On the World Productivity Distribution: Recent Convergence and Divergence Patterns

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10 October 2014

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November 9, 2014

Abstract

The post-World War II period has seen substantial changes in labor productivity around the world. Motivated by these changes, this article documents four facts about the world productivity distribution. First, there is a large and increasing disparity between the tails. Second, this disparity rapidly increased in the mid-1980s, slowed down in the next decade, and stabilized in the mid-2000s. Third, overtime, there has been substantial forward and backward mobility of countries and regions. Fourth, the upper tail of the distribution is more sensitive to improvements in human capital, while the lower tail is more sensitive to improvements in efficiency.

Keywords: average labor productivity, world productivity distribution, convergence

JEL Codes: O40, O50, E10

1 Introduction

Both convergence and divergence in output per worker characterize the post-World War II period. The world productivity distribution shows a noticeable divergence at the bottom, and convergence and overtaking at the top. For example, average labor productivity in Taiwan relative to that in the United States rose from 13 percent in 1960 to 78 percent in 2010. Conversely, in the same period of time, labor productivity in Venezuela dropped from 60 percent to 25 percent.

In line with the work of Abramovitz (1986), Parente and Prescott (1993), and Duarte and

Restuccia (2006), this article updates and expands the set of facts that theories of development should explain. Using data on potential GDP per worker, this article highlights three facts about disparity and mobility of the world productivity distribution between 1960 and 2010. In addition, two simple forecast exercises, following the work of Jones (1997a, b) and Quah (1993, 1996), suggest potential scenarios where convergence in labor productivity seems more plausible.

The first fact highlights large cross section disparities in labor productivity since 1960. For example, in 1960 an average worker in ten most productive countries of the sample produced about 40 times more output than the average worker in the ten least productive countries. Also, the shape of the world productivity distribution in 1960 appears unimodal and largely concentrated at the bottom—50 percent of the sampled countries show a relative output per worker no greater than 17 percent relative to that in United States.

The second fact points to the speed at which the disparity in labor productivity has been evolving. After more than two decades of relative stability, productivity disparities across countries rapidly increased in the mid-1980s. In the next decade, however, the speed of this divergence slowed down; particularly since mid-2000s, the data suggest a small tendency towards convergence.

These two facts consistently update and extend the previous literature. Parente and Prescott (1993) report stable differences in labor productivity across countries for the coverage period ending in 1985. Duarte and Restuccia (2006) not only verify this stability, but also —after extending the coverage period until 1996— document a rapidly increasing dispersion. In this context, this article not only updates the disparity facts until 2010, but also provides some initial evidence on the stabilization of the productivity differences due to improvements in poor countries.

The third fact documents substantial forward and backward mobility of countries and even regions within world productivity distribution. For example, labor productivity in Asia relative to that in the United States rose from 15 percent in 1960 to 37 percent in 2010. In contrast, labor productivity in Latin America declined from 28 percent in 1960 to 23 percent in 2010. Overall, these forward and backward mobility patterns seem consistent with the polarization of the world productivity distribution and the "twin-peaks" hypothesis suggested by Quah (1993, 1996).

Given the previous facts, a natural question emerges: how might the world productivity distribution look in the future? Analysis based on an aggregate production function provides some insights answer this questions. Jones (1997a) emphasizes that potential differences in output per worker can be attributed to current differences in population growth rates, physical investment rates, human capital stocks, and technology levels (TFP). Building on this approach, countries above the 75th percentile are expected to increase their convergence rate and even overtake the technological leader. Less developed countries, however, might remain very close to, or even fall behind, their 2010 labor productivity levels. The results also emphasize the role of total factor productivity (TFP) as the key driver of this convergence and divergence process.

An alternative yet complementary framework to forecast the world productivity distribution (over a more distant time horizon) uses Markov methods. This is an approach taken by Quah (1993, 1996) and Jones (1997b) among others. Based on historical mobility frequencies, the results suggest that labor productivity might still be characterized by a bimodal distribution, with a small yet significant number of countries at the bottom.

Overall, this article contributes to the earlier literature in three ways. First, it adds the period between 1996 and 2010 to the analysis. Second, it characterizes disparity, mobility, and the steady-state distribution of labor productivity using trended data to abstract from business-cycle fluctuations. Third, it presents a comprehensive view (past, current, and future) of the evolution of labor productivity for a large sample of countries.

The article proceeds as follows. Section 2 documents the main disparity and mobility facts. Section 3 describes how the world productivity distribution might look in the near future using a neoclassical production function approach. Assuming a more distant time horizon, Sections 4 describes the world productivity distribution using Markov methods. Section 7 offers some concluding remarks.

