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ABSTRACT. Understanding the drivers of productivity remains one of the most sought after phenomena in economics. The ability to create produce more from less resources is undoubtedly appealing. Using recently updated Penn World Table data, we investigate to what degree previous results using a popular productivity decomposition are maintained. We find that, contrary to conclusions from earlier work, technical efficiency (catching up) played a more pronounced role in the global increase in productivity over the 1965-1990 period. We also find a larger effect for technical change than earlier work and a far lesser role for capital deepening. This suite of results augurs the coming information age that placed less weight on physical capital to create and sustain wealth. Taken together our findings here suggest that as data collection, its quality and evaluation methods evolve, so too will our understanding of productivity dynamics.

1. INTRODUCTION

Kumar & Russell (2002, KR hereafter) introduced a tripartite decomposition of labor productivity of countries, accounting for three distinct sources: technical change, efficiency change and capital deepening. They applied their method to a sample of nearly 50 countries, from 1965 to 1990, and found that capital deepening was the main source that drove the labor productivity (or income per worker) of countries to attain extraordinary performances. It also was the main source for the change of the entire distribution of income per worker from unimodal to bi-modal during that period. In a follow up study, Henderson & Russell (2005, HR hereafter) generalized that approach to a quadripartite decomposition, by accounting for another important source of labor productivity – human capital deepening.[1]

A curious (or puzzling) result from HR's work is the relative lack of efficiency change of countries over the 1965-1990 time period that they studied. In KR, it was only 3.9%, while in HR it diminished to 0.7%. That is, in both studies, and especially in HR, the conclusion was that, on

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[1] Badunenko & Romero-Ávila (2013) further extended this approach by accounting for financial development in the decomposition. For a detailed review of this method, other variations and empirical applications, see Badunenko, Henderson & Zelenyuk (2017).

average, the efficiency of countries in the world has practically not changed over the quarter of that century. A similar phenomenon was also observed for the entire distribution of efficiency change for the sample. That is, when looking at the big picture, there was not much (or at all) of the well-wished "catching-up" phenomenon happening over a 25-year span of fairly rapid (relative to the past) development of the world.

We note that the *average* efficiency change here masks several important phenomena. The group of the so-called Asian Tigers had an average efficiency change of 41.3% while Latin American countries had, on average, a decay in efficiency change of -17.2% (HR, Table 4). Looking at some individual countries reveals some substantial changes in efficiency, yet they were balanced with drops in efficiency of other countries, showing little change overall.

Examining the estimates for individual countries in HR also revealed some unexpected and puzzling findings: e.g., Denmark dropped by 8%, The Netherlands by 10%, New Zealand by 21%, Dominican Republic by 32%. Finland, when not accounting for human capital deepening had an efficiency change of 46%, which subsequently dropped to 1.4% after allowing for human capital in the decomposition. The United States went from no efficiency change (due to being on the frontier in both periods) in KR to a near 10% drop due to falling off the frontier in 1990 in HR. In fact looking closely at Table 3 in HR, whether human capital is accounted for or not appears to have minimal effects on either technical change or capital deepening compared to the impacts on efficiency change. To our knowledge, these stark differences have not been scrutinized.

The goal of this paper is to revisit these interesting studies, using the same methods (and we refer the readers there for the details of notation to save space) for a more recent vintage of both the Penn World Table (PWT) and the ubiquitous Barro-Lee human capital dataset. To be more precise, HR relied on PWT version 5.6 (Summers & Heston 1991) and one of the earliest versions of the well worn Barro-Lee human capital dataset (Barro & Lee (1993, 1996, 2001)). Recent research has suggested that revisions to the Penn World Table (Ciccone & Jarociński 2010, Johnson, Larson, Papageorgiou & Subramanian 2013) or different measures of human capital (Cohen & Soto 2007, Delgado, Henderson & Parmeter 2014) can lead to different conclusions in cross-country growth/productivity studies. In turn, this suggests the importance of revisiting key studies, to re-confirm which conclusions are maintained and where it might be needed to update our understanding of the past. Such an update can then help better understand the present and, possibly, shed light on how to best move into the future.

To do so, we deploy the most recent version of the Penn World Table (PWT) and revisions to Barro-Lee data to determine if there are any substantive changes to the insights of KR and HR. We find a few important differences. First, rather than almost no technical efficiency, we find that the average level of efficiency change is 9.6%. Second, the contribution of capital deepening in the decomposition substantially reduced from 41% to 27%. Third, the contribution from technology change became more pronounced, up at 12% from about 7% in HR or about 6% in KR. Interestingly, the effect of human capital and productivity change remained similar as in HR.

These results/changes may have rather profound insights into growth in the later half of the 21st century. In particular, it suggests that (unlike was perceived before), the efficiency change or "catching-up" phenomenon is real and may continue contributing to world's development. This is especially salient if developed countries help developing countries to catch up faster to the technology frontier by disseminating knowledge, help building key institutions and facilitating access to capital markets (Stiglitz 2011).

2. Data

The data used for aggregate output, physical capital, human capital (HC) and labor are derived from the PWT version 10 (Feenstra, Inklaar & Timmer 2015), focusing on years 1965 and 1990 for the same countries as in HR.

The major difference between the GDP measure in HR using the PWT version 5.6 (PWT5.6) versus our data lies in the incorporation of new purchasing power parities (PPPs) data for most countries for the years 2011 to 2017. PWT version 10 (PWT10) adds revised International Comparison Program (ICP) benchmarks for 2011, new benchmarks for 2017 and interpolated ICP benchmarks for the intermediate years 2012-2016. The reference year was shifted to 2017, which means that all variables are denoted in 2017 international prices. As a result, the price levels for the expenditure categories are revised substantially compared to the previous release.

For physical capital, the measurement has also been modified substantially since PWT5.6. The biggest distinction from the earlier concepts of capital stock measures is the introduction of new 'productive capital input' measures that are considered as more appropriate for comparing productivity across countries and over time. In a nutshell, the improvements are due to the implementation of a new method for estimating initial capital stocks, revision of deflators for the investment, introduction of the real internal rate of return on capital (IRR) and the use of IRR together with asset-specific depreciation rates and investment deflators to estimate the user cost of capital for each of the nine assets distinguished in PWT (see Inklaar, Woltjer, Albarrán & Gallardo (2019) for a more detailed discussion of the new methodology).

Importantly, PWT10 updates previous human capital index data by drawing in part upon the average years of schooling data from Barro & Lee (2013) and in part on data by Cohen & Leker (2014), which updated the work of Cohen & Soto (2007). The choice of human capital data for each country is listed in Table A1 and Figure A1 shows box-plots of the dataset we use.

3. RESULTS

We first successfully replicated the results of KR and HR and then we considered four distinct changes. First, we deploy the same time frame and variables as in HR but use PWT10.[2] We then use HC as in HR but use output, physical capital and labor inputs from PWT10.[3] This is followed by the use of HC as provided in PWT10 (which comes from Barro & Lee (2013) and Cohen & Leker (2014)) but use output and other inputs as in HR.[4] Finally, recognizing the four countries which are not available in PWT10, we drop those countries from the original HR data to ensure that it is not these countries alone that are driving our results.[5] Here we compare two sets of results. The first is the original set of results from HR sample, which we refer to as "PWT5.6" hereafter. The second set of results are the results obtained from the 'updated data', which we label as "PWT10" hereafter, to indicate that the data was from PWT10 selected such that it is comparable to the sample of HR. Specifically, note that the full PWT10 data has more countries than HR used while also missing some of countries they used.[6]

3.1. Estimates for Individual Countries and Groups of Countries.

We present the results generated with PWT10 in the main text and report others in the supplementary material. Our findings are stark. Even with the removal of the four countries from HR, their results are unchanged, but once we switch to PWT10, we see several important and instructive differences.

Figure 1 visualizes the estimated frontiers in 1965 and 1990 along with the original observations, while Table 1 reports the estimates for each country in the sample for both vintages of

[2]We note at the outset here that this analysis requires us to drop four countries Honduras, Panama, Sierra Leone and Yugoslavia that did not have full data availability.

[3]Detailed results are attached in supplementary material B.

[4]Detailed results are attached in supplementary material C.

[5]Detailed results are attached in supplementary material D.

[6]Aggregate output, physical capital and labor inputs were measured in thousands in PWT5.6. We divide them by one thousand to make it comparable with PWT10 (measured in millions).

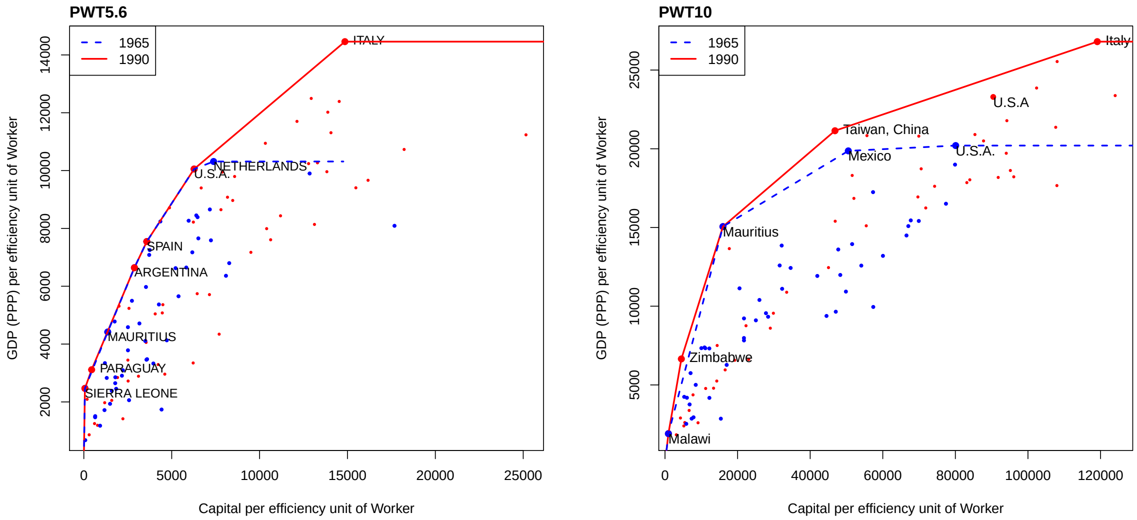

FIGURE 1. Estimated frontiers in 1965 and 1990.

the data.[7] Notable features in Figure 1 are: almost no technological expansion between 1965 and 1990 in the original HR analysis up to about 7,000.[8] The frontiers at low levels of capitalization in HR were defined by a combination of Sierra Leone, Paraguay and Mauritius, while using PWT10 they are defined by Malawi and Zimbabwe. Paraguay, found to be fully efficient in 1990 by HR, is only 42% efficient in our results. Argentina, another country on the 1965 frontier in HR, is only 64% efficient when using PWT10. The same is true for Spain, which is now replaced by Mauritius in defining the frontier. Mauritius' relative high GDP per efficiency unit of labor are largely driven by its extremely low labor levels. When determining the frontier at high levels of capitalization using PWT10, in addition to Italy and the United States (which defined the frontier in HR), Mexico and Taiwan appear on the best practice frontiers in 1965 and 1990, respectively. The Netherlands, a fully efficient country in 1965 in HR's sample, falls below the frontier, to 0.72, almost a 30% reduction in efficiency.

Looking more closely at efficiency changes of individual countries in Table 1 also leads us to some interesting findings. A number of advanced economies with negative efficiency changes in HR now have positive efficiency change (i.e., "catching-up" effect) in the updated data. For example, the efficiency for Austria over the period changes from -5.8% to 25.6%, Denmark from

[7]Due to the fact that output is measured in different dollar equivalents we cannot plot both sets of frontiers on the same curve: HR is in 1985 international prices, while PWT10 are in 2017 international prices.
[8]Taken as capital per efficiency unit of worker measure with 1985 international dollars.

-8.2% to 8.3%, Sweden from -14.7% to 6.1%, Switzerland from -19% to 0.8%, and U.K. from -0.9% to 22.5% . Some countries with positive efficiency changes in PWT5.6 demonstrate even more rapid catching-up movements. The efficiency change of Finland goes up from 1.4% to 35.1%, France from 2.4% to 21.5%, Greece from 10.8% to 38.2%, Japan from 10% to 79% and South Korea from 36.6% to nearly 200%.

Interestingly, these improvements in efficiency are almost balanced by a few significant drops of efficiency in countries such as India, Sri Lanka, Kenya, Paraguay and Thailand, etc, leaving average efficiency scores approximately equivalent at about the same levels in both approaches and in both years (see Table 1). Over time, the mean efficiency index increased slightly from 0.65 to 0.68, as opposed to a decrease from 0.68 to 0.67 in HR. Figure 2 plots the distributions of the estimated efficiency indices in 1965 and 1990 for both PWT5.6 and PWT10. Figure 3 shows the estimated densities of efficiency change for PWT5.6 and PWT10. We see that as discussed in both KR and HR, there was little discrepancy in the overall distribution of efficiency change, while with PWT10, there is a large rightward shift in the probability mass, again confirming that with PWT10 we witness a large catching up effect.

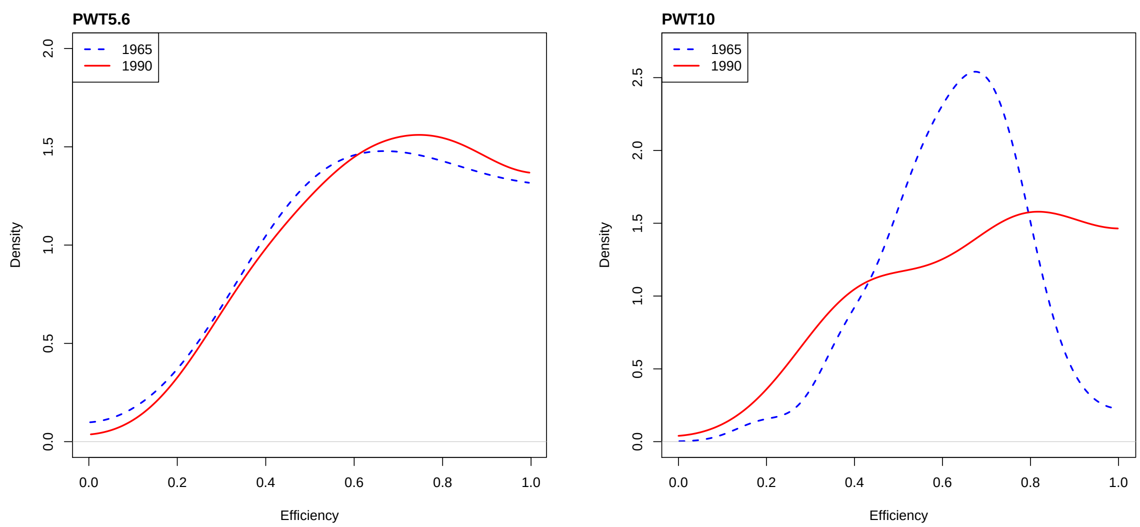

FIGURE 2. Efficiency indexes for 1965 and 1990

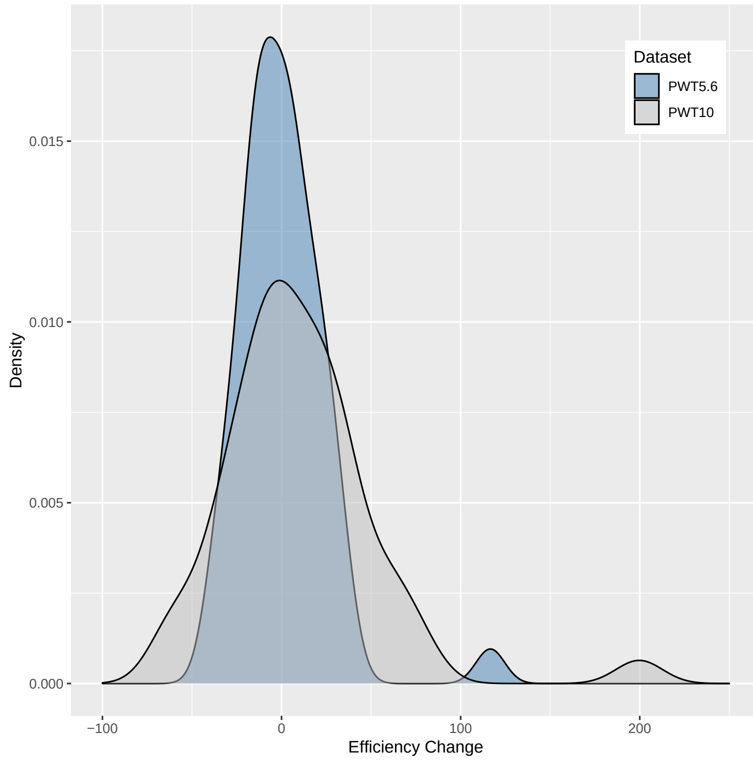

FIGURE 3. Estimated densities of efficiency change for PWT5.6 and PWT10.

TABLE 1. Efficiency scores for 1965 and 1990, PWT5.6 and PWT10.

