{80}) = g(y_{80} \times TECH \times KFACC \times KDACC)$	0.076	Fail to reject
24	$f(y_{80}) = g(y_{80} \times TECH \times KFACC \times HACC)$	0.026	Reject
25	$f(y_{80}) = g(y_{80} \times TECH \times KDACC \times HACC)$	0.191	Fail to reject
26	$f(y_{80}) = g(y_{80} \times KFACC \times KDACC \times HACC)$	0.042	Reject
27	$f(y_{80}) = g(y_{80} \times EFF \times TECH \times KFACC \times KDACC)$	0.065	Fail to reject
28	$f(y_{80}) = g(y_{80} \times EFF \times TECH \times KFACC \times HACC)$	0.050	Reject
29	$f(y_{80}) = g(y_{80} \times EFF \times TECH \times KDACC \times HACC)$	0.134	Fail to reject
30	$f(y_{80}) = g(y_{80} \times EFF \times KFACC \times KDACC \times HACC)$	0.050	Reject
31	$f(y_{80}) = g(y_{80} \times TECH \times KFACC \times KDACC \times HACC)$	0.022	Reject

We aim to explore the role of each of the five growth-accounting components in the transformation of the productivity distribution from 1980 to 2005. Rewrite the pent-partite decomposition of labor productivity changes in (10) as follows:

$$y_c = (EFF \times TECH \times KFACC \times KDACC \times HACC) \times y_b. \tag{15}$$

The labor productivity distribution in 2005 can be constructed by consecutively multiplying labor productivity in 1980 by each of the five factors, which allows us to isolate the effect of each component. For example, the counterfactual 2005 productivity distribution of the variable

$$y^E = EFF \times y_b \tag{16}$$

isolates the impact on the distribution of changes in efficiency only, assuming a stationary world production frontier without any movement along the frontier. This counterfactual distribution is illustrated as a dotted curve in Figure 5a, along with the actual distributions in 1980 and 2005. The moderate loss of probability mass in the middle and the gains in the at the ″poor″ mode reflect the fact that efficiency change could be responsible for the intensification of bimodality during the 25-year period. As suggested in Row 3 of Table 5, introducing efficiency change into 1980 productivity distribution leads to rejection of the null hypothesis even at the 1% level. Table 5 also shows that efficiency change is the only component that by itself leads to bimodality at the 1% level. The result of Li-Fan-Ullah test, however, summarized in row 2 of Table 6, rejects the null hypothesis that efficiency change is solely responsible for shifting the 1980 productivity distribution to that of 2005.

The counterfactual 2005 productivity distribution of the variable

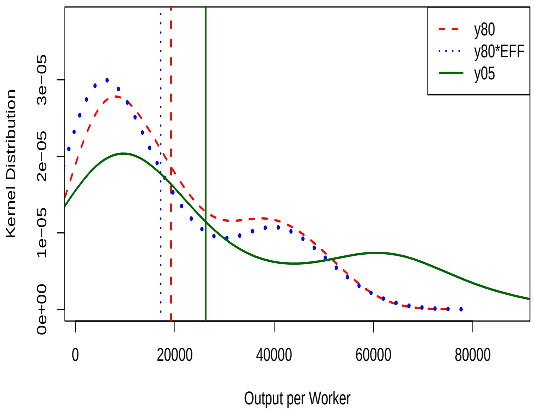
$$y^{ET} = (EFF \times TECH) \times y_b = TECH \times y^E \tag{17}$$

isolates the effect of efficiency and technology changes on productivity distribution, assuming no movement along the frontier. Figure 5b illustrates that neither the distribution nor the mean of the distribution is obviously affected by the introduction of technology change, which reinforces the result from Table 3 that technological change contributes little to the mean productivity growth. The results of the Li-Fan-Ullah test, presented in row 7 of Table 6 and Table 7, also suggest that technological change has little effect on the move of the 1980 productivity distribution to that of 2005.