2 Disparity and Mobility Facts

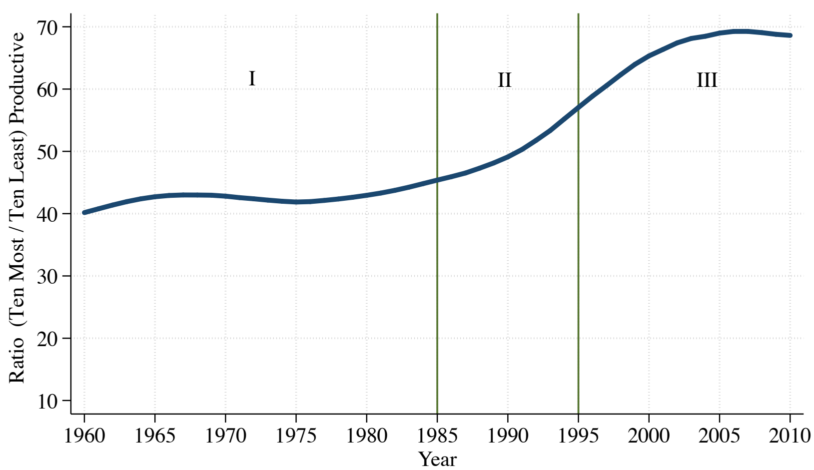
This section characterizes the cross-section dynamics of labor productivity around the world using a balanced sample of 92 countries for the period 1960-2010.[1] To build upon and extend previous findings, the organization and presentation of facts follows the work of Duarte and Restuccia (2006)

[1]See Appendix A for a description about the construction of the sample.

2.1 Large and Increasing Disparities

One of the main motivating facts in the field of economic growth and development is the large and increasing disparity in output per worker across countries. This subsection presents the behavior of disparity indicators between 1960 and 2010. Focusing first on the top and bottom of the world productivity distribution, Figure 1 illustrates the labor productivity gap between the ten most productive and ten least productive countries for each year since 1960 until 2010. Over this period, the productive gap between the tails of the distribution varied from 39 to 68 times. By 2010 the average worker in the ten most productive countries produced 67.6 times more output than the average worker in the least productive group of countries. Historically, the first decade of the new millennium records the largest disparity between the tails of distribution in the post-World War II period.

Figure 1: Output per Worker—Ratio of the Ten Most Productive to the Ten Least Productive Countries



Notes: Between 1960 and 2010, the following countries comprised the ten most productive group with the highest frequency (i.e., 51 years): Australia, Belgium, Netherlands, Norway, United States. The following countries comprised the ten least productive group with the highest frequency (i.e., 51 years): Burundi, Ethiopia, Malawi, Mozambique, Zimbabwe.

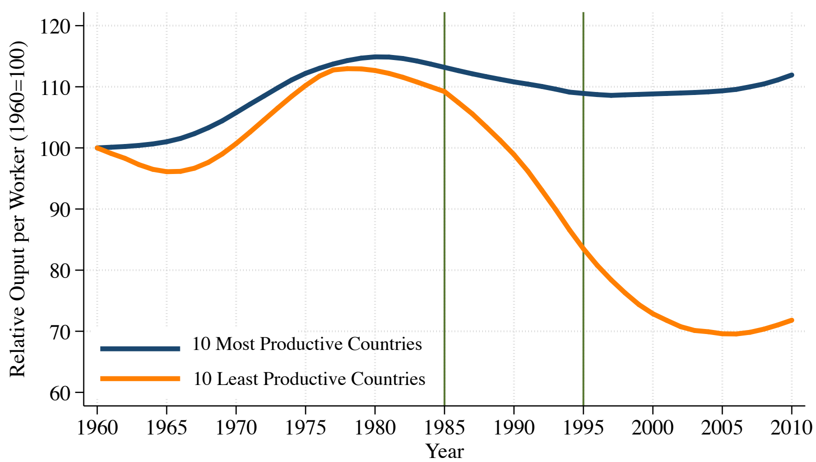
Consistent with earlier findings in the literature, Figure 1 suggests that the disparity between the tails of the distribution has been roughly constant during the first two decades of the sample period. Since the mid-1980s until the mid-2000s, however, there has been a rapid increase in the productivity gap between the top and bottom of the distribution.[2]The first line drawn at

[2]As noted by Sala-i-Martin (2006), increasing differences in average income per capita or average output per worker at the country level may not imply higher income inequality, or any other welfare measure, at the world level, since global inequality is also a function of within country inequality. In addition, worldwide improvements in life expectancy and other health measures are not directly captured in standard productivity and income

1985 represents the ending period of the first strand of the previous literature, which emphasizes constant disparities between the tails of the distribution. That literature includes the work of Parente and Prescott (1993), and Chari et al. (1997). The second line drawn at 1995 represents the second strand of the earlier literature, which emphasizes rather increasing disparities. That literature inclues the work of Duarte and Restuccia (2006)

Extending the findings of the earlier literature, Figure 1 also documents that since the mid-1990s this increasing productivity disparity has slowed down. Moreover, after 2006 the gap has stabilized and shifted its tendency. Evaluating more extensible the nature of this trend, Figure 2 suggests that the recent stabilization of the productivity gap is driven by improvements at the bottom of the distribution.