	Efficiency 1965		Efficiency 1990		Efficiency Change (%)	
Country	PWT5.6	PWT10	PWT5.6	PWT10	PWT5.6	PWT10
Argentina	1.00	0.59	0.64	0.40	−36.1	−31.7
Australia	0.74	0.75	0.76	0.75	3.5	−0.4
Austria	0.80	0.63	0.75	0.79	−5.8	25.6
Belgium	0.72	0.77	0.86	0.98	19.5	28.3
Bolivia	0.50	0.37	0.42	0.36	−16.9	−3.9
Canada	0.84	0.86	0.80	0.84	−4.6	−2.6
Chile	0.85	0.71	0.63	0.54	−26.1	−24.4
Colombia	0.48	0.50	0.54	0.60	13.3	20.0
Denmark	0.73	0.70	0.67	0.76	−8.2	8.3
Dominican Republic	0.80	0.49	0.54	0.54	−32.3	8.9
Ecuador	0.42	0.56	0.40	0.49	−4.5	−12.2
Finland	0.66	0.55	0.67	0.75	1.4	35.1

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Table 1 – *Continued from previous page*

	Efficiency 1965		Efficiency 1990		Efficiency Change (%)	
Country	PWT5.6	PWT10	PWT5.6	PWT10	PWT5.6	PWT10
France	0.85	0.77	0.87	0.94	2.4	21.5
Greece	0.55	0.49	0.61	0.68	10.8	38.2
Guatemala	0.96	0.68	0.85	0.54	−11.6	−20.3
Honduras	0.52	−−	0.44	−−	−14.3	−−
Hong Kong SAR, China	0.46	0.56	1.00	0.95	116.6	71.1
Iceland	0.94	0.94	0.87	0.87	−7.4	−7.2
India	0.44	0.38	0.47	0.33	7.2	−12.0
Ireland	0.67	0.58	0.82	0.91	22.4	55.9
Israel	0.61	0.61	0.80	0.81	30.3	32.9
Italy	0.76	0.63	1.00	1.00	32.1	58.3
Jamaica	0.62	0.57	0.54	0.39	−12.6	−31.4
Japan	0.54	0.41	0.60	0.74	10.2	79.1
Kenya	0.31	0.54	0.37	0.41	19.4	−23.3
Malawi	0.27	1.00	0.30	0.38	10.8	−61.9
Mauritius	1.00	1.00	0.99	0.89	−1.1	−11.3
Mexico	0.996	1.00	0.82	0.73	−17.7	−27.2
Netherlands	1.00	0.72	0.90	0.87	−10.4	19.7
New Zealand	0.83	0.80	0.66	0.69	−21.0	−13.5
Norway	0.78	0.66	0.65	0.73	−17.1	10.3
Panama	0.46	−−	0.33	−−	−27.3	−−
Paraguay	0.98	0.66	1.00	0.42	2.5	−36.3
Peru	0.66	0.74	0.40	0.36	−38.4	−51.1
Philippines	0.42	0.35	0.43	0.41	2.7	16.5
Portugal	0.75	0.70	0.92	0.74	21.9	4.7
Sierra Leone	1.00	−−	0.78	−−	−22.0	−−
South Korea	0.41	0.20	0.57	0.59	36.6	199.7
Spain	1.00	0.64	0.93	0.88	−7.3	36.8
Sri Lanka	0.33	0.79	0.35	0.48	4.7	−38.8
Sweden	0.84	0.70	0.72	0.74	−14.7	6.1
Switzerland	0.96	0.82	0.78	0.82	−19.0	0.8
Syria	0.62	0.50	0.80	0.46	30.0	−8.7
Taiwan, China	0.52	0.62	0.62	1.00	17.9	61.0
Thailand	0.45	0.41	0.56	0.38	25.4	−6.7
Turkey	0.56	0.73	0.61	0.85	7.5	16.5
U.K.	0.92	0.64	0.91	0.78	−0.9	22.5

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Table 1 – *Continued from previous page*

	Efficiency 1965		Efficiency 1990		Efficiency Change (%)	
Country	PWT5.6	PWT10	PWT5.6	PWT10	PWT5.6	PWT10
U.S.A.	1.00	1.00	0.90	0.95	−9.8	−5.2
West Germany[9]	0.69	0.50	0.74	0.70	7.6	41.2
Yugoslavia	0.65	−−	0.55	−−	−15.5	−−
Zambia	0.48	0.70	0.33	0.26	−30.9	−62.7
Zimbabwe	0.21	0.74	0.25	1.00	19.4	34.7

As in HR, we adopt the "Fisher Ideal" decomposition of the productivity growth into *EFF*, *TECH*, *KACC* and *HACC*, where *EFF* represents the ratio of the efficiency indexes in two periods, *TECH* measures the technological change by the shift in the frontier in the output direction and *KACC* and *HACC* measure the effects of physical and human capital deepening along the frontiers, respectively.[10] Table 2 reports the mean, median and standard error of the estimates of changes in productivity and the decomposition of labor productivity growth into the change in efficiency (EffCh, $[EFF-1]\times 100$), change in technology (TechCh, $[TECH-1]\times 100$), physical capital deepening (KCh, $[KACC-1]\times 100$) and human capital deepening (HCh, $[HACC-1]\times 100$). The average growth in labor productivity is 83%, slightly larger than the 79% in HR. Although ordering of the average contributions are similar to what was found in HR, the effect of efficiency change from the updated data is much more pronounced, up to nearly 10% in our analysis compared with less than 1% in HR. We also observe larger effects of technology improvement, up at 12% from about 7% in HR or about 6% in KR, and slightly higher (though very similar) effect of human capital deepening. Another important finding comes from the physical capital deepening. Although remaining the principle driving force in the average growth of productivity, the contribution of physical capital deepening declines from 60% in KR to 41% in HR (accounting for HC) to 27% in our analysis (with PWT10).

Table 3 reports the decomposition factors for several groups of countries. Here, one can see that OECD countries experienced productivity gains above the world average mainly due to faster rates of efficiency change according to the updated data, rather than physical capital deepening identified in HR. Asian Tigers also exhibited a phenomenal growth rate in labor productivity. Similar to OECD countries, it is primarily attributable to the well-above-average

[9]It is "West Germany" in PWT5.6 and "Germany" in PWT10.
[10]More details can be found in Section 3.1 of HR.

TABLE 2. Overall Summary of Decomposition.

Metric	Data	Efficiency 1965	Efficiency 1990	ProdCh	EffCh	TechCh	KCh	HCh
Mean	PWT5.6	0.68	0.67	79.26	0.82	6.85	40.59	16.53
	PWT10	0.65	0.68	82.76	9.60	12.26	26.80	17.32
Median	PWT5.6	0.68	0.66	61.95	−1.00	1.45	29.55	14.70
	PWT10	0.65	0.73	56.15	5.40	12.10	14.60	17.00
SE	PWT5.6	0.02	0.02	8.16	2.48	0.93	3.72	0.89
	PWT10	0.02	0.02	9.65	4.31	0.67	3.83	0.72

contributions of efficiency gains, followed by substantial physical capital deepening, and to a lesser extent, human capital deepening. The labor productivity change of Latin America was 38% according to the updated data, which is slightly higher than 33% found in HR. However, the difference is mostly driven by technological change of 9.5% according to the updated data compared with the 0.5% in HR. Regarding the poor labor productivity growth performance of Africa, one can see that although there is a further decay in efficiency change, the negative effect is offset by a faster technological change and a much higher physical capital deepening, leading to 23% labor productivity change according to PWT10, slightly higher than the 18% presented in HR.

TABLE 3. Percentage changes of quadripartite decomposition indexes (country groups)

Groups	Data	ProdCh	EffCh	TechCh	KCh	HCh
OECD	PWT5.6	83.3	0.4	14.3	39.5	14.8
	PWT10	93.1	20.9	14.9	16.6	18.4
Asian Tigers	PWT5.6	279.5	41.3	5.3	113.1	24.4
	PWT10	296.6	80.8	7.1	74.8	24.3
Latin America	PWT5.6	33.1	−17.2	0.5	38.2	16.6
	PWT10	38.0	−15.3	9.5	36.3	16.1
Africa	PWT5.6	18.0	−0.9	0.8	4.0	13.9
	PWT10	23.2	−24.9	13.9	39.9	9.1
Non-OECD	PWT5.6	76.1	0.9	1.2	41.4	18.0
	PWT10	73.3	−0.8	9.9	36.2	16.3
All countries	PWT5.6	78.6	0.7	7.1	40.5	16.6
	PWT10	82.8	9.6	12.3	26.8	17.3

3.2. **Regression Analysis of the Labor Productivity Decomposition.** Figure 4 contains plots of the four productivity-component growth rates against output per worker in 1965, along with fitted regression lines for the updated data.[11] Slope coefficients and associated t statistics are reported in Table 4 both for the original and updated data.

Comparing with HR's results in their Figure 5 (see Figure A3 in the supplemental appendix), we find that the relationship between efficiency change and initial level of productivity shifted from negative to positive, although statistically insignificant. Panel (A) demonstrates efficiency growth occurred for most middle and high income countries. Efficiency changes for high income countries remain negative and relatively small. This is different from both KR and HR who noted that efficiency contributed little, if anything, to lower income inequality across countries.

Panel (B) suggests that the technological change contributed to productivity growth positively for many countries. Moreover, high income countries have benefited more than lower income countries, However, the magnitude of the coefficients are larger than HR. Panel (C) shows that physical capital deepening was positive for most countries and it appeared to have a significant relationship with initial level of labor productivity. Same as HR, the negative slope reveals that the international pattern of capital deepening has contributed to convergence. Panel (D) exhibits a positive, although insignificant, relationship between contribution of human capital deepening to economic growth and initial level of labor productivity, which is different from the negative (although insignificant) relationship presented in HR.

TABLE 4. Slope coefficients and t statistics of OLS regressions

Data	(EFF-1)×100	(TECH-1)×100	(KACC-1)×100	(HACC-1)×100
PWT5.6	-6.30*	8.87***	-14.35**	-2.10
	(-1.97)	(5.18)	(-2.25)	(-1.34)
PWT10	0.87	1.34**	-11.18***	0.60
	(0.20)	(2.03)	(-2.84)	(0.87)

Note: t statistics in parenthesis, calculated based on robust standard errors. ***, ** and * indicate statistical significance (according to the two-sided asymptotic N(0,1) test) at the 0.01, 0.05, and 0.1 levels, respectively.

[11] Specifically, the lines are OLS fitted lines with robust standard errors.

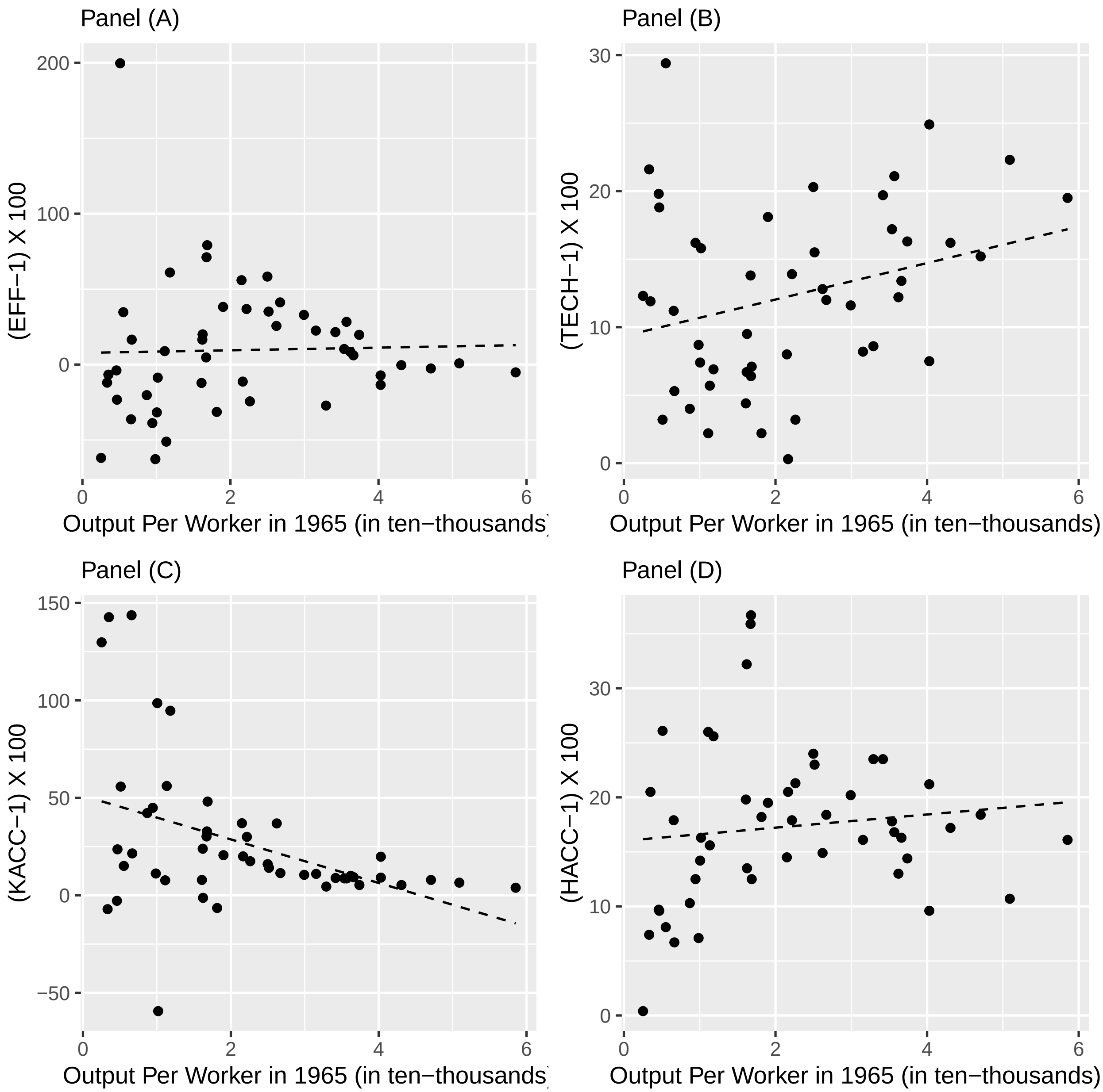


FIGURE 4. Four decomposition indexes plotted against 1965 output per worker using PWT10.

3.3. **Distribution Dynamics of Labor Productivity.** We now turn to the analysis of the distribution dynamics of labor productivity. Figure 5 shows that over the 25-year period, the distribution of labor productivity has been transformed from a unimodal into a bimodal distribution with a higher mean.

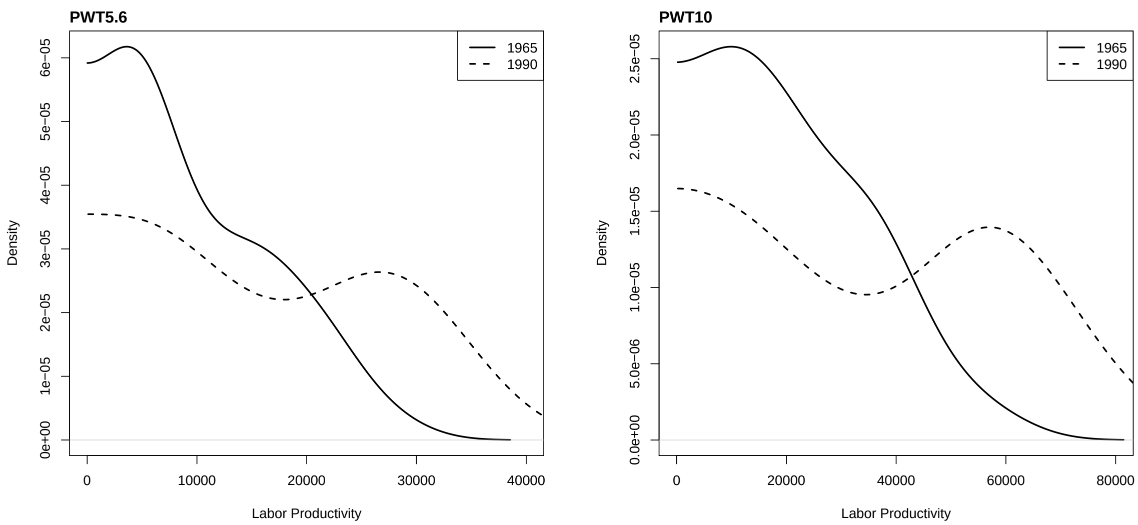


FIGURE 5. Labor productivity for PWT5.6 and PWT10

As in HR, we attempt to explain the polarization of the distribution in terms of the quadripartite decomposition and present the results of Silverman tests for multimodality (Silverman 1981) in Table 5. The test results confirm that the estimated distribution of labor productivity in 1990 is very likely to be bimodal.

KR and HR found that the principal determinant of the polarization is the combination of changes in efficiency with the other components of the decomposition. Efficiency changes, combined with either physical or human capital deepening, account for the shift to bimodality at the 5% significance level. The updated data suggests that efficiency changes alone lead to the bimodal distribution (p value = 0.006). While this tendency was also observed by HR (p value = 0.091), we provide more convincing evidence using PWT10. Other tests rejecting unimodality entail the contribution of efficiency changes (lines 6-8 and lines 12-14). The shifts in the distribution brought by sequentially introducing each of the four decomposition factors are illustrated in Figure 6.

TABLE 5. Tests for Multi-modality of Distributions, p values.

		H_0: One Mode H_A: More Than One Modes		H_0: Two Modes H_A: More Than Two Modes	
	Distribution	PWT10	PWT5.6	PWT10	PWT5.6
0	$f(y_{65})$	0.494	0.458	0.812	0.588
1	$f(y_{90})$	0.024	0.010	0.484	0.256
2	$f(y_{65} \times EFF)$	0.006	0.091	0.542	0.484
3	$f(y_{65} \times TECH)$	0.602	0.839	0.918	0.239
4	$f(y_{65} \times KACC)$	0.772	0.097	0.572	0.188
5	$f(y_{65} \times HACC)$	0.482	0.338	0.278	0.262
6	$f(y_{65} \times EFF \times TECH)$	0.042	0.155	0.810	0.545
7	$f(y_{65} \times EFF \times KACC)$	0.014	0.020	0.404	0.564
8	$f(y_{65} \times EFF \times HACC)$	0.022	0.042	0.366	0.412
9	$f(y_{65} \times TECH \times KACC)$	0.836	0.072	0.786	0.582
10	$f(y_{65} \times TECH \times HACC)$	0.582	0.663	0.708	0.645
11	$f(y_{65} \times KACC \times HACC)$	0.386	0.076	0.670	0.361
12	$f(y_{65} \times EFF \times TECH \times KACC)$	0.018	0.030	0.512	0.776
13	$f(y_{65} \times EFF \times TECH \times HACC)$	0.050	0.218	0.792	0.077
14	$f(y_{65} \times EFF \times KACC \times HACC)$	0.026	0.000	0.258	0.210
15	$f(y_{65} \times TECH \times KACC \times HACC)$	0.292	0.149	0.914	0.656

Note: We use the *multimode* package in R to test the number of modes and perform a calibrated Silverman test (Hall & York 2001) in the context of testing for a single mode to improve its level accuracy.

We also perform the Li-Fan-Ullah test (Li 1996) to formally assess contributions of the decomposition factors to changes in the distribution of labor productivity. Both KR and HR concluded that physical capital deepening appears to be the driving force in explaining the overall change in the distribution from 1965 to 1990 at the 5% significance level. We compare our results in Table 6 with that of HR at 10% significance level due to the small sample size. Li tests rejected the null hypothesis that any of the four decomposition factor is solely responsible for moving the 1965 distribution to that of 1990 (lines 2-5). In fact, the introduction of one additional component does not seem to affect the distribution materially either (lines 6-11). This contrasts with HR findings that joint effects of technology change and physical capital deepening account for the overall change in distribution at 10% significance level. We observe that only when efficiency change, combined with technological change and human capital deepening, or with physical capital deepening and human capital deepening, will it adjust the distribution of