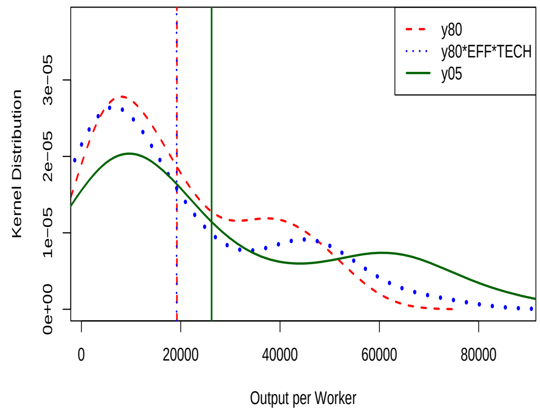
We are especially interested in the isolated impact of foreign capital deepening on the productivity distribution, obrained by examining the counterfactual distribution of the variable

$$y^{ETKF} = (EFF \times TECH \times KFACC) \times y_b = KFACC \times y^{ET}. \tag{18}$$

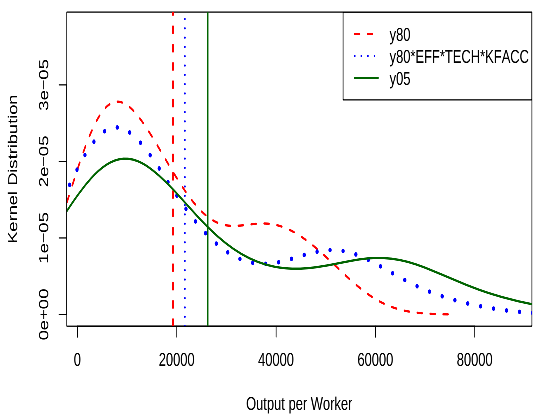
The resulting counterfactual distribution is drawn in Figure 5c. There is significant loss of probability mass at the ″poor mode″ and gains at high productivity countries, which makes the distribution very close to 2005 one. The Li-Fan-Ullah test in Row 17 of Table 6 fails to reject the null hypothesis, supporting the finding that the counterfactual distribution of y^{ETKF} and the actual 2005 distribution are similar. Note that the distribution test is rejected in Row 17 of Table 7,



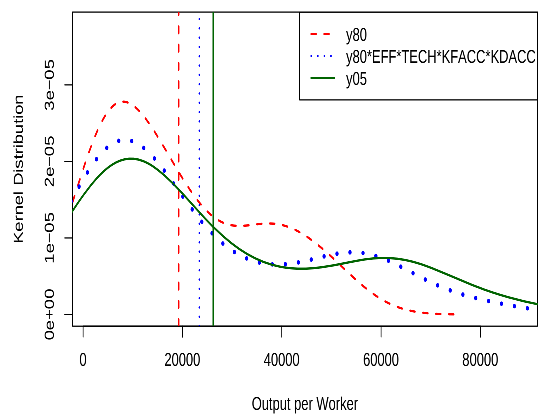
(a) Effect of Efficiency Change



(b) Effect of Technological Change



(c) Effect of Foreign Capital Deepening



(d) Effect of Domestic Capital Deepening

Figure 5: Counterfactual Distributions of Output per Worker
(sequence of introducing effects of decomposition: EFF, TECH, KFACC, and KDACC)

suggesting that the counterfactual distribution, after introducing foreign capital deepening, is still close to that of 1980, which means that supplements from other factors are needed to complete the shift.

The additional effect of domestic capital accumulation on the distribution of y^{ETKF} can be observed by successively multiplying $KDACC$:

$$y^{ETKFKD} = (EFF \times TECH \times KFACC \times KDACC) \times y_b = KDACC \times y^{ETKF}. \tag{19}$$

Figure 5d depicts the resulting counterfactual distribution, which only changes slightly. Row 27 of Table 7 also shows that Li-Fan-Ullah test fails to reject the identity of the counterfactual distribution and the 1980 distribution. Thus, the supplement from human capital accumulation is needed to complete the shift of the distribution from 1980 and 2005.