Figure 2: Relative Output per Worker-Ten Most Productive and Ten Least Productive Countries (1960=100)



Notes: Average output per worker relative to that in the U.S. for the ten most productive and least productive countries. Both series are normalized to 100 in 1960. As reference, in 1960 the average relative output per worker of the ten most productive countries is 85.88 percent, while for the ten least productive countries, it is 2.20 percent.

Figure 2 reports the average labor productivity relative to that in the United States for the ten most productive and least productive groups, each normalized to 100 in 1960. Overall, this figure shows that the increase in the disparity between the tails of the distribution is mostly driven by the decline in productivity in the least productive productive countries. For example, from 1977 to 2006, relative productivity decreased by 42 percent. Since 2006, however, the ten poorest countries have grown even faster than the ten richest countries. This positive growth

statistics, yet they help reducing income, welfare, and productivity differences in the world (Becker et al., 2005; Weil, 2007; Jones and Klenow, 2010).

Table 1: Relative Output per Worker by Percentile

	1960	1970	1980	1990	2000	2010
Percentile:			(percent)			
P10	3.6	3.1	3.0	2.4	2.1	2.0
P20	4.7	4.5	4.4	3.5	2.9	3.8
P30	6.3	6.2	7.4	5.9	5.3	6.1
P40	8.2	10.1	10.7	10.2	8.3	9.6
P50	15.8	16.6	22.5	18.5	15.6	17.2
P60	23.1	25.5	27.9	25.2	23.1	25.9
P70	33.1	38.0	44.3	39.8	33.7	33.9
P80	47.5	63.4	72.6	74.2	74.4	78.0
P90	64.2	76.4	88.3	85.9	86.3	83.1
Ratio:						
P90/P10	18.0	24.9	29.2	35.9	41.8	41.0
P80/P20	10.0	14.2	16.4	21.1	25.3	20.5

episode ends up a 30-year period of productivity divergence.

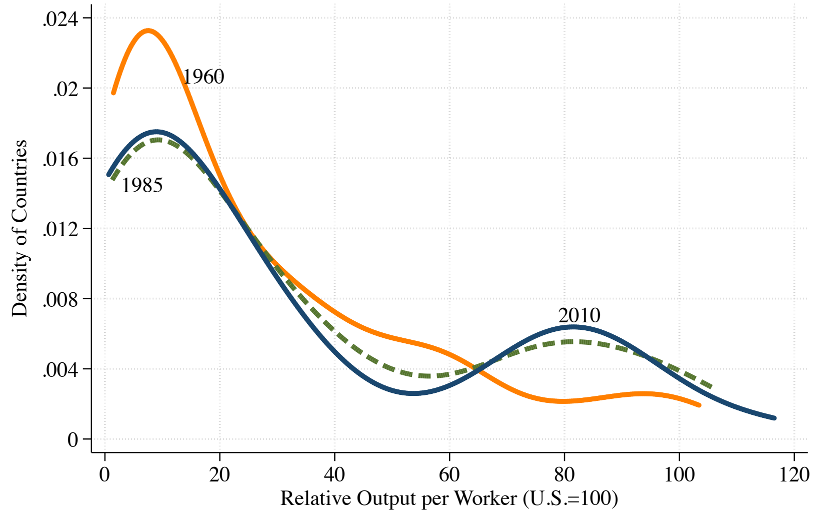
Moving beyond the analysis of the tails of world productivity distribution, Table 1 reports the relative labor productivity for a selected number of percentiles and years. The last two rows report the ratio of the ninetieth percentile to the tenth percentile and the ratio of the eightieth percentile to the twentieth percentile.

In 1960, the least productive countries of the tenth percentile showed an average productivity of 3.6 percent relative to that in the United States. In the same year, the most productive percentile percentile achieved 64.2 percent of the productivity in the United States. This difference yields a ratio of 18 between the highest and lowest percentile. Note that both percentile ratios increased substantially until the year 2000, but then they started decreasing. Moreover, all other percentiles showed improvements in the last decade. This global coververgence episode occurred after more than two decades of productivity divergence in all percentile groups.[3]

When considering the entire distribution, our sample seems consistent with the "twin peaks" hypothesis (Quah (1993a,b), Quah (1996), Jones (1997)). Using gaussian kernel densities at different points in time, Figure 3 shows the movement in the mass of countries from the middle to both right and left of the distribution. This polarization of the distribution characterizes the third fact on the cross-sectional dynamics of labor productivity is evaluated at the country and regional levels in the next subsection.

[3]From a geographical perspective, only Asian economies improved their relative productivity in the 1980s and 1990s, though at a slower pace compared to other decades.