TABLE 6. Distribution hypothesis tests

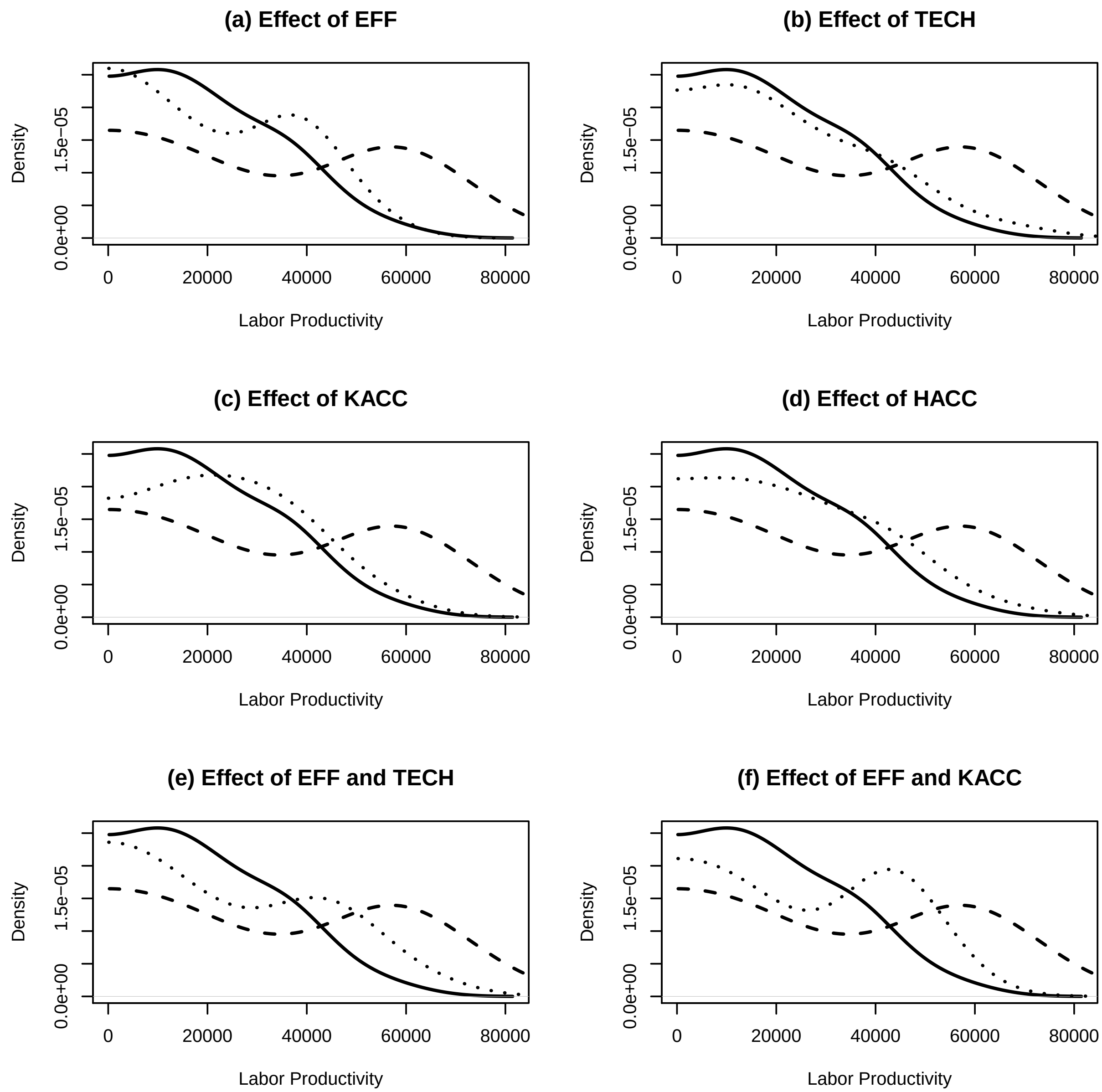
	H_0: Distributions are equal H_1: Distributions are not equal	Bootstrap p-value	10% significance level PWT10	 PWT5.6
1	$g(y_{90})$ vs. $f(y_{65})$	0.001	H_0 rejected	H_0 rejected
2	$g(y_{90})$ vs. $f(y_{65} \times EFF)$	0.002	H_0 rejected	H_0 rejected
3	$g(y_{90})$ vs. $f(y_{65} \times TECH)$	0.003	H_0 rejected	H_0 rejected
4	$g(y_{90})$ vs. $f(y_{65} \times KACC)$	0.000	H_0 rejected	H_0 rejected
5	$g(y_{90})$ vs. $f(y_{65} \times HACC)$	0.003	H_0 rejected	H_0 rejected
6	$g(y_{90})$ vs. $f(y_{65} \times EFF \times TECH)$	0.015	H_0 rejected	H_0 rejected
7	$g(y_{90})$ vs. $f(y_{65} \times EFF \times KACC)$	0.000	H_0 rejected	H_0 rejected
8	$g(y_{90})$ vs. $f(y_{65} \times EFF \times HACC)$	0.010	H_0 rejected	H_0 rejected
9	$g(y_{90})$ vs. $f(y_{65} \times TECH \times KACC)$	0.005	H_0 rejected	H_0 not rejected
10	$g(y_{90})$ vs. $f(y_{65} \times TECH \times HACC)$	0.018	H_0 rejected	H_0 rejected
11	$g(y_{90})$ vs. $f(y_{65} \times KACC \times HACC)$	0.002	H_0 rejected	H_0 not rejected
12	$g(y_{90})$ vs. $f(y_{65} \times EFF \times TECH \times KACC)$	0.061	H_0 rejected	H_0 not rejected
13	$g(y_{90})$ vs. $f(y_{65} \times EFF \times TECH \times HACC)$	0.344	H_0 not rejected	H_0 rejected
14	$g(y_{90})$ vs. $f(y_{65} \times EFF \times KACC \times HACC)$	0.110	H_0 not rejected	H_0 not rejected
15	$g(y_{90})$ vs. $f(y_{65} \times TECH \times KACC \times HACC)$	0.036	H_0 rejected	H_0 not rejected

Note: We make decisions based on 10% level of significance due to the small sample size.

1965 labor productivity to be statistically indistinguishable from that in 1990. Again, this highlights the more prominent role of the efficiency change or “catching-up" phenomenon, in the labor productivity dynamics.

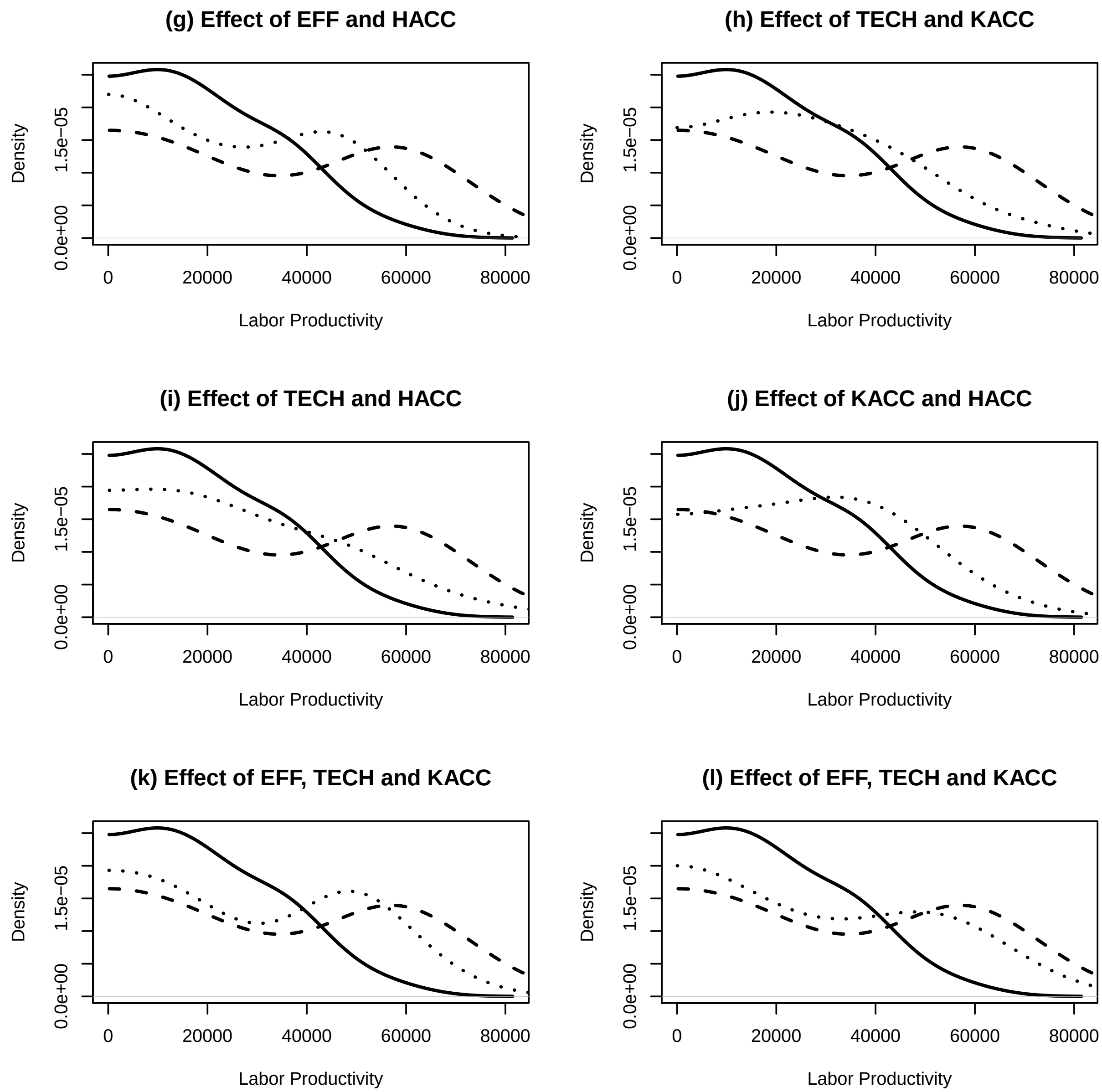
4. CONCLUDING REMARKS

As the perpetual quest for enduring productivity growth continues, so too does the quantification of output, capital and other measures which are routinely debated and discussed by economists. It is only natural that at various junctures newer data is taken to older results to determine if similar outcomes arise. Here we undertook just such an experiment, applying the most recent vintage of the Penn World Table cross-country output database to a popular productivity decomposition analysis. With new data in tow we discovered several important features of productivity growth over the 1965-1990 period that were not available with the data available earlier.



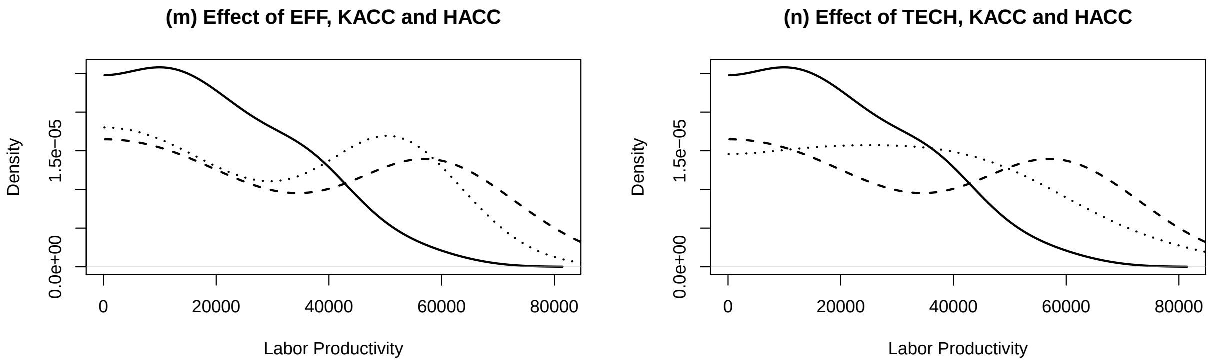
Note: In each panel, the solid curve is the actual 1965 distribution of output per worker, whereas the dashed curve is the actual 1990 distribution of output per worker. The dotted curves of each panel are the counterfactual distributions isolating the effects of components as labeled.

FIGURE 6. Counterfactual distributions of output per worker



Note: In each panel, the solid curve is the actual 1965 distribution of output per worker, whereas the dashed curve is the actual 1990 distribution of output per worker. The dotted curves of each panel are the counterfactual distributions isolating the effects of components as labeled.

FIGURE 6. Counterfactual distributions of output per worker (continued)



Note: In each panel, the solid curve is the actual 1965 distribution of output per worker, whereas the dashed curve is the actual 1990 distribution of output per worker. The dotted curves of each panel are the counterfactual distributions isolating the effects of components as labeled.

FIGURE 6. Counterfactual distributions of output per worker (continued)

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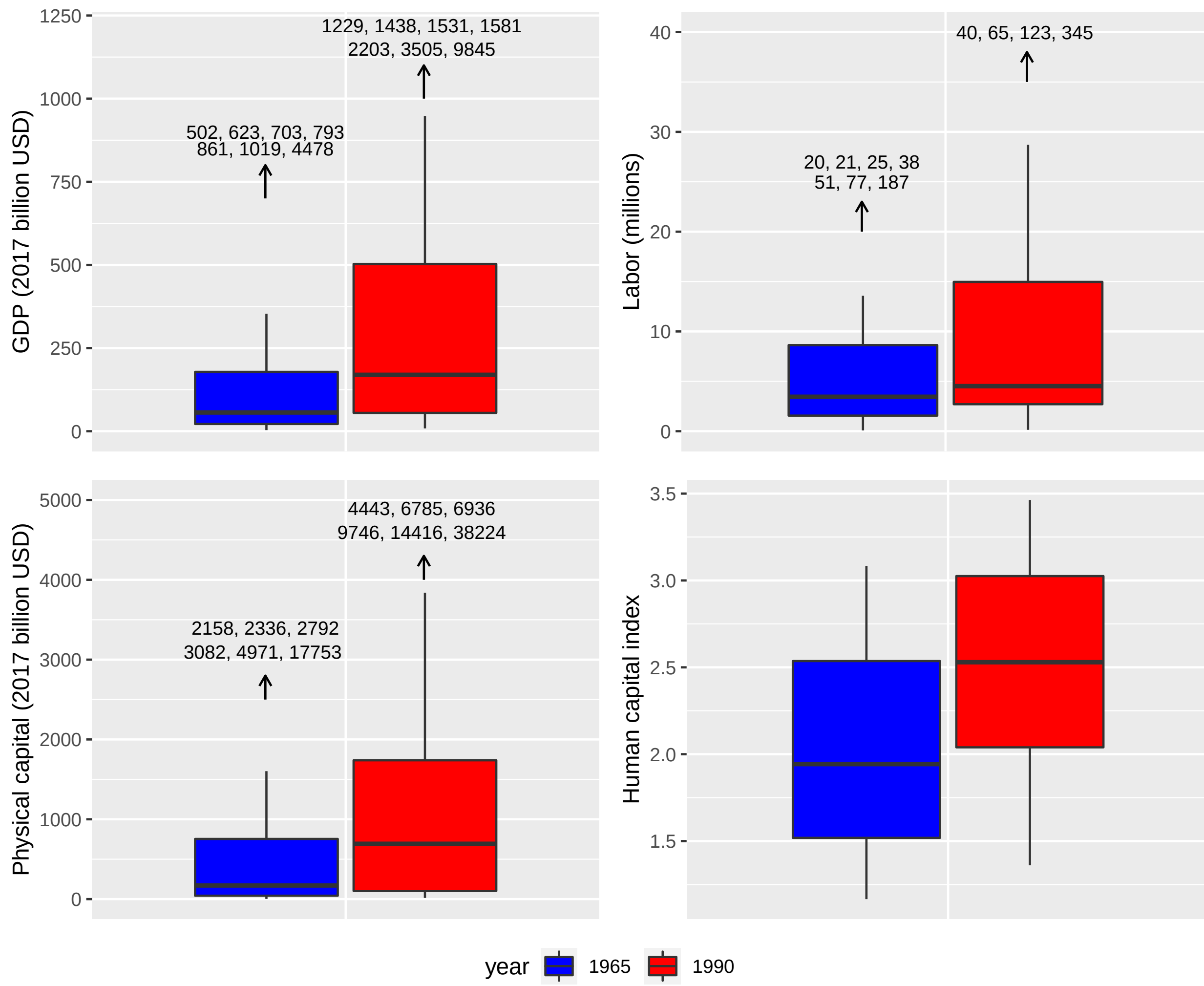
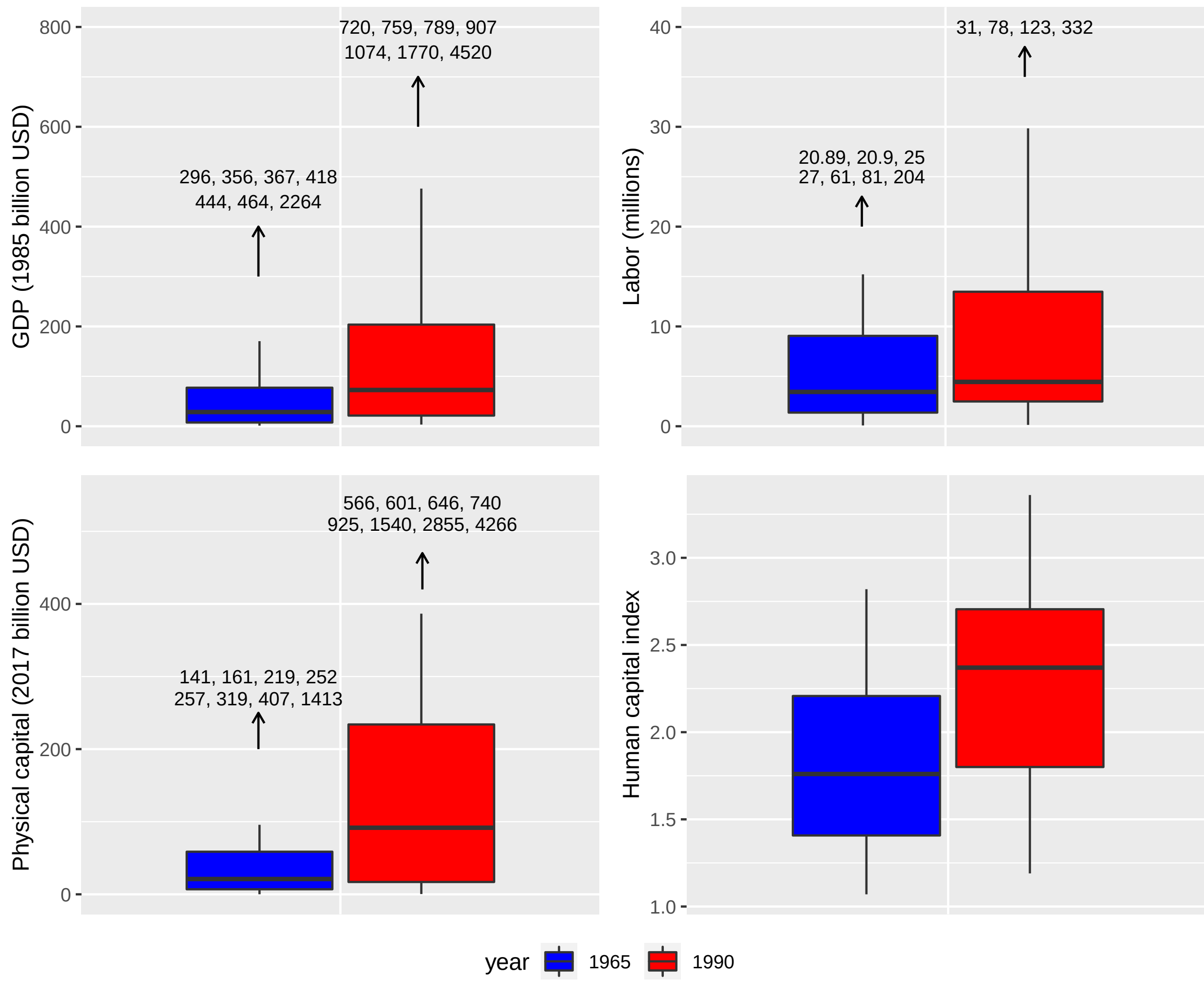
SUPPLEMENTARY MATERIAL A



Note: Due to heavily skewed data several orders of magnitude larger than the median, outliers are not plotted but are labeled on each subfigure.

FIGURE A1. Box plots for PWT5.6



Note: Due to heavily skewed data several orders of magnitude larger than the median, outliers are not plotted but are labeled on each subfigure.

FIGURE A2. Box plots for PWT10

TABLE A1. Choice of human capital source by country.