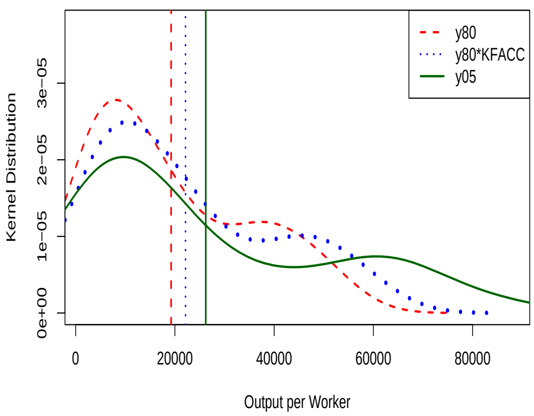
We also tried other sequencing combination. As illustrated in Figure 6–Figure 9, the results are not sensitive to changes in the sequencing order. The introduction of efficiency change always leads to international polarization. Foreign capital deepening, along with human capital accumulation, brings the 1980 productivity distribution to that of 2005. With the absence of either foreign capital deepening or human capital accumulation in the sequence, the counterfactual labor productivity distribution is significantly different from that of 2005 (or significantly close to that of 1980.)

5 Conclusion

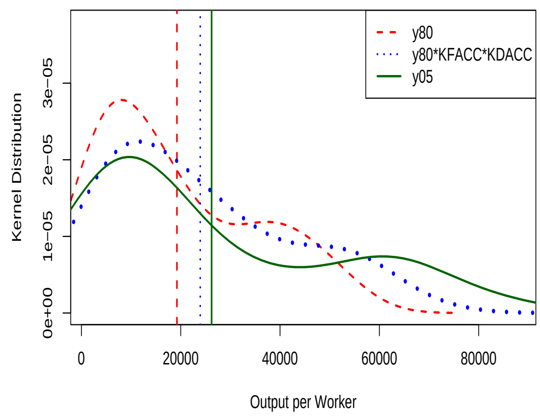
In this paper, we extend the HR decomposition of labor productivity growth by breaking physical capital accumulation into foreign direct investment and domestic investment. Thus, labor productivity growth is decomposed into components attributable to technological change, technological catch-up, foreign capital accumulation, domestic capital accumulation and human capital accumulation.

We employ the recently released PWT (version 6.3) to extend the HR panel to include data up to 2005, thus increasing the HR sample of countries by half. Our set of countries is a good representation of the world's economy, comprising developed, newly industrialized, developing, and transitional economies.

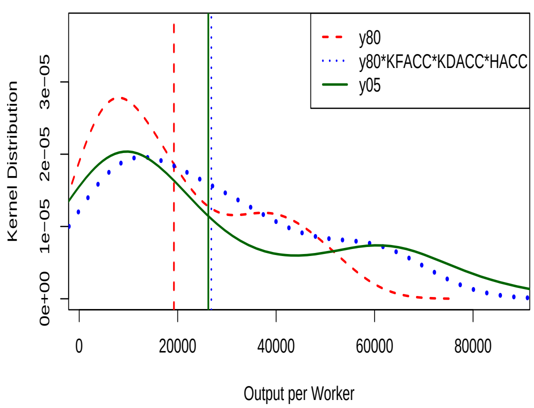
These extensions allow us to uncover the role foreign capital has played in international macroeconomic convergence. Our principal conclusions are as follows:



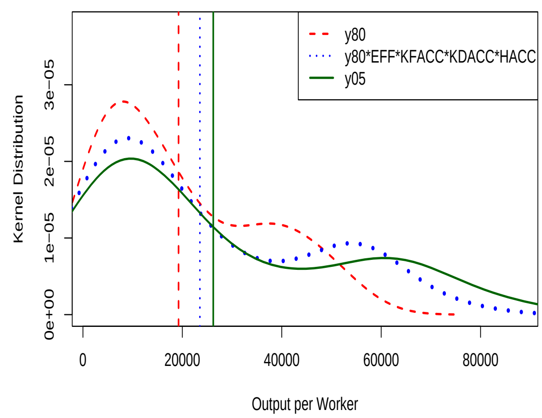
(a) Effect of Foreign Capital Deepening



(b) Effect of Domestic Capital Deepening

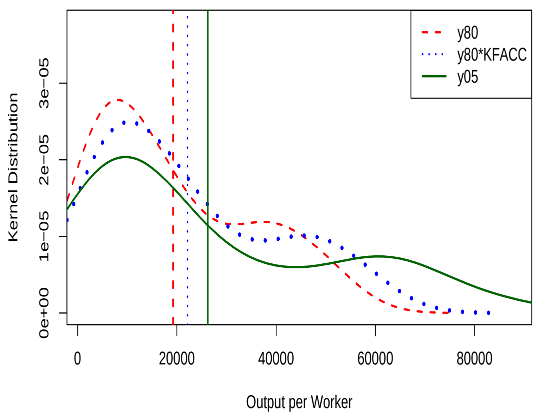


(c) Effect of Human Capital Accumulation

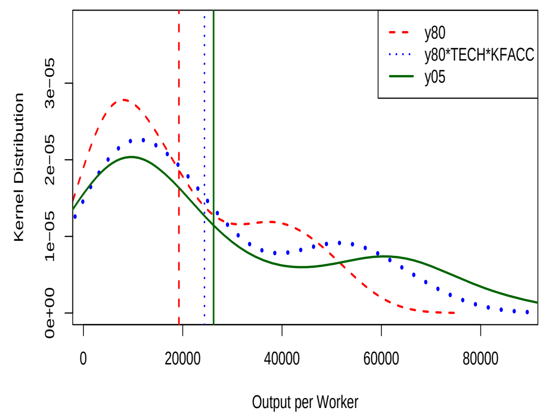


(d) Effect of Efficiency Change

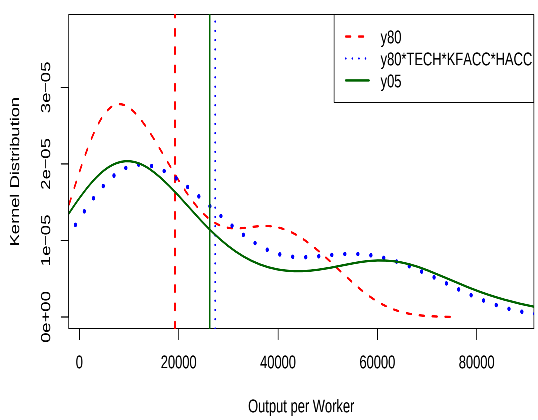
Figure 6: Counterfactual Distributions of Output per Worker
(sequence of introducing effects of decomposition: KFACC, KDACC, HACC, and EFF)