Figure 3: Distribution of Relative Output per Worker



2.2 Substantial Mobility within the Distribution

Table 2 reports a mobility matrix based on the frequency of country movements over a period of 51 years. Based on their relative productivity in 1960 and 2010, the first column and the row classify countries into seven intervals. The variable $\tilde{y}$ indicates a country's labor productivity relativity to that in the United States. The labels for each interval are somewhat arbitrary cutoffs for low (L), upper low (UL), lower-middle (LM), middle (M), upper-middle (UM), lower-high (LH), and high (H) productivity levels. For example, the first element of this matrix, 0.86, indicates that out of all the low-productivity countries (L) in 1960, only 14 percent of those countries upgraded their status to an upper-low productivity country (UL) by the year 2010.

Table 2: Mobility Matrix 1960-2010

	L_{2010}	UL_{2010}	LM_{2010}	M_{2010}	UM_{2010}	LH_{2010}	H_{2010}
$(\tilde{y} < 2.5)\ L_{1960}$	***0.86***	0.14	0	0	0	0	0
$(2.5 \leq \tilde{y} < 5)\ UL_{1960}$	0.27	***0.40***	0.07	0.27	0	0	0
$(5 \leq \tilde{y} < 10)\ LM_{1960}$	0.18	0.29	***0.35***	0.12	0.06	0	0
$(10 \leq \tilde{y} < 20)\ M_{1960}$	0	0	0.29	***0.29***	0.21	0.21	0
$(20 \leq \tilde{y} < 40)\ UM_{1960}$	0	0	0.06	0.22	***0.44***	0.17	0.11
$(40 \leq \tilde{y} < 80)\ LH_{1960}$	0	0	0	0	0.13	***0.27***	0.6
$(\tilde{y} > 80)\ H_{1960}$	0	0	0	0	0	0.33	***0.67***

Values in the off-diagonal elements of the matrix indicate the mobility frequencies of countries. The distribution shows a higher degree of mobility in the middle compared to the extremes. Among all the middle-productivity countries, most improvements occurred for the high-productivity countries in this subset. For example, out of all lower-middle (LM) productivity countries in 1960, 35 percent of those countries remained in the same productivity interval, while 47 percent moved backward and 18 percent moved forward after 51 years. In contrast, out of all upper-middle (UM) productivity countries in 1960, 44 percent of those countries remained in the same productivity interval, while and 28 percent moved backwards and 28 percent moved forward after 51 years. Overall, these results reiterate the story of Figure 3: the post-war period is characterized by both convergence and divergence patterns (that is, countries moving from the middle to both right and left of the labor productivity distribution).

Figure 4 also characterizes the mobility within the distribution by comparing the level of relative productivity for each country in 1960 and 2010. The solid 45-degree line represents countries in which productivity relative to that in the United States has not changed from 1960 to 2010. Countries above (below) the solid 45-degree line improved (deteriorated) their position relative to the technological frontier. The dashed lines indicate the median relative productivity for each year.

Figure 4: Relative Output per Worker- 1960 vs 2010

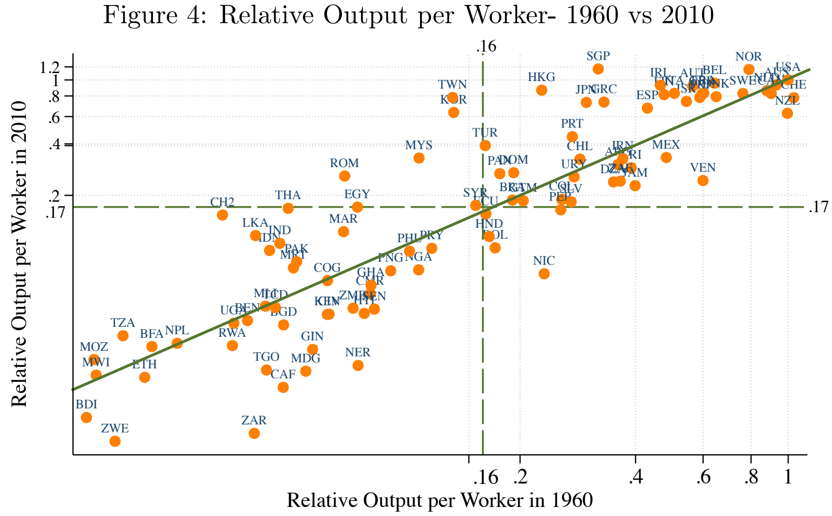
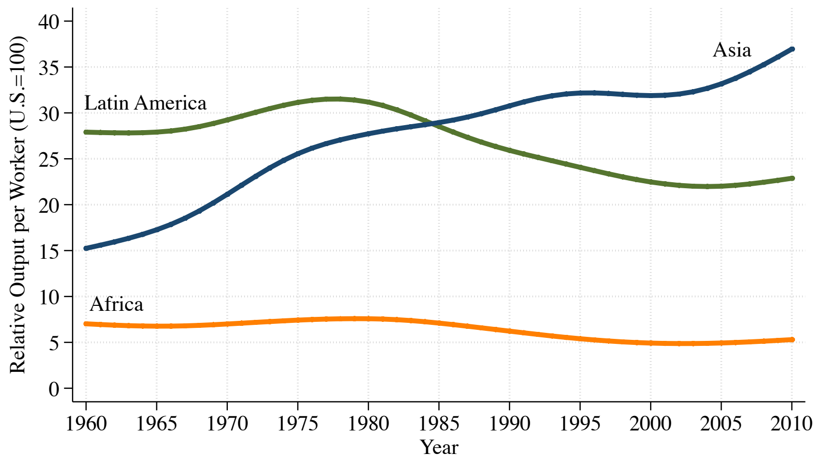