Country	Source	Argument
Argentina	BL	closer to UIS in level
Australia	CLS	DD matches CSL trend
Austria	CLS	DD matches CSL trend and closer in levels
Belgium	BL	similar series in CSL, but BL is longer
Bolivia	CLS	levels closer to UIS, but similar trend as BL
Canada	CLS	BL shows several declines; CSL closer in level to DD
Chile	CLS	slightly smoother trend than BL, but very similar
Colombia	CLS	UIS closer to CSL
Denmark	CLS	BL shows declines and a low level compared to DD and UIS
Dominican Republic	BL	levels closer to UIS, broadly similar trend
Ecuador	CLS	slightly smoother trend than BL, but fairly similar
Finland	CLS	smoother trend and closer to DD (in trend and level) than BL
France	CLS	smoother trend and closer to DD (in trend and level) than BL
Germany	CLS	CSL close to DD and UIS, BL is too low and distorted trend
Greece	CLS	BL shows declines in early years, levels and trends similar from 1970s onwards
Guatemala	BL	CSL short time series, few UIS observations; both similar to BL
China, Hong Kong SAR	BL	level similar to UIS
Iceland	BL	only source
India	BL	similar series in CSL, but BL is longer
Ireland	CLS	closer to DD in level
Israel	BL	only source
Italy	CLS	very similar series, but CSL closer to DD
Jamaica	CLS	enrolment more consistent with flattening profile around 2000 rather than BL's acceleration
Japan	CLS	decline in BL data, CSL closer to DD
Kenya	CLS	level similar to UIS, but similar trends in CSL and BL
South Korea	CLS	decline in BL data
Malawi	CLS	level similar to UIS
Mauritius	CLS	decline in BL data
Mexico	CLS	level similar to UIS, but similar trends in CSL and BL
Netherlands	CLS	CSL close to DD and UIS, BL is too low and distorted trend
New Zealand	BL	closer to DD in level, despite some declines in BL
Norway	CLS	CSL close to DD and UIS, BL is too low and shows decline
Paraguay	BL	closer to UIS in level
Peru	BL	similar series in CSL, but BL is longer
Philippines	BL	similar series in CSL, but BL is longer
Portugal	BL	closer to DD in level
Spain	CLS	levels closer to UIS (late sample) and similar level and trend as DD
Sri Lanka	BL	only source
Sweden	CLS	closer to DD and UIS in level
Switzerland	CLS	BL much lower than CSL and DD, plus decline in BL series
Syria	CLS	enrolment suggests continued increases in attainment, rather than flattening
Taiwan, China	BL	only source
Thailand	CLS	decline in BL data
Turkey	BL	similar series in CSL, but BL is longer
U.K.	CLS	levels closer to UIS (late sample) and similar level and trend as DD
U.S.A.	BL	closer to DD and UIS in level
Zambia	BL	very similar series, but BL is longer
Zimbabwe	BL	very similar series, but BL is longer

Notes: BL: Barro & Lee (2013); CSL: Cohen & Soto (2007)/Cohen & Leker (2014) data; UIS: UNESCO data; DD: De la Fuente & Doménech (2006) data; enrolment data through World Bank Education statistics.

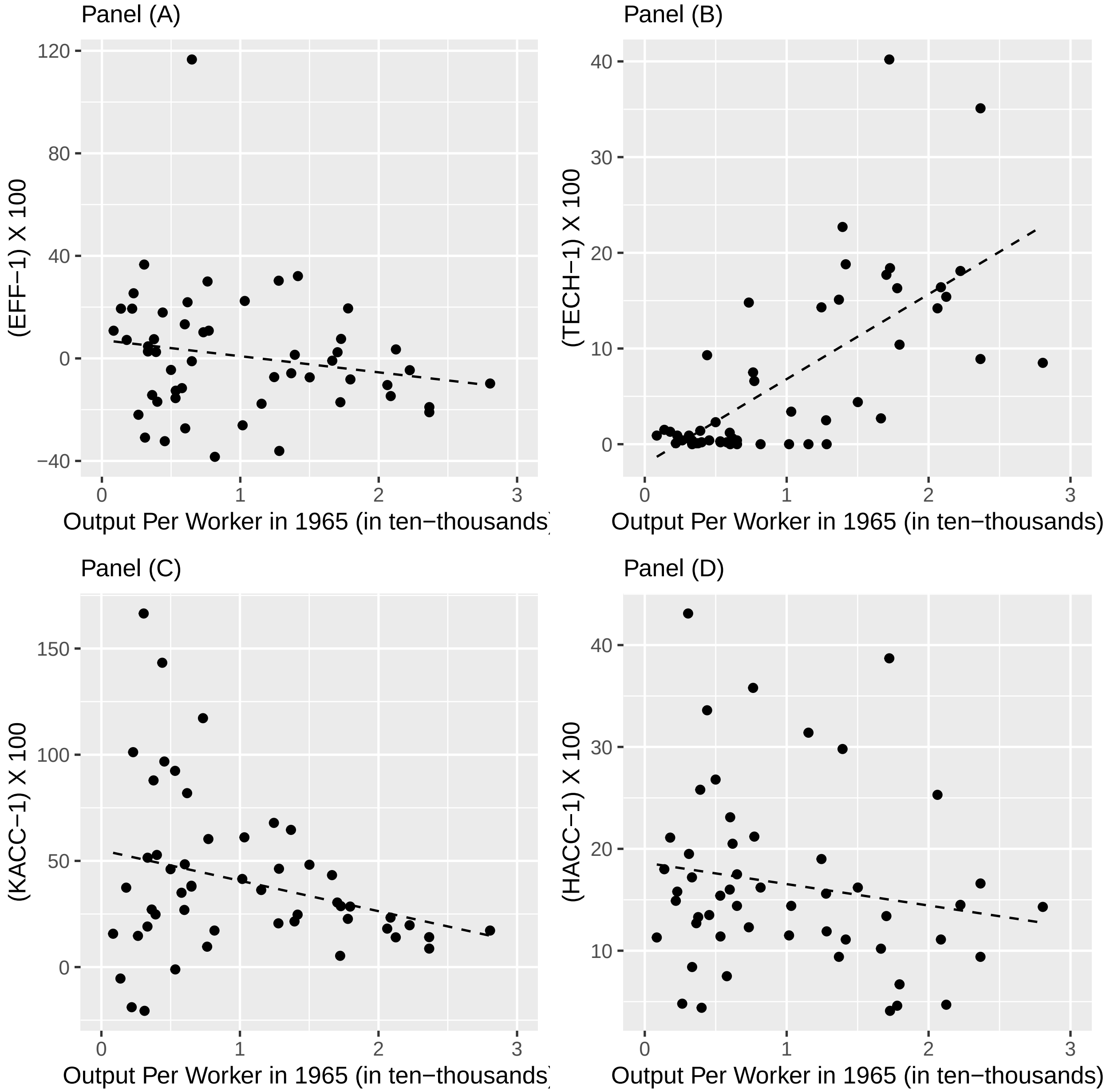


FIGURE A3. Four decomposition indexes plotted against 1965 output per worker using PWT5.6.

SUPPLEMENTARY MATERIAL B: ESTIMATION RESULTS USING HC AS IN HR BUT USING OUTPUT, PHYSICAL CAPITAL AND LABOR INPUTS FROM PWT10.

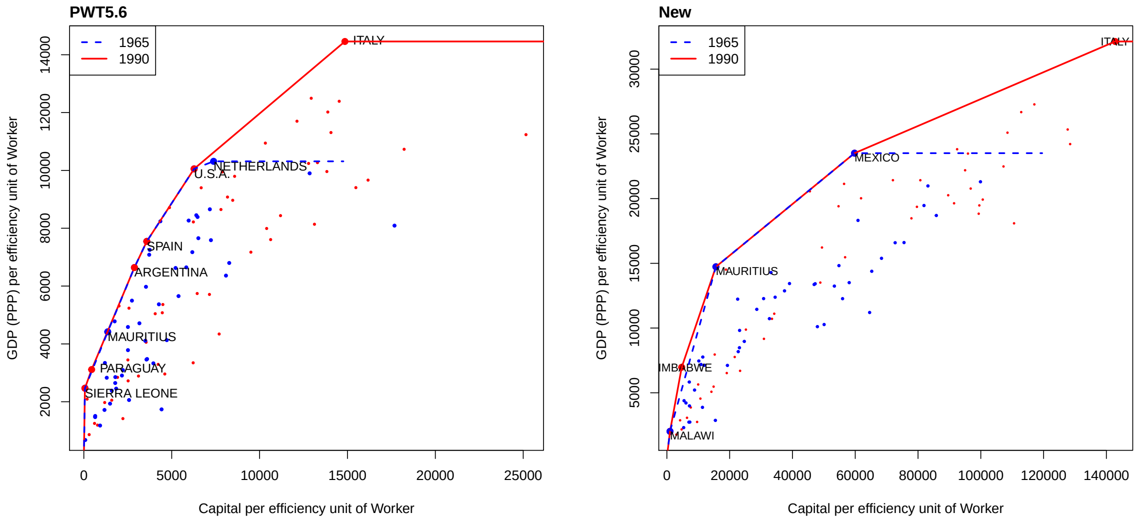


FIGURE B1. Estimated frontiers in 1965 and 1990

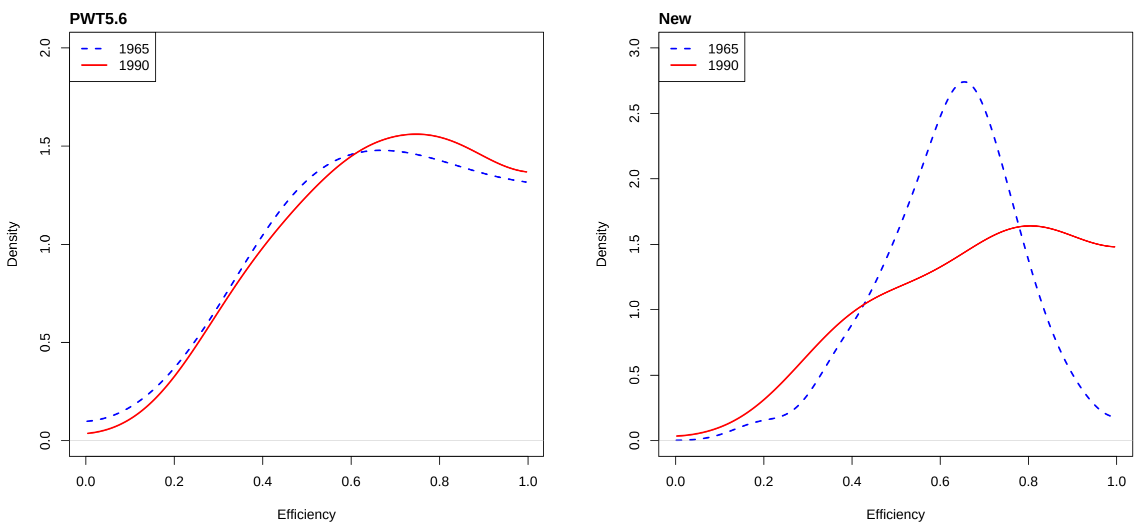


FIGURE B2. Efficiency indexes for 1965 and 1990

TABLE B1. Efficiency scores for 1965 and 1990

Country	Efficiency 1965		Efficiency 1990		Efficiency Change (%)	
	PWT5.6	PWT10	PWT5.6	PWT10	PWT5.6	PWT10
Argentina	1.00	0.59	0.64	0.41	-36.1	-30.3
Australia	0.74	0.65	0.76	0.76	3.5	16.0
Austria	0.80	0.66	0.75	0.79	-5.8	19.6
Belgium	0.72	0.61	0.86	0.92	19.5	50.2
Bolivia	0.50	0.36	0.42	0.38	-16.9	3.0
Canada	0.84	0.78	0.80	0.82	-4.6	4.8
Chile	0.85	0.76	0.63	0.59	-26.1	-22.8
Colombia	0.48	0.48	0.54	0.63	13.3	32.9
Denmark	0.73	0.64	0.67	0.73	-8.2	14.1
Dominican Republic	0.80	0.51	0.54	0.59	-32.3	17.3
Ecuador	0.42	0.59	0.40	0.52	-4.5	-12.9
Finland	0.66	0.54	0.67	0.70	1.4	30.6
France	0.85	0.71	0.87	0.93	2.4	31.2
Greece	0.55	0.48	0.61	0.63	10.8	31.5
Guatemala	0.96	0.68	0.85	0.55	-11.6	-18.6
Honduras	0.52	−−	0.44	−−	-14.3	−−
Hong Kong SAR, China	0.46	0.54	0.996	0.93	116.6	70.6
Iceland	0.94	0.83	0.87	0.79	-7.4	-4.6
India	0.44	0.38	0.47	0.31	7.2	-16.9
Ireland	0.67	0.60	0.82	0.86	22.4	42.9
Israel	0.61	0.60	0.80	0.83	30.3	40.0
Italy	0.76	0.58	1.00	1.00	32.1	71.6
Jamaica	0.62	0.67	0.54	0.49	-12.6	-27.8
Japan	0.54	0.46	0.60	0.76	10.2	64.6
Kenya	0.31	0.54	0.37	0.43	19.4	-20.4
Malawi	0.27	1.00	0.30	0.38	10.8	-62.3
Mauritius	1.00	1.00	0.99	0.94	-1.1	-5.6
Mexico	0.997	1.00	0.82	0.76	-17.7	-24.4
Netherlands	1.00	0.80	0.90	0.86	-10.4	8.3
New Zealand	0.83	0.78	0.66	0.68	-21.0	-13.9
Norway	0.78	0.71	0.65	0.68	-17.1	-3.5
Panama	0.46	−−	0.33	−−	-27.3	−−
Paraguay	0.98	0.65	1.00	0.42	2.5	-35.3
Peru	0.66	0.74	0.40	0.37	-38.4	-50.3

Continued on next page

Table B1 – *Continued from previous page*

Country	Efficiency 1965		Efficiency 1990		Efficiency Change (%)	
	PWT5.6	PWT10	PWT5.6	PWT10	PWT5.6	PWT10
Philippines	0.42	0.35	0.43	0.41	2.7	15.4
Portugal	0.75	0.67	0.92	0.72	21.9	7.2
Sierra Leone	1.00	−−	0.78	−−	-22.0	−−
South Korea	0.41	0.20	0.57	0.60	36.6	206.7
Spain	1.00	0.69	0.93	0.88	-7.3	26.7
Sri Lanka	0.33	0.79	0.35	0.53	4.7	-33.4
Sweden	0.84	0.66	0.72	0.73	-14.7	11.3
Switzerland	0.96	0.91	0.78	0.83	-19	-8.5
Syria	0.62	0.52	0.80	0.46	30.0	-12.6
Taiwan, China	0.52	0.62	0.62	0.99	17.9	60.5
Thailand	0.45	0.40	0.56	0.39	25.4	-3.1
Turkey	0.56	0.69	0.61	0.86	7.5	24.8
U.K.	0.92	0.64	0.91	0.84	-0.9	32.2
U.S.A.	1.00	0.89	0.90	0.89	-9.8	-0.8
West Germany	0.69	0.48	0.74	0.76	7.6	60.0
Yugoslavia	0.65	−−	0.55	−−	-15.5	−−
Zambia	0.48	0.70	0.33	0.26	-30.9	-62.4
Zimbabwe	0.21	0.74	0.25	1.00	19.4	34.8

TABLE B2. Overall Summary of Decomposition.

Metric	Data	Efficiency 1965	Efficiency 1990	ProdCh	EffCh	TechCh	KCh	HCh
Mean	PWT5.6	0.68	0.67	79.26	0.82	6.85	40.59	16.53
	PWT10	0.64	0.68	82.76	11.63	8.52	31.11	15.40
Median	PWT5.6	0.68	0.66	61.95	−1.00	1.45	29.55	14.70
	PWT10	0.65	0.72	56.15	7.75	7.85	19.05	15.35
SE	PWT5.6	0.02	0.02	8.16	2.48	0.93	3.72	0.89
	PWT10	0.02	0.02	9.65	4.38	0.74	3.91	0.80

TABLE B3. Percentage changes of quadripartite decomposition indexes (country groups)

Groups	Data	ProdCh	EffCh	TechCh	KCh	HCh
OECD	PWT5.6	83.3	0.4	14.3	39.5	14.8
	PWT10	93.1	22.5	9.4	23.6	16.5
Asian Tigers	PWT5.6	279.5	41.3	5.3	113.1	24.4
	PWT10	296.6	79.9	4.1	85.9	20.4
Latin America	PWT5.6	33.1	−17.2	0.5	38.2	16.6
	PWT10	38.0	−12.7	7.0	36.2	15.9
Africa	PWT5.6	18.0	−0.9	0.8	4.0	13.9
	PWT10	23.2	−23.2	13.2	40.0	7.7
Non-OECD	PWT5.6	76.1	0.9	1.2	41.4	18.0
	PWT10	73.3	1.7	7.7	38.0	14.4
All countries	PWT5.6	78.6	0.7	7.1	40.5	16.6
	PWT10	82.8	11.6	8.5	31.1	15.4

TABLE B4. Slope coefficients and t statistics of OLS regressions

Data	(EFF-1)×100	(TECH-1)×100	(KACC-1)×100	(HACC-1)×100
PWT5.6	-6.30*	8.87***	-14.35**	-2.10
	(-1.97)	(5.18)	(-2.25)	(-1.34)
PWT10	1.42	0.01	-10.71***	0.98
	(0.31)	(0.01)	(-2.72)	(1.30)

Note: t statistics in parenthesis, calculated based on robust standard errors. ***, ** and * indicate statistical significance (according to the two-sided asymptotic N(0,1) test) at the 0.01, 0.05, and 0.1 levels, respectively.

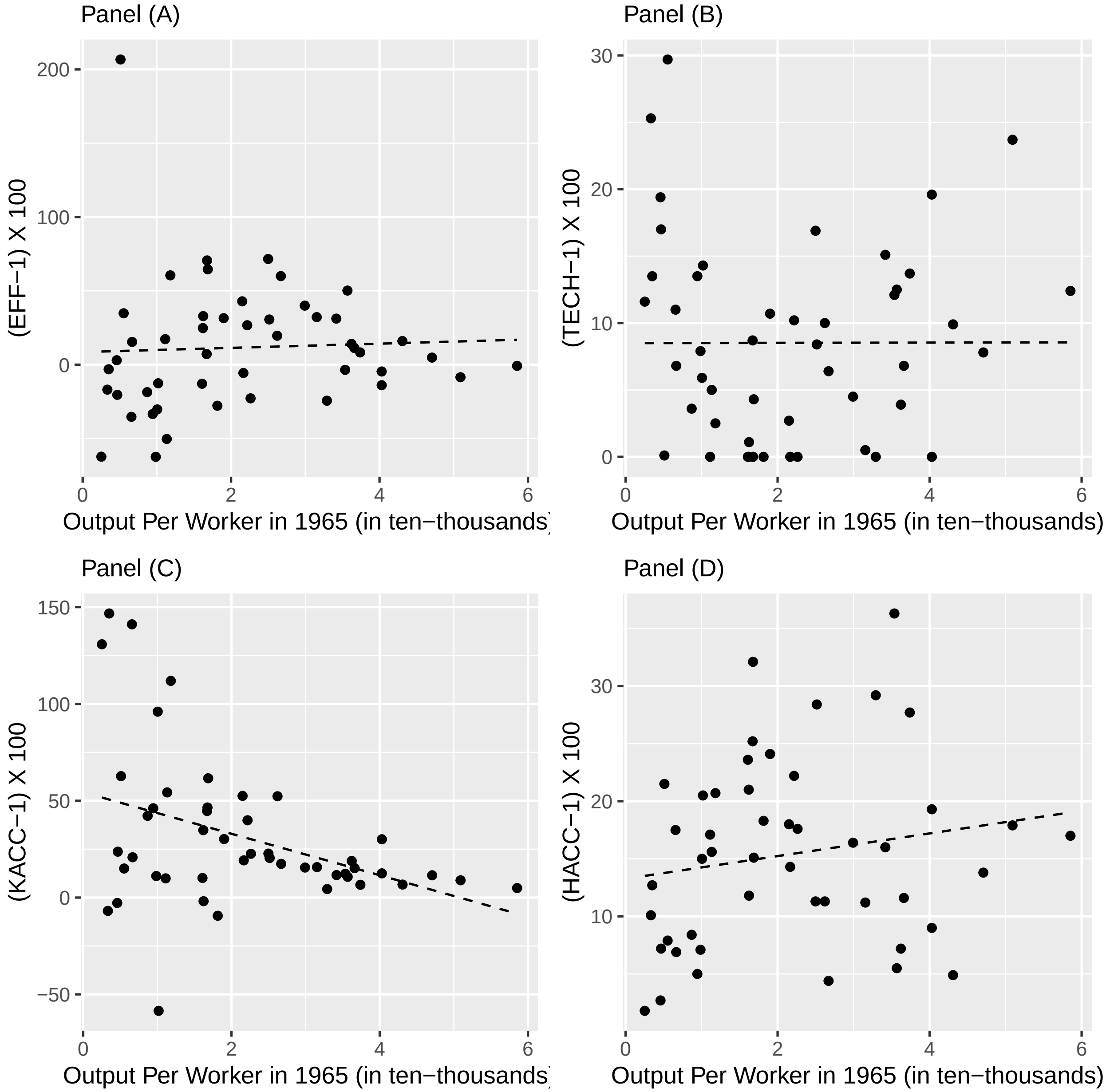


FIGURE B3. Four decomposition indexes plotted against 1965 output per worker.