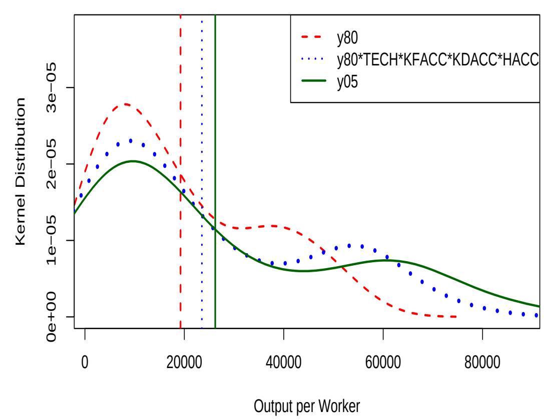
(a) Effect of Foreign Capital Deepening



(b) Effect of Technological Change

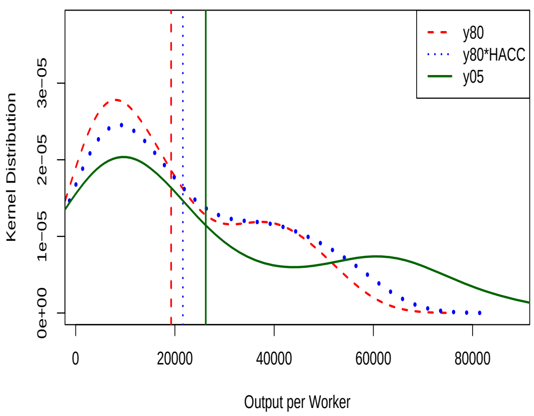


(c) Effect of Human Capital Accumulation

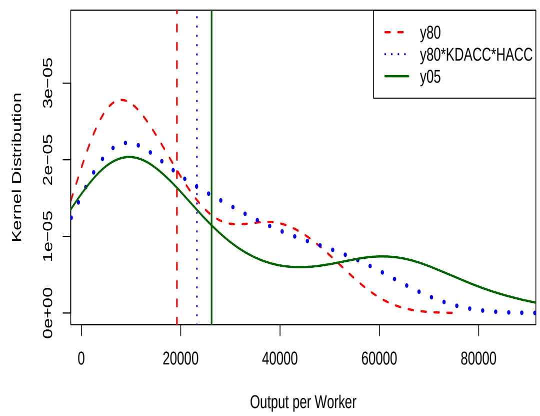


(d) Effect of Domestic Capital Deepening

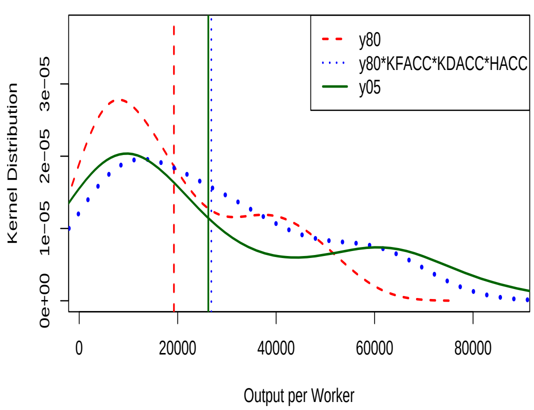
Figure 7: Counterfactual Distributions of Output per Worker
(sequence of introducing effects of decomposition: KFACC, TECH, HACC, and KDACC)



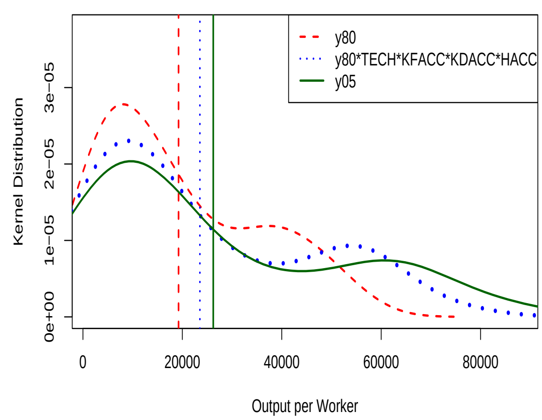
(a) Effect of Human Capital Accumulation