Figure 4 is useful for identifying large convergence and divergence experiences. Countries with the largest productivity improvements include Taiwan, South Korea, China, Hong Kong, and Romania. In contrast, countries with the largest productivity deterioration include the Democratic Republic of Congo, Niger, Central African Republic, Nicaragua, and Madagascar.

Another approach to continuously characterize mobility reports the level of relative productivity for every year since 1960 to 2010. Figure 4 summarizes this information from a regional perspective for Latin America, Asia and Africa.[4] Among these cases, the most noticeable pattern points to contrasting performance of Latin America and Asia. Although regional averages tend to mask interesting exceptions,[5] Figure 5 is still informative in suggesting that the bulk of diverging countries are primarily located in Latin America and Africa.

Figure 5: Relative Output per Worker by Developing Regions



So far this section has presented a set of facts about the increasing disparity and mobility within the world productivity distribution. These facts, naturally, lead to the question: what will the distribution of labor productivity look like in the future? The following two sections aim to answer this important question based on the characterization of a steady-state (long-run) equilibrium in both a determinist and a stochastic setting.

3 Labor Productivity in the Long Run

This section uses economic theory to deterministically estimate the long-run (steady-state) distribution of labor productivity. Briefly, the following subsection describes the model suggested by Jones (1997a), which is a variation of the standard neoclassical growth model. Within this framework, long-run labor productivity depends on the current equipment, skills, and technology available to workers. After introducing the model, the following subsections empirically describe the variables, parameters, which will be used in the computation of a steady-state distribution

[4]This regional classification is based on the macro geographical classification of the United Nations. See http://unstats.un.org/unsd/methods/m49/m49regin.htm for details.

[5]These exceptions are identifiable from Figure 4.

of output per worker for a sample of 85 countries.[6]

3.1 Model

Consider the following economy:

$$\begin{aligned} Y(t) &= K(t)^{\alpha}\left(A(t)H(t)\right)^{1-\alpha}, &(1)\\ H(t) &= e^{\phi S(t)}L(t), &(2)\\ \dot{k}(t) &= s_K(t)y(t)-(n(t)+\delta)k(t), &(3)\end{aligned}$$

where Y is total output, which is produced by physical capital K, human capital H, and labor-augmenting total factor productivity A. Human capital or skilled labor is produced by raw labor L, the time devoted to skill accumulation S , and the rate of return to a year of education ϕ. Letting lower case letters represent variables in per worker terms, the accumulation of physical capital per worker k depends on the investment rate s_K, the population growth n, and the depreciation rate δ.

To solve for a balanced growth path, all the variables should grow at constant rates. Then, in equilibrium, the growth rate of output per worker and the growth rate of capital per worker should be equal to the growth rate of total factor productivity, which is denoted as g_A. By construction of the model, the exogenous variables are the growth rate of technology, g_A, the physical capital investment rate, s_K, the human capital investment rate,S, and the population growth rate, n.

Given the previous settings, the value of output per worker along a balanced growth path is specified as follows:

$$y(t)=\left(\frac{s_K}{n+g_A+\delta}\right)^{\frac{\alpha}{1-\alpha}} hA(t). \tag{4}$$

Note that along this equilibrium state, all economies growth at the same exogenous rate, g_A, but the levels of technology. A, are not necessarily the same across countries. Finally, redefining per-worker variables relative to those of the United States we have

$$\tilde{y}(t)=\tilde{\xi}_K^{\frac{\alpha}{1-\alpha}}\tilde{h}\tilde{A}(t), \tag{5}$$

[6] Due to the lack of systematic educational data, this section is based on a smaller 85-country sample. This sample, however, is still larger (in terms of the number of countries and time periods) than that used in Jones (1997).

where $\tilde{y} \equiv \frac{y(t)}{y_{US}(t)}$, $\tilde{\xi}_K \equiv \frac{\xi_K}{\xi_{KUS}}$, $\tilde{h} \equiv \frac{h}{h_{US}}$, $\tilde{A} \equiv \frac{A(t)}{A_{US}(t)}$, and $\xi_K \equiv \frac{s_K}{n+g_A+\delta}$. Equation 5 summarizes the most important prediction of the model: in a proximate sense,[7] the steady-state distribution of relative output per worker is a function of (1) the investment rate in physical capital, s_K, (2) the investment rate in human capital accumulation, S, (3) the population growth rate, n, and (4) the level of technology, A. Finally, as noted by Jones (1997a), other more fundamental factors such as political instability, macroeconomic policy, taxes and subsidies, social conflict, corruption and so on must work through one or more of these four proximate channels.