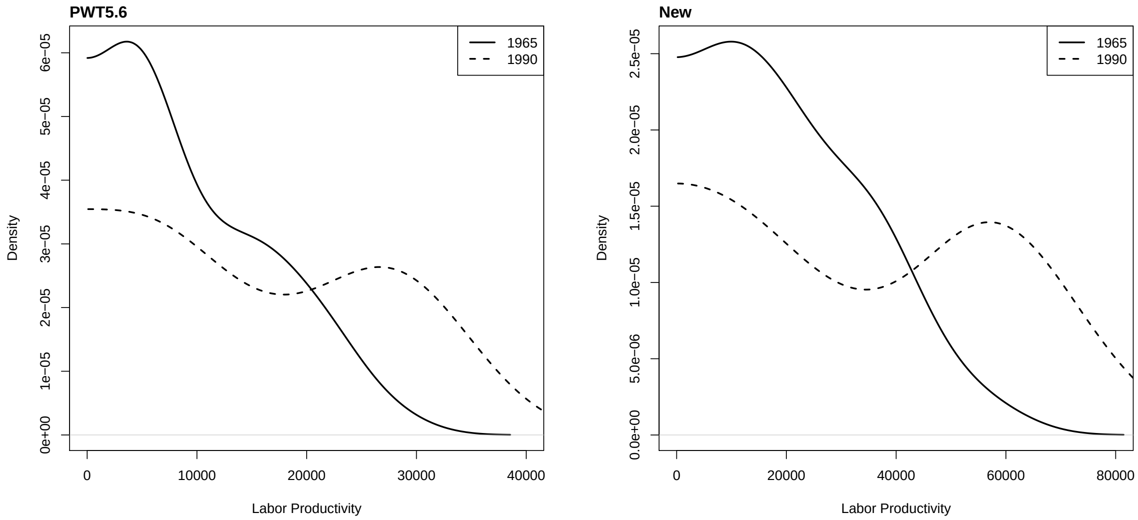


FIGURE B4. Labor productivity for PWT5.6 and PWT10

TABLE B5. Tests for Multi-modality of Distributions, p values.

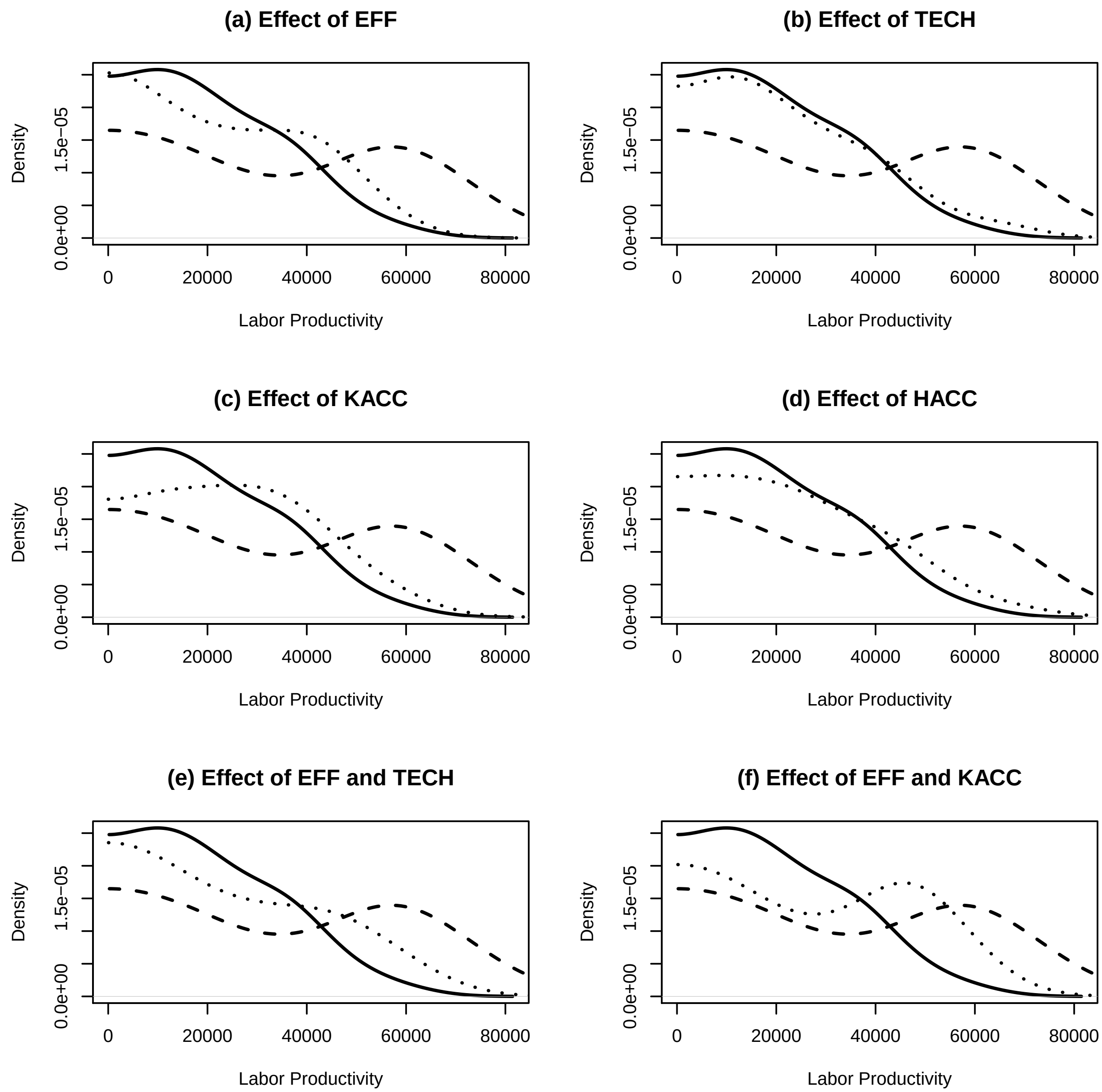
		H_0: One Mode H_A: More Than One Modes		H_0: Two Modes H_A: More Than Two Modes	
	Distribution	PWT10	PWT5.6	PWT10	PWT5.6
0	$f(y_{65})$	0.492	0.458	0.830	0.588
1	$f(y_{90})$	0.010	0.010	0.470	0.256
2	$f(y_{65} \times EFF)$	0.216	0.091	0.472	0.484
3	$f(y_{65} \times TECH)$	0.482	0.839	0.588	0.239
4	$f(y_{65} \times KACC)$	0.278	0.097	0.828	0.188
5	$f(y_{65} \times HACC)$	0.530	0.338	0.476	0.262
6	$f(y_{65} \times EFF \times TECH)$	0.490	0.155	0.554	0.545
7	$f(y_{65} \times EFF \times KACC)$	0.008	0.020	0.310	0.564
8	$f(y_{65} \times EFF \times HACC)$	0.024	0.042	0.478	0.412
9	$f(y_{65} \times TECH \times KACC)$	0.594	0.072	0.430	0.582
10	$f(y_{65} \times TECH \times HACC)$	0.440	0.663	0.922	0.645
11	$f(y_{65} \times KACC \times HACC)$	0.204	0.076	0.824	0.361
12	$f(y_{65} \times EFF \times TECH \times KACC)$	0.008	0.030	0.520	0.776
13	$f(y_{65} \times EFF \times TECH \times HACC)$	0.218	0.218	0.392	0.077
14	$f(y_{65} \times EFF \times KACC \times HACC)$	0.022	0.000	0.306	0.210
15	$f(y_{65} \times TECH \times KACC \times HACC)$	0.166	0.149	0.368	0.656

Note: We use the *multimode* package in R to test the number of modes and perform a calibrated Silverman test (Hall & York 2001) in the context of testing for a single mode to improve its level of accuracy.

TABLE B6. Distribution hypothesis tests

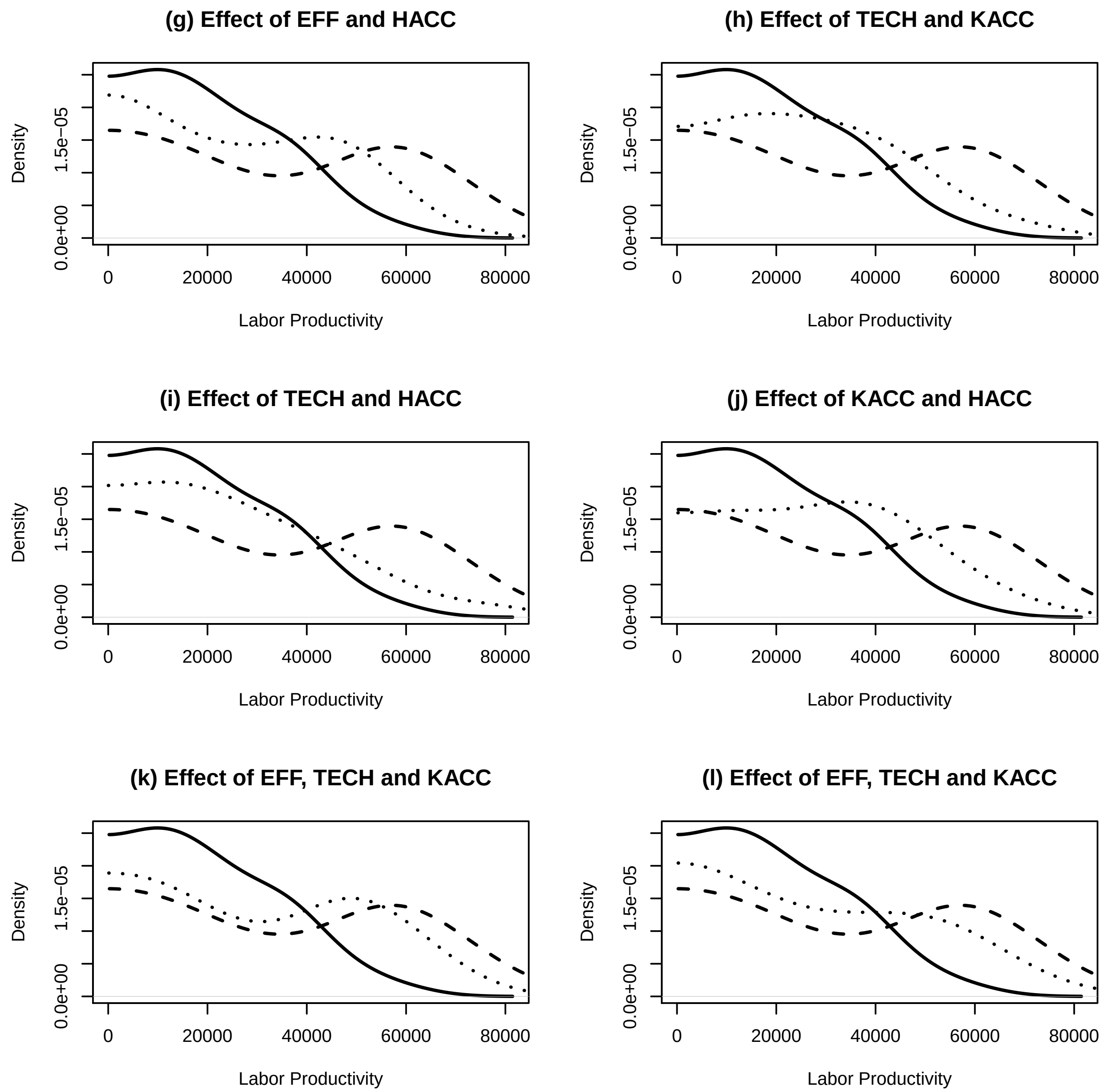
	H_0: Distributions are equal H_1: Distributions are not equal	Bootstrap p-value	10% significance level PWT10	 PWT5.6
1	$g(y_{90})$ vs. $f(y_{65})$	0.001	H_0 rejected	H_0 rejected
2	$g(y_{90})$ vs. $f(y_{65} \times EFF)$	0.000	H_0 rejected	H_0 rejected
3	$g(y_{90})$ vs. $f(y_{65} \times TECH)$	0.003	H_0 rejected	H_0 rejected
4	$g(y_{90})$ vs. $f(y_{65} \times KACC)$	0.001	H_0 rejected	H_0 rejected
5	$g(y_{90})$ vs. $f(y_{65} \times HACC)$	0.000	H_0 rejected	H_0 rejected
6	$g(y_{90})$ vs. $f(y_{65} \times EFF \times TECH)$	0.021	H_0 rejected	H_0 rejected
7	$g(y_{90})$ vs. $f(y_{65} \times EFF \times KACC)$	0.008	H_0 rejected	H_0 rejected
8	$g(y_{90})$ vs. $f(y_{65} \times EFF \times HACC)$	0.015	H_0 rejected	H_0 rejected
9	$g(y_{90})$ vs. $f(y_{65} \times TECH \times KACC)$	0.025	H_0 rejected	H_0 not rejected
10	$g(y_{90})$ vs. $f(y_{65} \times TECH \times HACC)$	0.016	H_0 rejected	H_0 rejected
11	$g(y_{90})$ vs. $f(y_{65} \times KACC \times HACC)$	0.003	H_0 rejected	H_0 not rejected
12	$g(y_{90})$ vs. $f(y_{65} \times EFF \times TECH \times KACC)$	0.219	H_0 not rejected	H_0 not rejected
13	$g(y_{90})$ vs. $f(y_{65} \times EFF \times TECH \times HACC)$	0.220	H_0 not rejected	H_0 rejected
14	$g(y_{90})$ vs. $f(y_{65} \times EFF \times KACC \times HACC)$	0.666	H_0 not rejected	H_0 not rejected
15	$g(y_{90})$ vs. $f(y_{65} \times TECH \times KACC \times HACC)$	0.098	H_0 rejected	H_0 not rejected

Note: We make decisions based on 10% level of significance due to the small sample size.



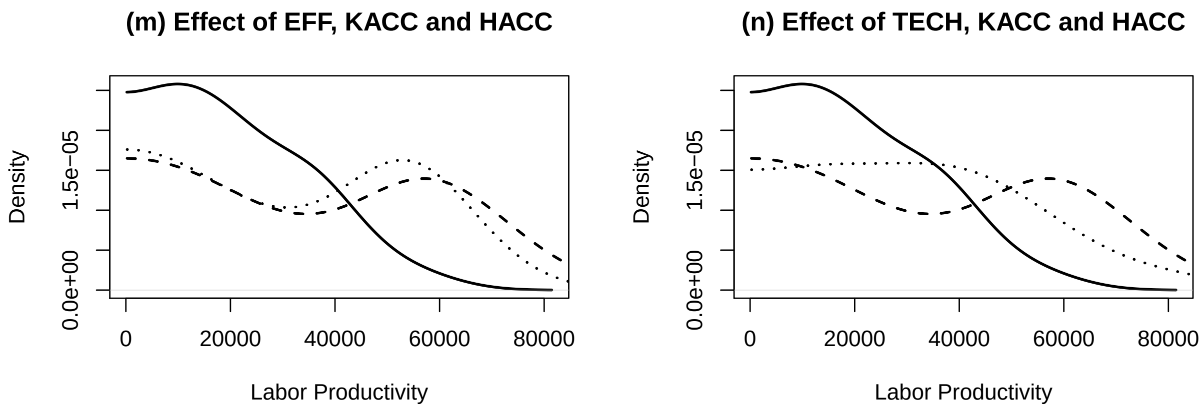
Note: In each panel, the solid curve is the actual 1965 distribution of output per worker, whereas the dashed curve is the actual 1990 distribution of output per worker. The dotted curves of each panel are the counterfactual distributions isolating the effects of components as labeled.

FIGURE B5. Counterfactual distributions of output per worker



Note: In each panel, the solid curve is the actual 1965 distribution of output per worker, whereas the dashed curve is the actual 1990 distribution of output per worker. The dotted curves of each panel are the counterfactual distributions isolating the effects of components as labeled.

FIGURE B5. Counterfactual distributions of output per worker (continued)



Note: In each panel, the solid curve is the actual 1965 distribution of output per worker, whereas the dashed curve is the actual 1990 distribution of output per worker. The dotted curves of each panel are the counterfactual distributions isolating the effects of components as labeled.

FIGURE B5. Counterfactual distributions of output per worker (continued)

SUPPLEMENTARY MATERIAL C: ESTIMATION RESULTS USING HC AS PROVIDED IN PWT10 BUT USING OUTPUT, PHYSICAL CAPITAL AND LABOR INPUTS AS IN HR.

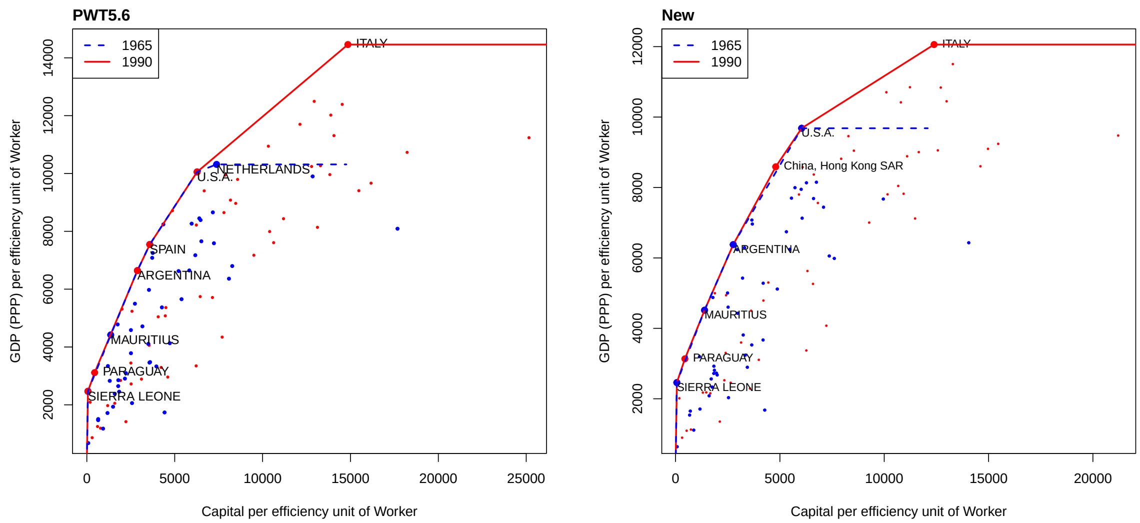


FIGURE C1. Estimated frontiers in 1965 and 1990.