(b) Effect of Domestic Capital Deepening

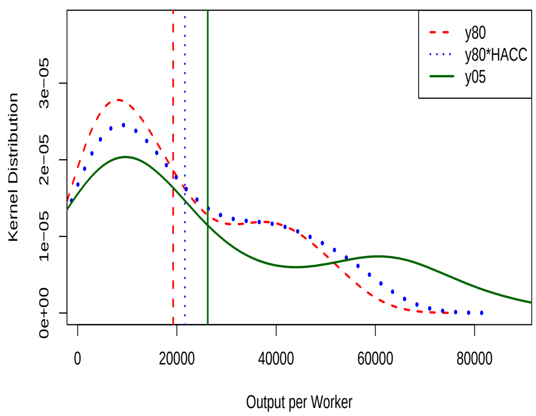


(c) Effect of Foreign Capital Deepening

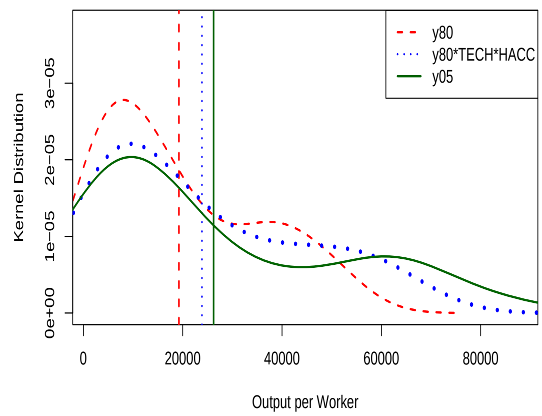


(d) Effect of Technological Change

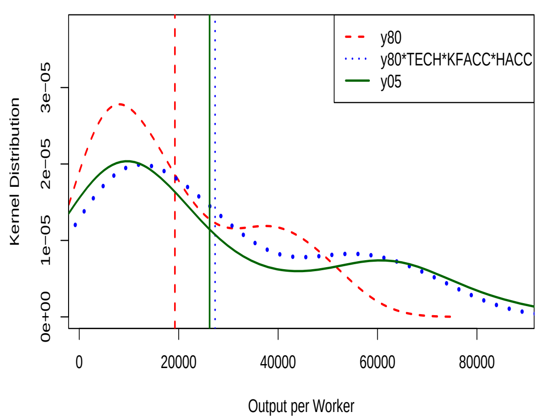
Figure 8: Counterfactual Distributions of Output per Worker
(sequence of introducing effects of decomposition: HACC, KDACC, KFACC, and TECH)



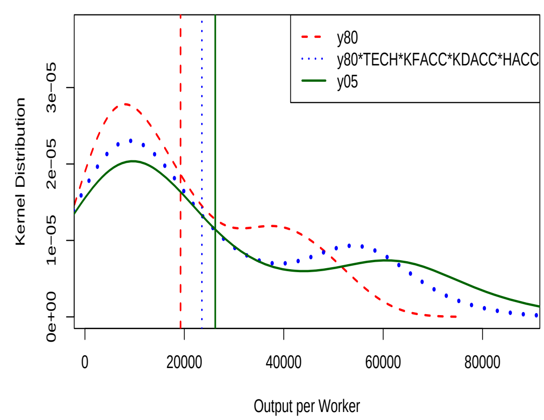
(a) Effect of Human Capital Deepening



(b) Effect of Technological Change



(c) Effect of Foreign Capital Accumulation



(d) Effect of Domestic Capital Deepening

Figure 9: Counterfactual Distributions of Output per Worker
(sequence of introducing effects of decomposition: HACC, TECH, KFACC, and KDACC)

1. The effects of foreign capital accumulation and domestic capital accumulation on productivity growth are dramatically different. Foreign capital accumulation, together with human capital accumulation, is the driving force of productivity growth; the contribution of domestic capital accumulation is much smaller.

2. Technological change is decidedly nonneutral, with most technological advancement taking place in countries that are highly foreign-capital intensive.

3. Foreign capital deepening and human capital accumulation are the primary driving forces behind increased international dispersion of labor productivity.

4. The further international polarization (the shift to a more obvious bimodal distribution) is brought about primarily by efficiency changes. Efficiency deterioration contributes to regression rather than progress on labor productivity in relatively low-productivity countries.

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