3.2 Determinants of the Steady State

Parameters

To calculate Equation 5 we need data on the parameters related to the shape of the production function: α, ϕ, and $g_A + \delta$. By construction, those parameters are assumed to be constant across countries and their calibration is based on standard estimates of the growth literature (See Table 3).

Table 3: Calibration of Parameters

Parameter	Calibration	Source
α	$\frac{1}{3}$	Mankiw, Romer, and Weil (1992)
ϕ	0.10	Psacharopoulos and Patrinos (1994)
$g_A + \delta$	0.075	Mankiw, Romer, and Weil (1992)

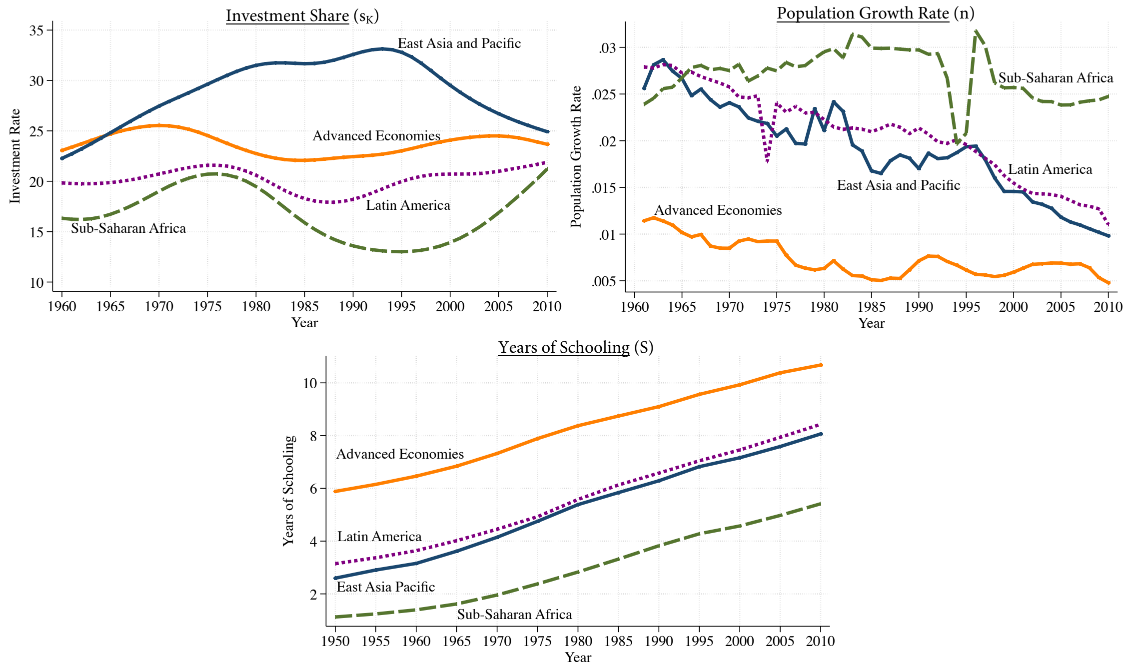
Variables

Equation 5 also requires variation across countries for s_K, n, S, and $\tilde{A}$. Last decade averages for the physical investment rate, s_K, and population growth rate, n, are computed from the Penn World Tables version 7.1. Data on average years of schooling, S, for the year 2010, are taken from Barro and Lee (2010). Finally, to estimate the relative level of technology $\tilde{A}$ in 2010, the paper follows "development accounting" decomposition suggested by Jones (1997a).

Figure 6 shows the behavior of three of four determinants of labor productivity (the construction of the relative level of technology is discussed in the next paragraph). Note that the rate of investment in physical capital s_K appears to be converging across regions. With the exception of countries in Sub-Saharan Africa, global convergence in population growth n is also

[7] See Acemoglu et al. (2005) and Acemoglu (2009) for a discussion of the relationship between proximate and fundamental causes in economic performance.

Figure 6: Regional Averages for s_K, n, and S



Notes: A smooth trend, based on the Hodrick-Prescott filter, is used to depict the behavior of physical investment rates. Equal weights for each country are used in the computation of regional averages. The regional definitions are from Barro and Lee (2010)

observable. In terms of educational attainment, although there are noticeable improvements in all regions, there still exists a large gap between advanced and developing economies.