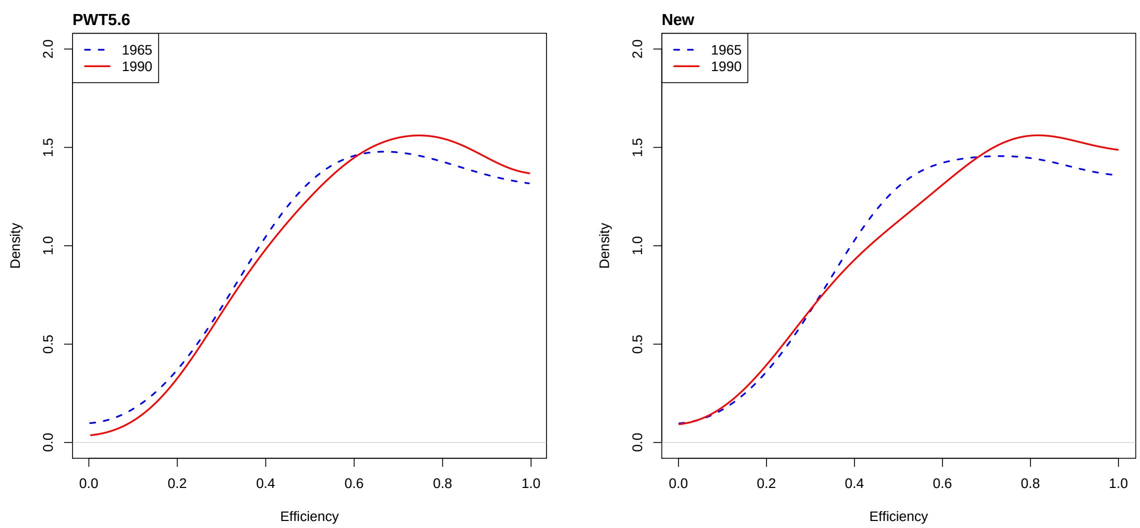


FIGURE C2. Efficiency indexes for 1965 and 1990

TABLE C1. Efficiency scores for 1965 and 1990

Country	Efficiency 1965		Efficiency 1990		Efficiency Change (%)	
	PWT5.6	PWT10	PWT5.6	PWT10	PWT5.6	PWT10
Argentina	1.00	1.00	0.64	0.65	-36.1	-35.4
Australia	0.74	0.77	0.76	0.77	3.5	-0.1
Austria	0.80	0.79	0.75	0.76	-5.8	-3.8
Belgium	0.72	0.79	0.86	0.95	19.5	20.2
Bolivia	0.50	0.52	0.42	0.40	-16.9	-23.7
Canada	0.84	0.84	0.80	0.87	-4.6	2.9
Chile	0.85	0.83	0.63	0.62	-26.1	-26.1
Colombia	0.48	0.47	0.54	0.53	13.3	13.4
Denmark	0.73	0.75	0.67	0.70	-8.2	-6.5
Dominican Republic	0.80	0.77	0.54	0.53	-32.3	-31.3
Ecuador	0.42	0.41	0.40	0.40	-4.5	-1.9
Finland	0.66	0.63	0.67	0.77	1.4	22.5
France	0.85	0.84	0.87	0.90	2.4	7.3
Greece	0.55	0.56	0.61	0.64	10.8	15.7
Guatemala	0.96	0.96	0.85	0.84	-11.6	-13.4
Honduras	0.52	0.50	0.44	0.44	-14.3	-13.2
Hong Kong SAR, China	0.46	0.49	1.00	1.00	116.6	106.1
Iceland	0.94	0.97	0.87	0.90	-7.4	-7.5
India	0.44	0.45	0.47	0.49	7.2	9.7
Ireland	0.67	0.67	0.82	0.85	22.4	26.2
Israel	0.61	0.60	0.80	0.76	30.3	26.0
Italy	0.76	0.74	1.00	1.00	32.1	35.8
Jamaica	0.62	0.54	0.54	0.47	-12.6	-13.4
Japan	0.54	0.52	0.60	0.61	10.2	17.8
Kenya	0.31	0.30	0.37	0.34	19.4	12.3
Mauritius	1.00	1.00	0.99	0.96	-1.1	-3.6
Malawi	0.27	0.26	0.30	0.31	10.8	20.0
Mexico	1.00	0.95	0.82	0.82	-17.7	-14.5
Netherlands	1.00	0.85	0.90	0.91	-10.4	6.4
New Zealand	0.83	0.84	0.66	0.70	-21.0	-17.2
Norway	0.78	0.66	0.65	0.75	-17.1	13.6
Panama	0.46	0.47	0.33	0.35	-27.3	-25.9
Paraguay	0.98	0.97	1.00	1.00	2.50	3.0
Peru	0.66	0.67	0.40	0.40	-38.4	-40.3

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Table C1 – *Continued from previous page*

	Efficiency 1965		Efficiency 1990		Efficiency Change (%)	
Country	PWT5.6	PWT10	PWT5.6	PWT10	PWT5.6	PWT10
Philippines	0.42	0.43	0.43	0.44	2.7	1.7
Portugal	0.75	0.76	0.92	0.88	21.9	16.1
Sierra Leone	1.00	1.00	0.78	0.76	-22.0	-24.5
South Korea	0.41	0.41	0.57	0.58	36.6	40.6
Spain	1.00	0.95	0.93	0.93	-7.3	-1.6
Sri Lanka	0.33	0.33	0.35	0.32	4.7	-5.5
Sweden	0.84	0.82	0.72	0.75	-14.7	-8.8
Switzerland	0.96	0.79	0.78	0.79	-19.0	-0.8
Syria	0.62	0.62	0.80	0.85	30.0	37.8
Taiwan, China	0.52	0.53	0.62	0.68	17.9	27.9
Thailand	0.45	0.48	0.56	0.56	25.4	17.6
Turkey	0.56	0.57	0.61	0.60	7.5	5.5
U.K.	0.92	0.91	0.91	0.85	-0.9	-7.0
U.S.A.	1.00	1.00	0.90	0.96	-9.8	-4.4
West Germany	0.69	0.69	0.74	0.71	7.6	4.1
Yugoslavia	0.65	−−	0.55	−−	-15.5	−−
Zambia	0.48	0.47	0.33	0.32	-30.9	-32.2
Zimbabwe	0.21	0.21	0.25	0.25	19.4	15.6

TABLE C2. Overall Summary of Decomposition.

		Efficiency						
Metric	Data	1965	1990	ProdCh	EffCh	TechCh	KCh	HCh
Mean	PWT5.6	0.68	0.67	79.26	0.82	6.85	40.59	16.53
	PWT10	0.67	0.68	79.08	3.20	5.16	36.72	17.94
Median	PWT5.6	0.68	0.66	61.95	−1.00	1.45	29.55	14.70
	PWT10	0.67	0.71	60.70	1.70	1.70	25.70	17.30
SE	PWT5.6	0.02	0.02	8.16	2.48	0.93	3.72	0.89
	PWT10	0.02	0.02	8.24	2.43	0.59	3.44	0.72

TABLE C3. Percentage changes of quadripartite decomposition indexes (country groups)

Groups	Data	ProdCh	EffCh	TechCh	KCh	HCh
OECD	PWT5.6	83.3	0.4	14.3	39.5	14.8
	PWT10	83.3	5.9	9.8	35.6	16.1
Asian Tigers	PWT5.6	279.5	41.3	5.3	113.1	24.4
	PWT10	279.6	42.0	4.4	103.9	28.7
Latin America	PWT5.6	33.1	−17.2	0.5	38.2	16.6
	PWT10	38.0	−15.3	2.5	37.6	16.8
Africa	PWT5.6	18.0	−0.9	0.8	4.0	13.9
	PWT10	18.0	−2.1	0.8	4.3	15.2
Non-OECD	PWT5.6	76.1	0.9	1.2	41.4	18.0
	PWT10	75.7	1.0	1.4	37.7	19.4
All countries	PWT5.6	78.6	0.7	7.1	40.5	16.6
	PWT10	79.1	3.2	5.2	36.7	17.9

TABLE C4. Slope coefficients and t statistics of OLS regressions

Data	(EFF-1)×100	(TECH-1)×100	(KACC-1)×100	(HACC-1)×100
PWT5.6	-6.30*	8.87***	-14.35**	-2.10
	(-1.97)	(5.18)	(-2.25)	(-1.34)
PWT10	-2.33	5.85***	-14.25**	-3.23**
	(-0.72)	(6.31)	(-2.40)	(-2.47)

Note: t statistics in parenthesis, calculated based on robust standard errors. ***, ** and * indicate statistical significance (according to the two-sided asymptotic N(0,1) test) at the 0.01, 0.05, and 0.1 levels, respectively.

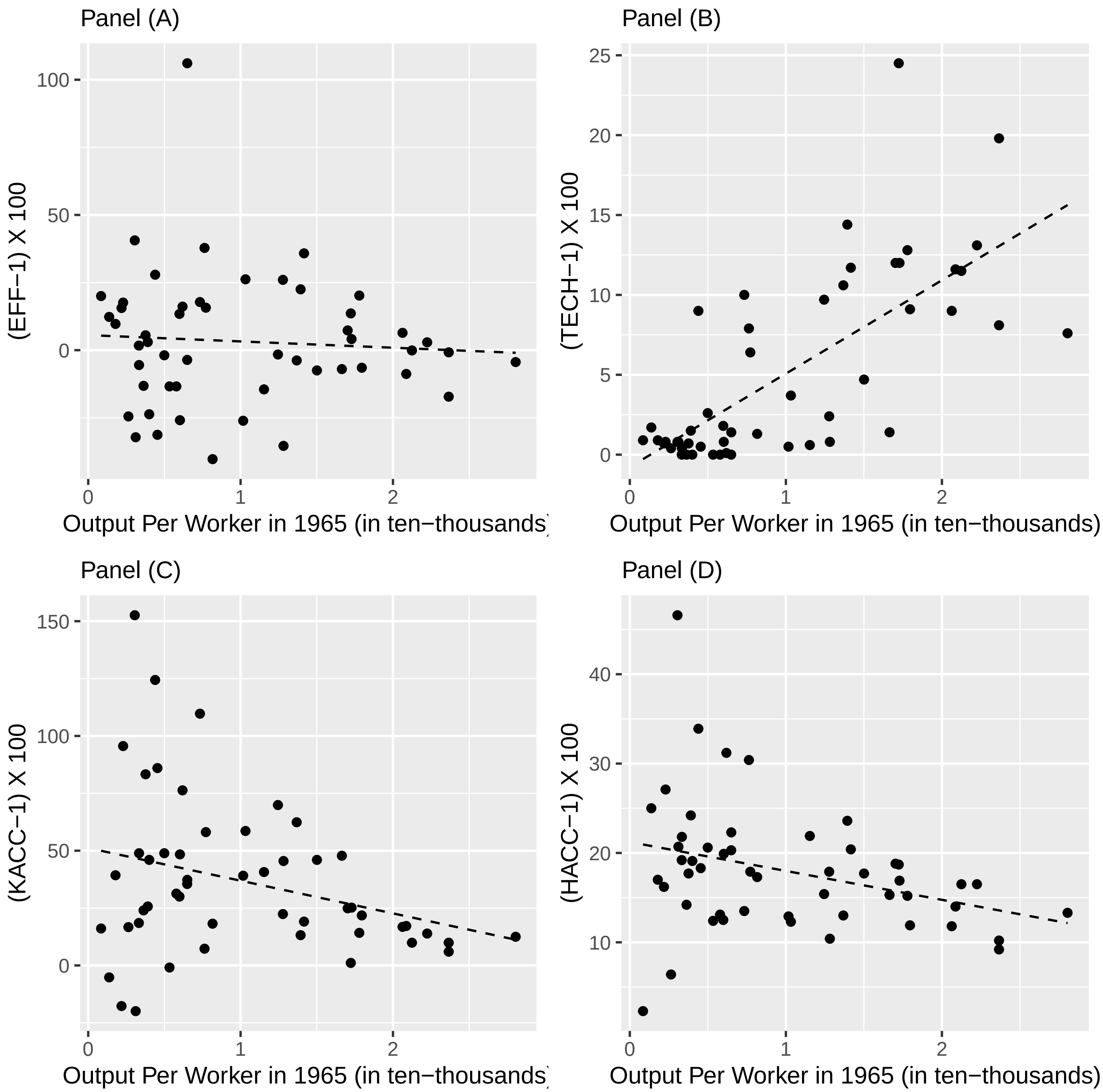


FIGURE C3. Four decomposition indexes plotted against 1965 output per worker.

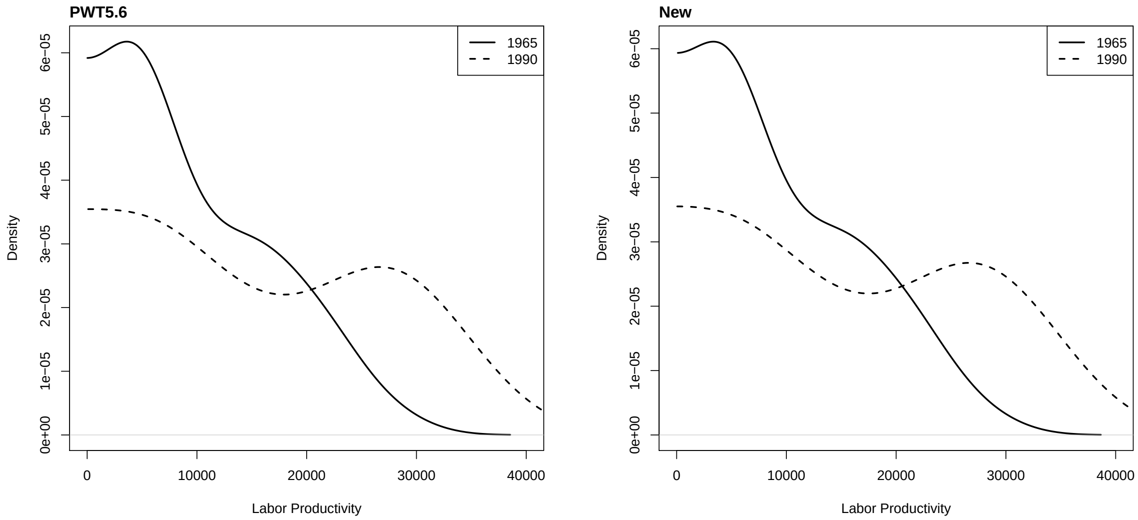


FIGURE C4. Labor productivity for PWT5.6 and PWT10

TABLE C5. Tests for Multi-modality of Distributions, p values.

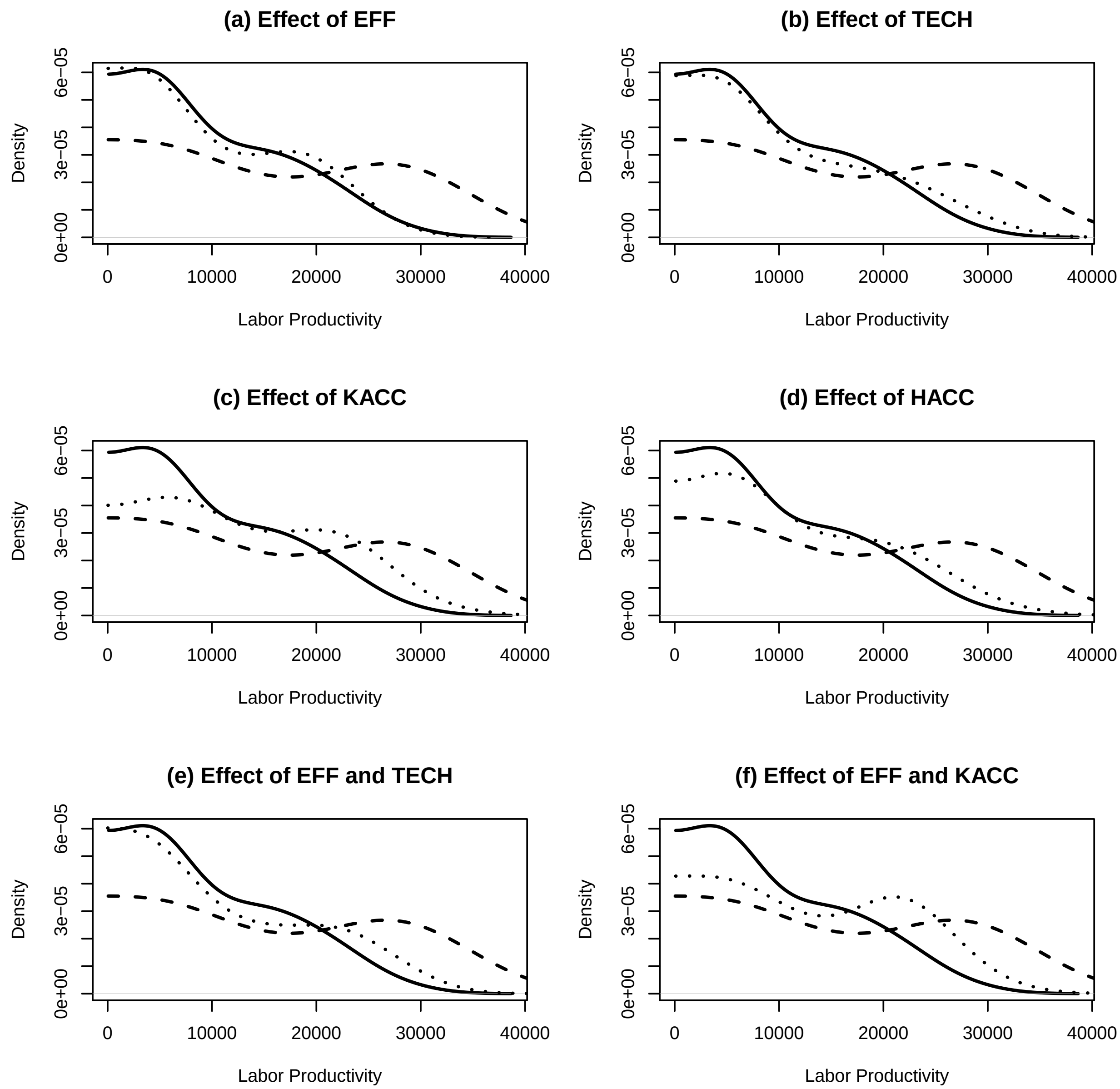
		H_0: One Mode H_A: More Than One Modes		H_0: Two Modes H_A: More Than Two Modes	
	Distribution	PWT10	PWT5.6	PWT10	PWT5.6
0	$f(y_{65})$	0.426	0.458	0.734	0.588
1	$f(y_{90})$	0.006	0.010	0.306	0.256
2	$f(y_{65} \times EFF)$	0.146	0.091	0.662	0.484
3	$f(y_{65} \times TECH)$	0.746	0.839	0.782	0.239
4	$f(y_{65} \times KACC)$	0.104	0.097	0.386	0.188
5	$f(y_{65} \times HACC)$	0.310	0.338	0.678	0.262
6	$f(y_{65} \times EFF \times TECH)$	0.252	0.155	0.382	0.545
7	$f(y_{65} \times EFF \times KACC)$	0.014	0.020	0.594	0.564
8	$f(y_{65} \times EFF \times HACC)$	0.120	0.042	0.434	0.412
9	$f(y_{65} \times TECH \times KACC)$	0.078	0.072	0.376	0.582
10	$f(y_{65} \times TECH \times HACC)$	0.514	0.663	0.852	0.645
11	$f(y_{65} \times KACC \times HACC)$	0.072	0.076	0.520	0.361
12	$f(y_{65} \times EFF \times TECH \times KACC)$	0.020	0.030	0.646	0.776
13	$f(y_{65} \times EFF \times TECH \times HACC)$	0.252	0.218	0.256	0.077
14	$f(y_{65} \times EFF \times KACC \times HACC)$	0.006	0.000	0.218	0.210
15	$f(y_{65} \times TECH \times KACC \times HACC)$	0.112	0.149	0.404	0.656

Note: We use the *multimode* package in R to test the number of modes and perform a calibrated Silverman test (Hall & York 2001) in the context of testing for a single mode to improve its level of accuracy.