The relative level of total factor productivity (TFP) is the last determinant we need to forecast the distribution of labor productivity. Table 4 summarizes the calculation of this variable for a selected sample of countries.[8] The overall finding of this exercise is that for the whole 85-country sample, the standard deviation of the natural logarithm of technology ($log\,\tilde{A}$) is about 80 percent of the standard deviation of the natural logarithm of output per worker ($log\,\tilde{y}$). This finding favors the predominant role of total factor productivity (TFP) in the determination of output per worker. Among the particular cases, it is worth noticing that although Japan shows the same capital-labor ratio as the United States, output per worker is about 31 percent less than because of lower TFP. In contrast, Hong Kong and the United Kingdom report higher TFP levels than the United States, but output per worker is lower mainly due to inferior educational attainment. Performance in developing countries lags far behind in all these variables, yet the major determinant of output per worker seems clearly TFP.

[8]Appendix B documents the relative TFP levels for the complete 85-country sample

Table 4: Relative TFP levels ($\tilde{A}$) in 2010

		Contributions		
	$log\,\tilde{y}$	$\alpha\, log\,\tilde{k}$	$(1-\alpha)\, log\,\tilde{h}$	$(1-\alpha)\, log\,\tilde{A}$
United States	0.00	0.00	0.00	**0.00**
Hong Kong	-0.14	0.03	-0.18	**0.01**
United Kingdom	-0.20	-0.15	-0.24	**0.20**
Japan	-0.31	0.00	-0.10	**-0.21**
Venezuela	-1.40	-0.38	-0.40	**-0.62**
Brazil	-1.67	-0.53	-0.37	**-0.78**
China	-1.88	-0.65	-0.33	**-0.91**
India	-2.28	-0.81	-0.53	**-0.94**
Cameroon	-2.98	-1.03	-0.46	**-1.49**
Mean (85 countries)	-1.80	-0.61	-0.35	**-0.84**
Standard Deviation	1.37	0.51	0.18	**0.73**

3.3 The Steady-State Distribution and Alternative Scenarios

Figures 7, 8 and 9 illustrate the main empirical results of this section. They describe the steady-state distribution of labor productivity under different assumptions. Also, Appendix B presents further information for every country in the sample.

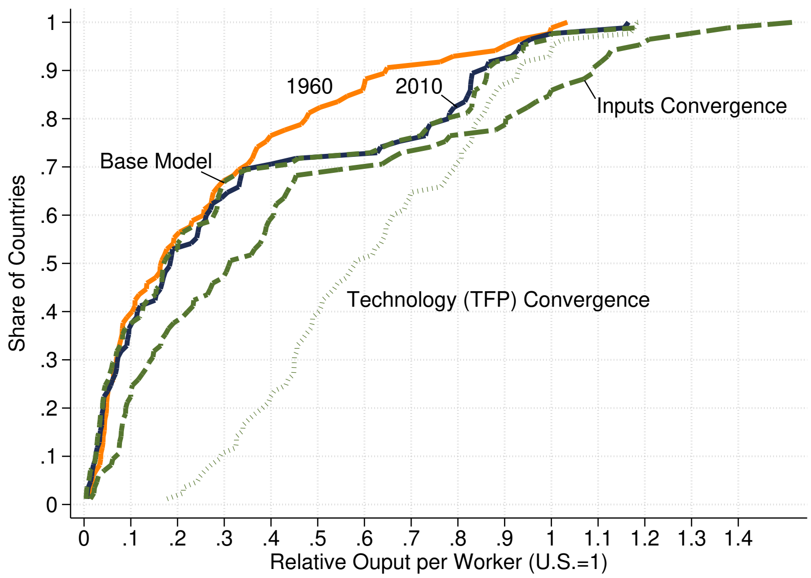
Base Model

To predict the steady-state output per worker, I use decade averages for the investment rate s_K and population n growth; also I assume the *relative* levels of TFP and human capital from 2010 to be constant in the near future. Given this setting, two results are worth noting.

First, consistent with the previous findings of the literature (Jones1997a), the steady-state distribution of labor productivity appears very similar to the 2010 distribution, particularly for the poorer 70 percent of the sample. The R^2 statistic comparing labor productivity in 2010 and in steady state equals 0.99. Also, the standard deviation raises from 34 percent to 35 percent and the median decreases from 19 percent to 17 percent. Overall, these statistics suggest that if todays' policies regarding human capital accumulation and technological progress remain invariant (in relative terms across countries), divergence in labor productivity —and income— is expected to continue in the future.

Second, although the 2010 and steady-state distribution look broadly similar, they also exhibit some interesting differences in terms of additional convergence (divergence) cases. For example, countries which are expected to have the largest improvement in labor productivity in the near future include China, India, South Korea, Romania, and Taiwan. In contrast, countries

Figure 7: Cumulative World Productivity Distributions



which are expected to have the largest deterioration include the Democratic Republic of Congo, Togo, Burundi, Cote d'Ivoire, and Central African Republic.

Inputs Convergence: The Power of Human Capital is at the Top

In this scenario, I equalize the physical investment rate s_K, and years of schooling S of all countries to that in the United States. The results of this experiment are somewhat mixed.