TABLE C6. Distribution hypothesis tests

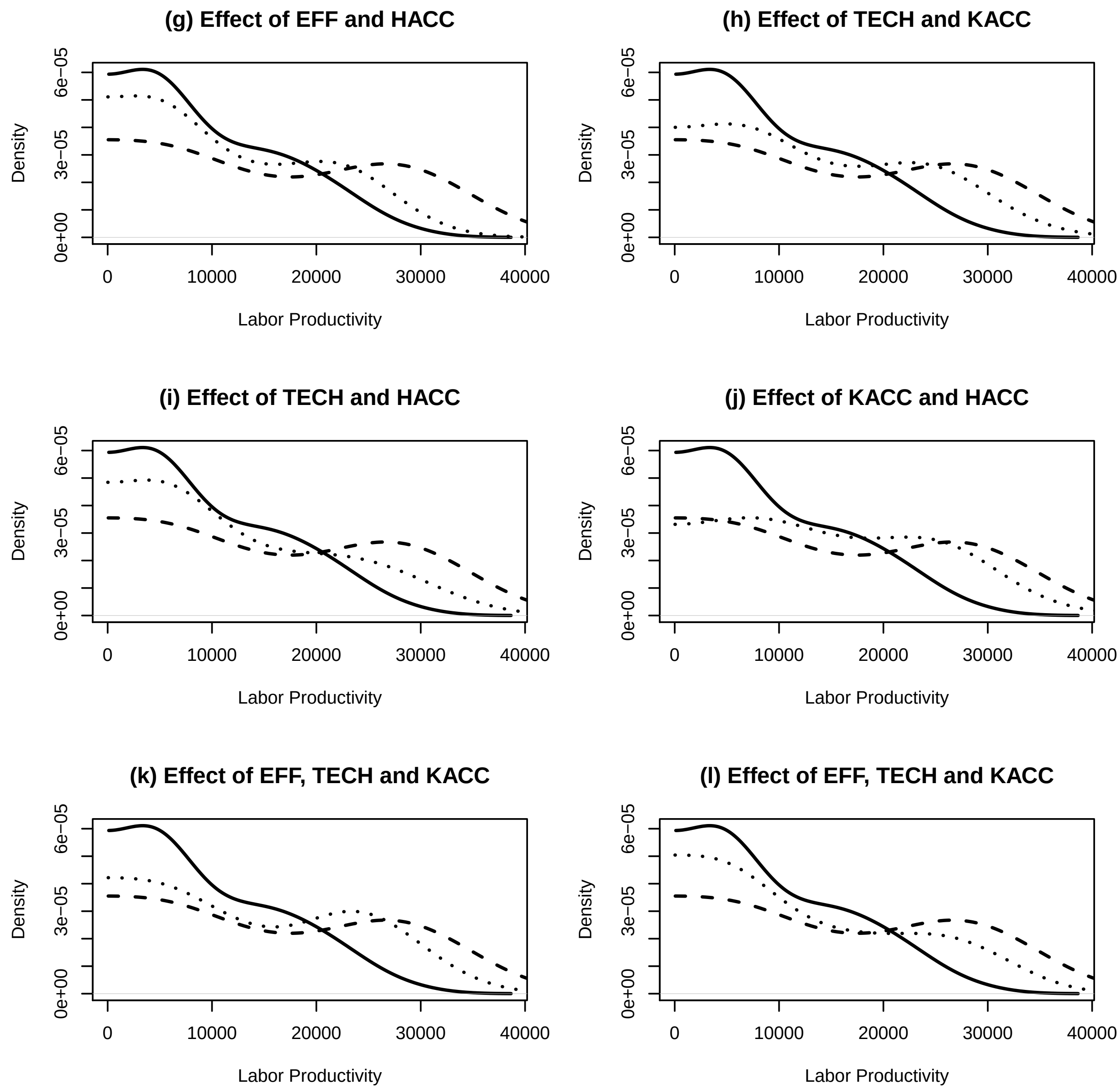
	H_0: Distributions are equal H_1: Distributions are not equal	Bootstrap p-value	10% significance level PWT10	 PWT5.6
1	$g(y_{90})$ vs. $f(y_{65})$	0.008	H_0 rejected	H_0 rejected
2	$g(y_{90})$ vs. $f(y_{65} \times EFF)$	0.003	H_0 rejected	H_0 rejected
3	$g(y_{90})$ vs. $f(y_{65} \times TECH)$	0.037	H_0 rejected	H_0 rejected
4	$g(y_{90})$ vs. $f(y_{65} \times KACC)$	0.109	H_0 not rejected	H_0 rejected
5	$g(y_{90})$ vs. $f(y_{65} \times HACC)$	0.065	H_0 rejected	H_0 rejected
6	$g(y_{90})$ vs. $f(y_{65} \times EFF \times TECH)$	0.027	H_0 rejected	H_0 rejected
7	$g(y_{90})$ vs. $f(y_{65} \times EFF \times KACC)$	0.010	H_0 rejected	H_0 rejected
8	$g(y_{90})$ vs. $f(y_{65} \times EFF \times HACC)$	0.086	H_0 rejected	H_0 rejected
9	$g(y_{90})$ vs. $f(y_{65} \times TECH \times KACC)$	0.611	H_0 not rejected	H_0 not rejected
10	$g(y_{90})$ vs. $f(y_{65} \times TECH \times HACC)$	0.296	H_0 not rejected	H_0 rejected
11	$g(y_{90})$ vs. $f(y_{65} \times KACC \times HACC)$	0.406	H_0 not rejected	H_0 not rejected
12	$g(y_{90})$ vs. $f(y_{65} \times EFF \times TECH \times KACC)$	0.373	H_0 not rejected	H_0 not rejected
13	$g(y_{90})$ vs. $f(y_{65} \times EFF \times TECH \times HACC)$	0.583	H_0 not rejected	H_0 rejected
14	$g(y_{90})$ vs. $f(y_{65} \times EFF \times KACC \times HACC)$	0.715	H_0 not rejected	H_0 not rejected
15	$g(y_{90})$ vs. $f(y_{65} \times TECH \times KACC \times HACC)$	0.737	H_0 not rejected	H_0 not rejected

Note: We make decisions based on 10% level of significance due to the small sample size.



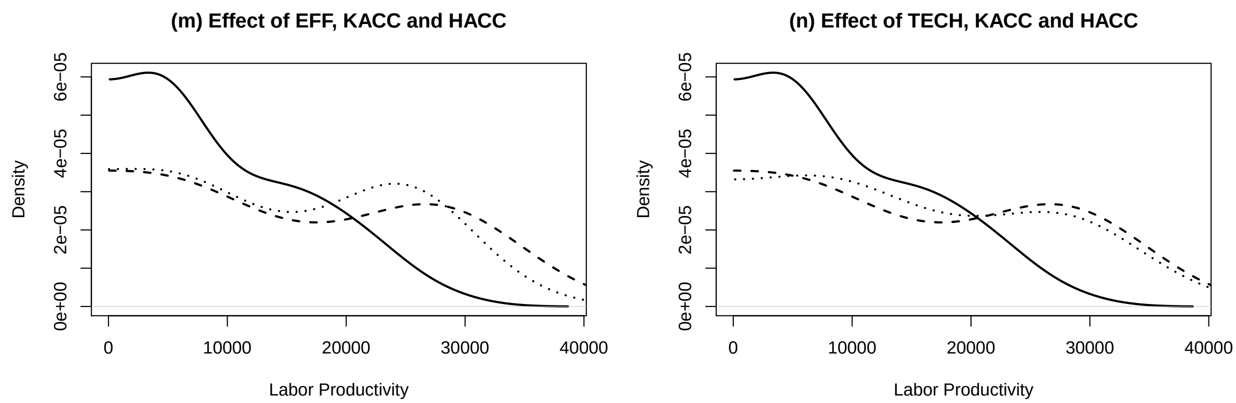
Note: In each panel, the solid curve is the actual 1965 distribution of output per worker, whereas the dashed curve is the actual 1990 distribution of output per worker. The dotted curves of each panel are the counterfactual distributions isolating the effects of components as labeled.

FIGURE C5. Counterfactual distributions of output per worker



Note: In each panel, the solid curve is the actual 1965 distribution of output per worker, whereas the dashed curve is the actual 1990 distribution of output per worker. The dotted curves of each panel are the counterfactual distributions isolating the effects of components as labeled.

FIGURE C5. Counterfactual distributions of output per worker (continued)



Note: In each panel, the solid curve is the actual 1965 distribution of output per worker, whereas the dashed curve is the actual 1990 distribution of output per worker. The dotted curves of each panel are the counterfactual distributions isolating the effects of components as labeled.

FIGURE C5. Counterfactual distributions of output per worker (continued)

SUPPLEMENTARY MATERIAL D: ESTIMATION RESULTS USING PWT5.6, EXCLUDING HONDURAS, PANAMA, SIERRA LEONE AND YUGOSLAVIA.

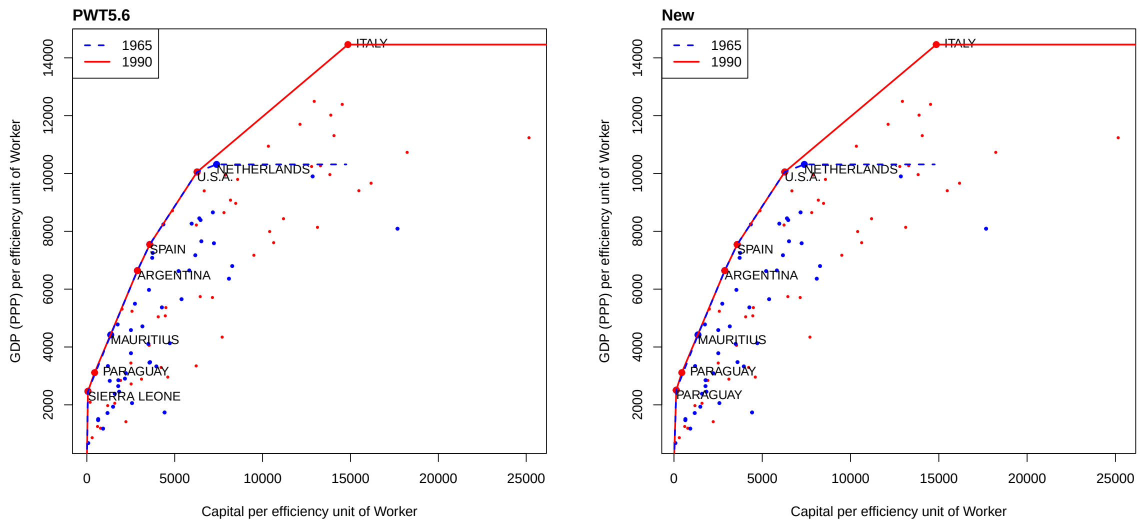


FIGURE D1. Estimated frontiers in 1965 and 1990.

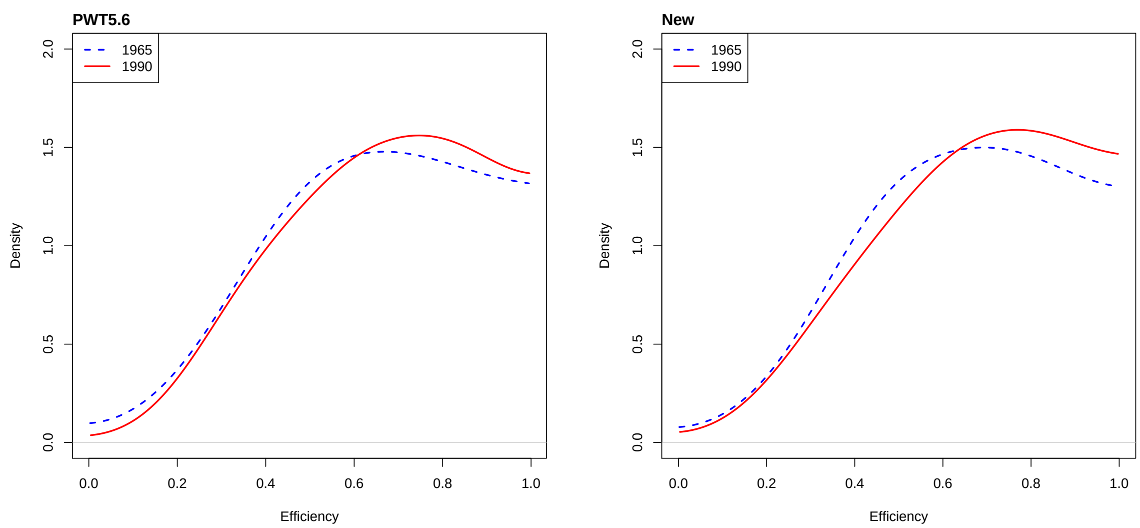


FIGURE D2. Efficiency indexes for 1965 and 1990

TABLE D1. Efficiency scores for 1965 and 1990

	Efficiency 1965		Efficiency 1990		Efficiency Change (%)	
Country	PWT5.6	PWT10	PWT5.6	PWT10	PWT5.6	PWT10
Argentina	1.00	1.00	0.64	0.64	-36.1	-36.1
Australia	0.74	0.74	0.76	0.76	3.5	3.5
Austria	0.80	0.80	0.75	0.75	-5.8	-5.8
Belgium	0.72	0.72	0.86	0.86	19.5	19.5
Bolivia	0.50	0.50	0.42	0.42	-16.9	-16.9
Canada	0.84	0.84	0.80	0.80	-4.6	-4.6
Chile	0.85	0.85	0.63	0.63	-26.1	-26.1
Colombia	0.48	0.48	0.54	0.54	13.3	13.3
Denmark	0.73	0.73	0.67	0.67	-8.2	-8.2
Dominican Republic	0.80	0.80	0.54	0.54	-32.3	-32.4
Ecuador	0.42	0.42	0.40	0.40	-4.5	-4.5
Finland	0.66	0.66	0.67	0.67	1.4	1.4
France	0.85	0.85	0.87	0.87	2.4	2.4
Greece	0.55	0.55	0.61	0.61	10.8	10.8
Guatemala	0.96	0.96	0.85	0.85	-11.6	-11.6
Honduras	0.52	−−	0.44	−−	-14.3	−−
Hong Kong SAR, China	0.46	0.46	1.00	1.00	116.6	116.6
Iceland	0.94	0.94	0.87	0.87	-7.4	-7.4
India	0.44	0.44	0.47	0.47	7.2	6
Ireland	0.67	0.67	0.82	0.82	22.4	22.4
Israel	0.61	0.61	0.80	0.80	30.3	30.3
Italy	0.76	0.76	1.00	1.00	32.1	32.1
Jamaica	0.62	0.62	0.54	0.54	-12.6	-12.6
Japan	0.54	0.54	0.60	0.60	10.2	10.2
Kenya	0.31	0.31	0.37	0.37	19.4	18.7
Malawi	0.27	0.43	0.30	0.30	10.8	-29.1
Mauritius	1.00	1.00	0.99	0.99	-1.1	-1.1
Mexico	1.00	1.00	0.82	0.82	-17.7	-17.7
Netherlands	1.00	1.00	0.90	0.90	-10.4	-10.4
New Zealand	0.83	0.83	0.66	0.66	-21.0	-21
Norway	0.78	0.78	0.65	0.65	-17.1	-17.1
Panama	0.46	−−	0.33	−−	-27.3	−−
Paraguay	0.98	1.00	1.00	1.00	2.5	0
Peru	0.66	0.66	0.40	0.40	-38.4	-38.4

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Table D1 – *Continued from previous page*

	Efficiency 1965		Efficiency 1990		Efficiency Change (%)	
Country	PWT5.6	PWT10	PWT5.6	PWT10	PWT5.6	PWT10
Philippines	0.42	0.42	0.43	0.43	2.7	2.7
Portugal	0.75	0.75	0.92	0.92	21.9	21.9
Sierra Leone	1.00	−−	0.78	−−	-22.0	−−
South Korea	0.41	0.42	0.57	0.57	36.6	36.3
Spain	1.00	1.00	0.93	0.93	-7.3	-7.3
Sri Lanka	0.33	0.33	0.35	0.35	4.7	4.7
Sweden	0.84	0.84	0.72	0.72	-14.7	-14.7
Switzerland	0.96	0.96	0.78	0.78	-19.0	-19
Syria	0.62	0.62	0.80	0.80	30.0	30
Taiwan, China	0.52	0.52	0.62	0.62	17.9	17.9
Thailand	0.45	0.46	0.56	0.56	25.4	24
Turkey	0.56	0.56	0.61	0.61	7.5	7.5
U.K.	0.92	0.92	0.91	0.91	-0.9	-0.9
U.S.A.	1.00	1.00	0.90	0.90	-9.8	-9.8
West Germany	0.69	0.69	0.74	0.74	7.6	7.6
Yugoslavia	0.65	−−	0.55	−−	-15.5	−−
Zambia	0.48	0.48	0.33	0.33	-30.9	-30.9
Zimbabwe	0.21	0.21	0.25	0.25	19.4	19.4

TABLE D2. Overall Summary of Decomposition.

		Efficiency						
Metric	Data	1965	1990	ProdCh	EffCh	TechCh	KCh	HCh
Mean	PWT5.6	0.68	0.67	79.26	0.82	6.85	40.59	16.53
	PWT10	0.69	0.68	82.98	1.58	7.48	42.19	16.28
Median	PWT5.6	0.68	0.66	61.95	−1.00	1.45	29.55	14.70
	PWT10	0.71	0.67	64.80	-0.45	2.50	35.65	14.45
SE	PWT5.6	0.02	0.02	8.16	2.48	0.93	3.72	0.89
	PWT10	0.02	0.02	8.33	2.53	0.94	3.83	0.90

TABLE D3. Percentage changes of quadripartite decomposition indexes (country groups)

Groups	Data	ProdCh	EffCh	TechCh	KCh	HCh
OECD	PWT5.6	83.3	0.4	14.3	39.5	14.8
	PWT10	83.3	0.6	14.1	39.5	14.8
Asian Tigers	PWT5.6	279.5	41.3	5.3	113.1	24.4
	PWT10	279.6	41.0	5.3	113.5	24.5
Latin America	PWT5.6	33.1	−17.2	0.5	38.2	16.6
	PWT10	40.1	-16.3	4.2	41.1	15.5
Africa	PWT5.6	18.0	−0.9	0.8	4.0	13.9
	PWT10	22.7	-4.6	1.1	16.8	14.3
Non-OECD	PWT5.6	76.1	0.9	1.2	41.4	18.0
	PWT10	82.7	2.5	1.4	44.6	17.6
All countries	PWT5.6	78.6	0.7	7.1	40.5	16.6
	PWT10	83.0	1.6	7.5	42.2	16.3

TABLE D4. Slope coefficients and t statistics of OLS regressions

Data	(EFF-1)×100	(TECH-1)×100	(KACC-1)×100	(HACC-1)×100
PWT5.6	-6.30*	8.87***	-14.35**	-2.10
	(-1.97)	(5.18)	(-2.25)	(-1.34)
PWT10	-6.93*	8.61***	-18.73***	-1.94
	(-1.89)	(4.95)	(-2.69)	(-1.16)

Note: t statistics in parenthesis, calculated based on robust standard errors. ***, ** and * indicate statistical significance (according to the two-sided asymptotic N(0,1) test) at the 0.01, 0.05, and 0.1 levels, respectively.

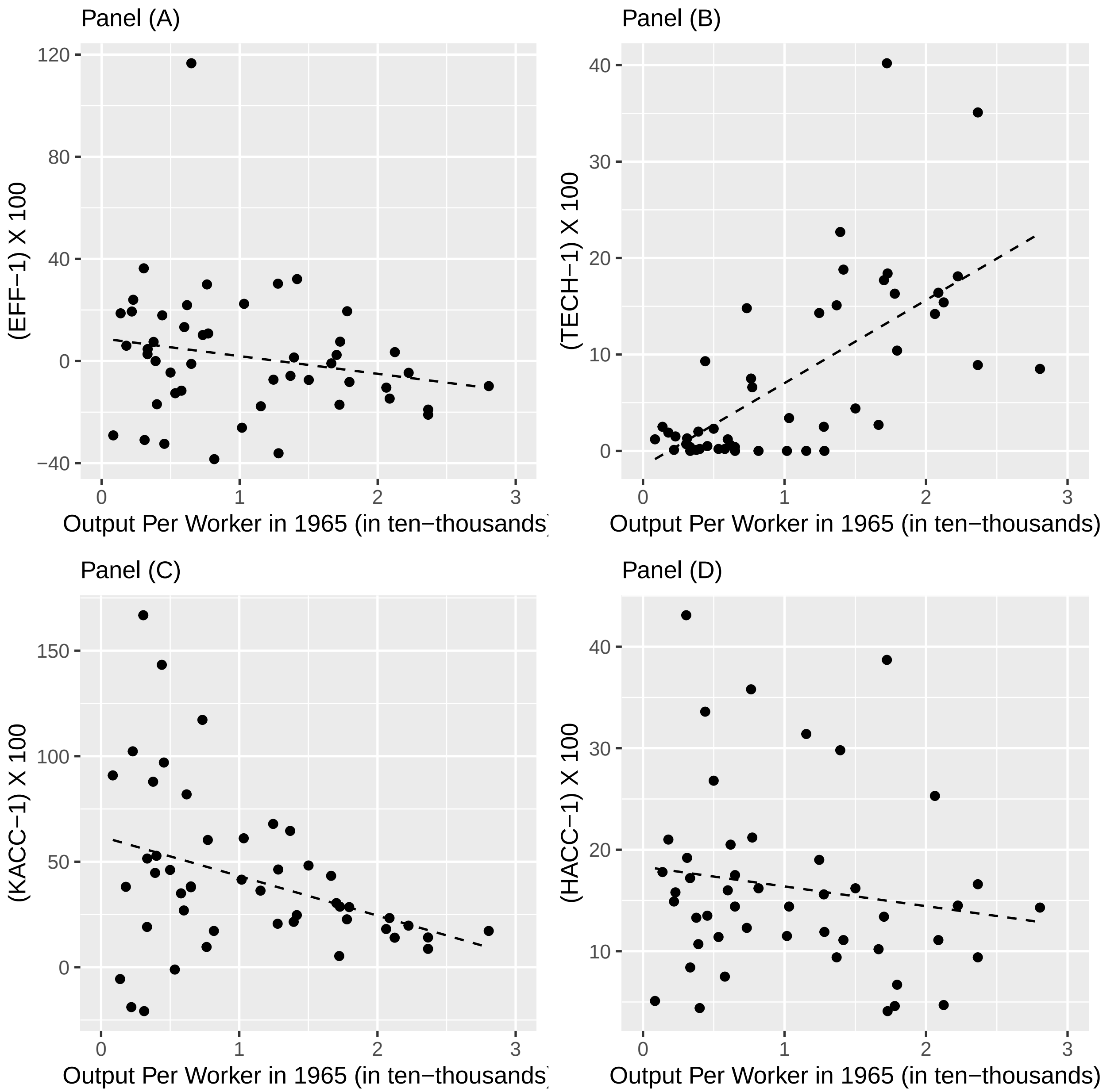


FIGURE D3. Four decomposition indexes plotted against 1965 output per worker.

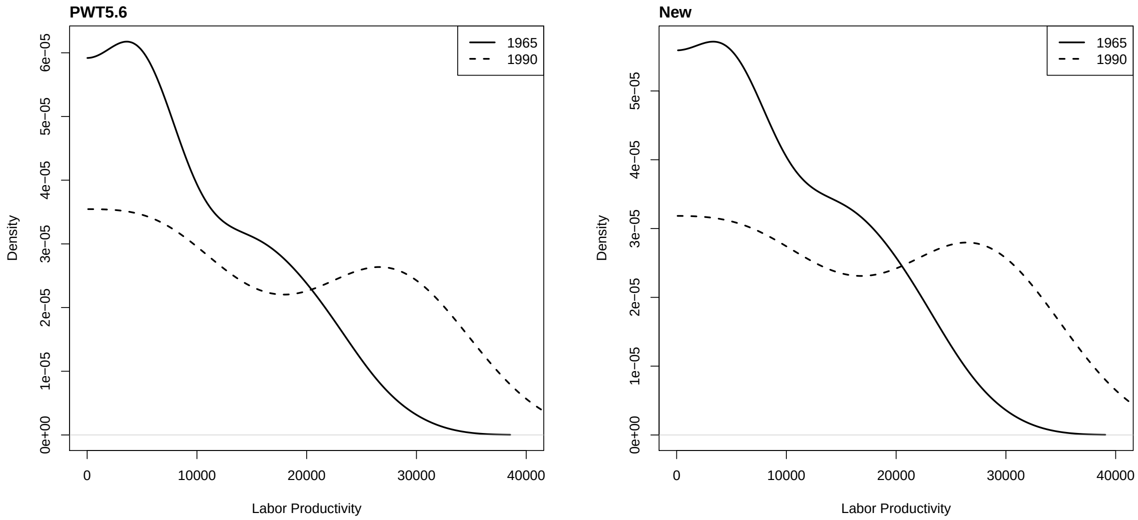


FIGURE D4. Labor productivity for PWT5.6 and PWT10

TABLE D5. Tests for Multi-modality of Distributions, p values.

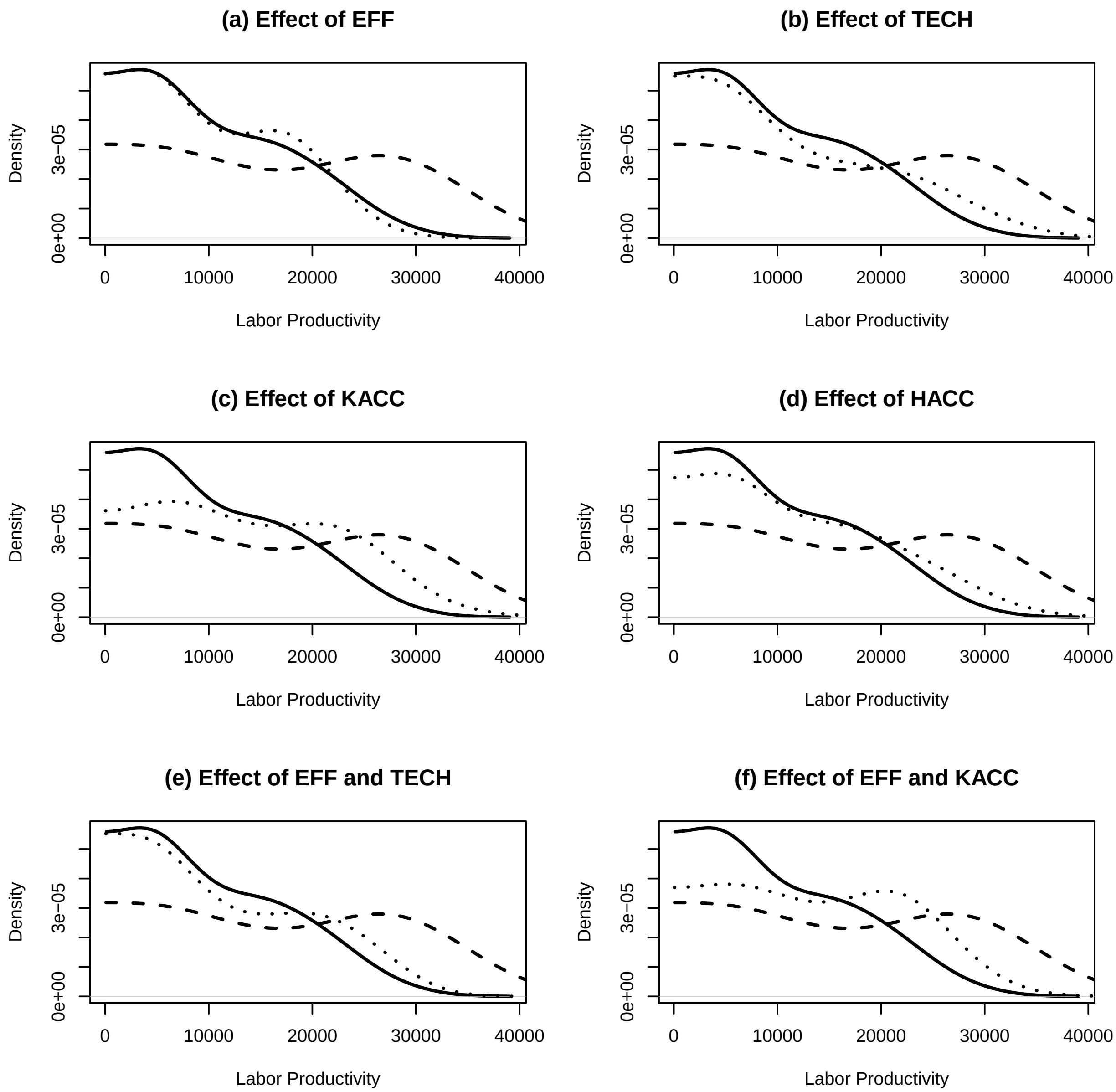
		H_0: One Mode H_A: More Than One Modes		H_0: Two Modes H_A: More Than Two Modes	
	Distribution	PWT10	PWT5.6	PWT10	PWT5.6
0	$f(y_{65})$	0.492	0.458	0.830	0.588
1	$f(y_{90})$	0.010	0.010	0.470	0.256
2	$f(y_{65} \times EFF)$	0.216	0.091	0.472	0.484
3	$f(y_{65} \times TECH)$	0.482	0.839	0.588	0.239
4	$f(y_{65} \times KACC)$	0.278	0.097	0.828	0.188
5	$f(y_{65} \times HACC)$	0.530	0.338	0.476	0.262
6	$f(y_{65} \times EFF \times TECH)$	0.490	0.155	0.554	0.545
7	$f(y_{65} \times EFF \times KACC)$	0.008	0.020	0.310	0.564
8	$f(y_{65} \times EFF \times HACC)$	0.024	0.042	0.478	0.412
9	$f(y_{65} \times TECH \times KACC)$	0.594	0.072	0.430	0.582
10	$f(y_{65} \times TECH \times HACC)$	0.440	0.663	0.922	0.645
11	$f(y_{65} \times KACC \times HACC)$	0.204	0.076	0.824	0.361
12	$f(y_{65} \times EFF \times TECH \times KACC)$	0.008	0.030	0.520	0.776
13	$f(y_{65} \times EFF \times TECH \times HACC)$	0.218	0.218	0.392	0.077
14	$f(y_{65} \times EFF \times KACC \times HACC)$	0.022	0.000	0.306	0.210
15	$f(y_{65} \times TECH \times KACC \times HACC)$	0.166	0.149	0.368	0.656

Note: We use the *multimode* package in R to test the number of modes and perform a calibrated Silverman test (Hall & York 2001) in the context of testing for a single mode to improve its level of accuracy.

TABLE D6. Distribution hypothesis tests

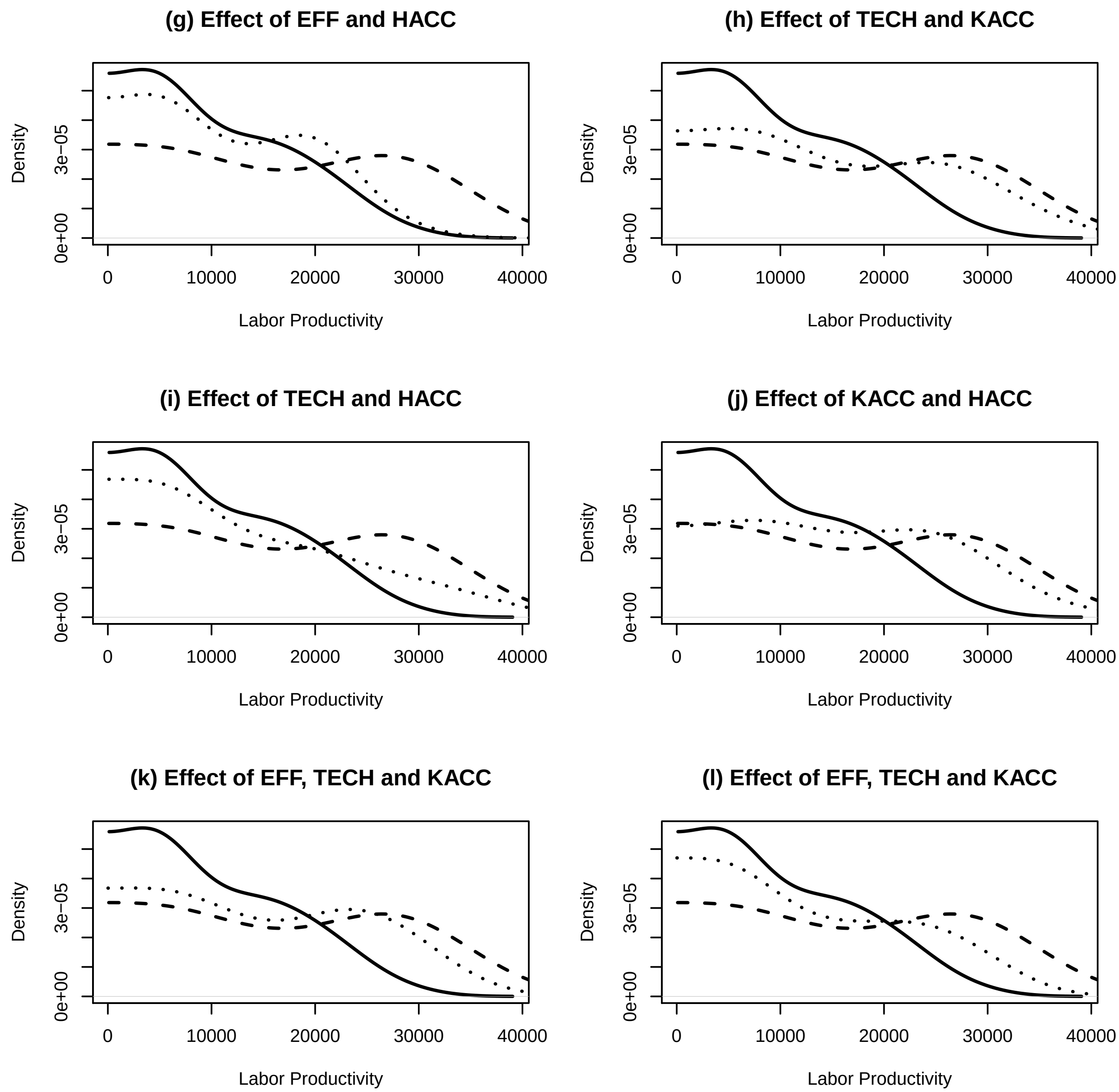
	H_0: Distributions are equal H_1: Distributions are not equal	Bootstrap p-value	10% significance level PWT10	 PWT5.6
1	$g(y_{90})$ vs. $f(y_{65})$	0.001	H_0 rejected	H_0 rejected
2	$g(y_{90})$ vs. $f(y_{65} \times EFF)$	0.000	H_0 rejected	H_0 rejected
3	$g(y_{90})$ vs. $f(y_{65} \times TECH)$	0.003	H_0 rejected	H_0 rejected
4	$g(y_{90})$ vs. $f(y_{65} \times KACC)$	0.000	H_0 rejected	H_0 rejected
5	$g(y_{90})$ vs. $f(y_{65} \times HACC)$	0.021	H_0 rejected	H_0 rejected
6	$g(y_{90})$ vs. $f(y_{65} \times EFF \times TECH)$	0.008	H_0 rejected	H_0 rejected
7	$g(y_{90})$ vs. $f(y_{65} \times EFF \times KACC)$	0.015	H_0 rejected	H_0 rejected
8	$g(y_{90})$ vs. $f(y_{65} \times EFF \times HACC)$	0.025	H_0 rejected	H_0 rejected
9	$g(y_{90})$ vs. $f(y_{65} \times TECH \times KACC)$	0.016	H_0 rejected	H_0 not rejected
10	$g(y_{90})$ vs. $f(y_{65} \times TECH \times HACC)$	0.003	H_0 rejected	H_0 rejected
11	$g(y_{90})$ vs. $f(y_{65} \times KACC \times HACC)$	0.219	H_0 not rejected	H_0 not rejected
12	$g(y_{90})$ vs. $f(y_{65} \times EFF \times TECH \times KACC)$	0.220	H_0 not rejected	H_0 not rejected
13	$g(y_{90})$ vs. $f(y_{65} \times EFF \times TECH \times HACC)$	0.666	H_0 not rejected	H_0 rejected
14	$g(y_{90})$ vs. $f(y_{65} \times EFF \times KACC \times HACC)$	0.098	H_0 rejected	H_0 not rejected
15	$g(y_{90})$ vs. $f(y_{65} \times TECH \times KACC \times HACC)$	0.737	H_0 not rejected	H_0 not rejected

Note: We make decisions based on 10% level of significance due to the small sample size.



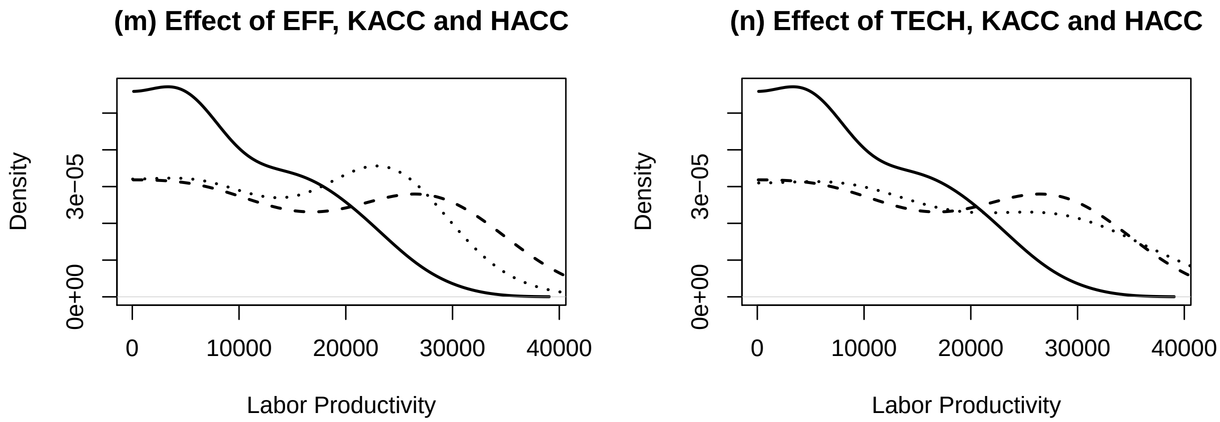
Note: In each panel, the solid curve is the actual 1965 distribution of output per worker, whereas the dashed curve is the actual 1990 distribution of output per worker. The dotted curves of each panel are the counterfactual distributions isolating the effects of components as labeled.

FIGURE D5. Counterfactual distributions of output per worker



Note: In each panel, the solid curve is the actual 1965 distribution of output per worker, whereas the dashed curve is the actual 1990 distribution of output per worker. The dotted curves of each panel are the counterfactual distributions isolating the effects of components as labeled.

FIGURE D5. Counterfactual distributions of output per worker (continued)



Note: In each panel, the solid curve is the actual 1965 distribution of output per worker, whereas the dashed curve is the actual 1990 distribution of output per worker. The dotted curves of each panel are the counterfactual distributions isolating the effects of components as labeled.

FIGURE D5. Counterfactual distributions of output per worker (continued)