Figure 8 (panel a) shows that almost all countries[9] improve their position (they lay above the 45-degree line) after allowing for full convergence in inputs. Further analysis reveals that human capital is the main driver when shifting the distribution. Also the largest effect of human capital convergence is concentrated at the top of the distribution. The median labor productivity raises from 19 percent in 2010 to 31 percent; and the upper middle and top[10] of the distribution show the largest improvements. The downside of this scenario, however, is an increase in the disparity of labor productivity. The standard deviation of relative output per worker raises from 34 percent in 2010 to 40 percent in steady state.

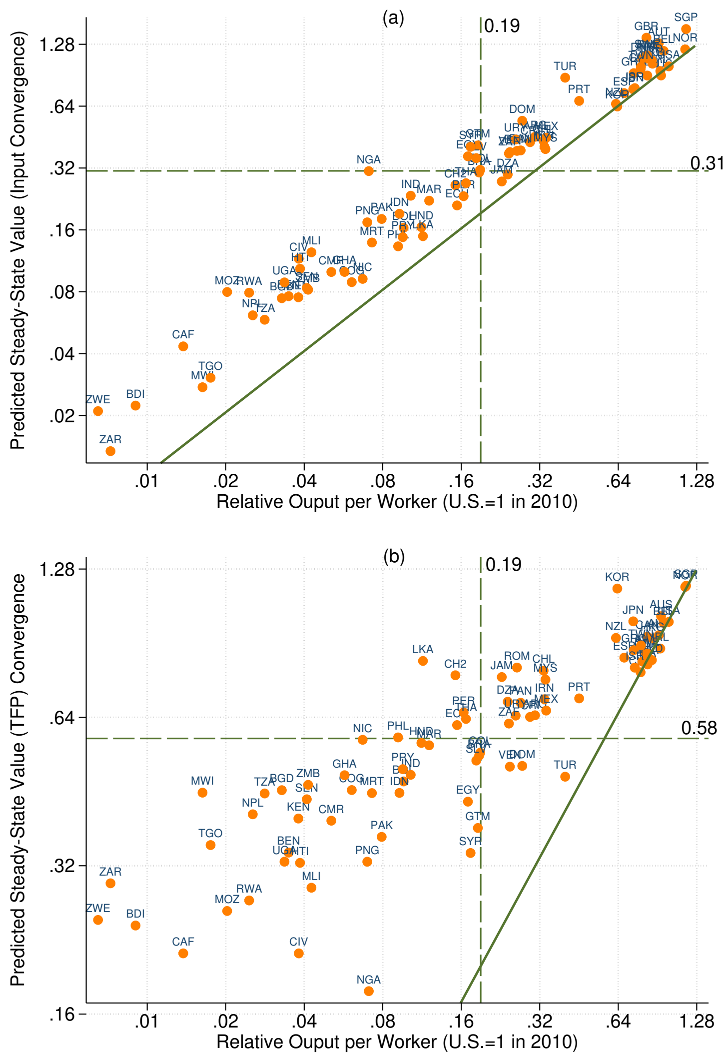
Evaluating the shape of the cumulative distribution in steady state, Figure 7 points to a

[9] Only Australia deteriorates its 2010 position.

[10] In this scenario nine countries overtake the United States and join Singapore and Norway as new technological leaders. The new overtakers include the United Kingdom, Austria, Belgium, Sweden, Finland, Italy, France, Denmark, Netherlands, and Hong Kong.

potential explanation for understanding the unsatisfactory results of input convergence. Productivity at the bottom of the distribution appears very sticky in spite of additional accumulation of productive factors (inputs). Other countries, at the middle and top of the distribution, get better returns with similar endowment levels. This results suggests that it is not only the low level of inputs what keeps productivity stagnant in the poorest countries, but also the way in which inputs are used. In the next scenario, I empirically test this well known argument of the economic growth literature.

Figure 8: Output per Worker- 2010 vs Predicted Steady State



Technology (TPF) Convergence: The Main Determinant of Development

In this scenario, I allow countries with less than the United States TFP level converge to this benchmark, and the twelve countries with higher TFP maintain their technological advantage.

Results in this setting are more encouraging, TFP convergence both condenses and shifts the steady-state distribution. Contrary to input convergence, the standard deviation of relative labor productivity falls from 34 percent in 2010 to 25 percent in steady state. Almost all countries lay above the 45-degree line[11] —all developing countries move forward within the steady state distribution— and the median raises from 34 percent to 62 percent. The overall magnitude of this improvement appears more clearly in Figure 7. TFP convergence shifts the entire cumulative distribution with larger effects on countries at the bottom 70 percent of the distribution. This result is consistent with the growth and development accounting literature in the sense that TFP differences are at least as important as capital accumulation differences. Particularly for this exercise, the effect of TFP convergence on the median country about two times the effect of input convergence.

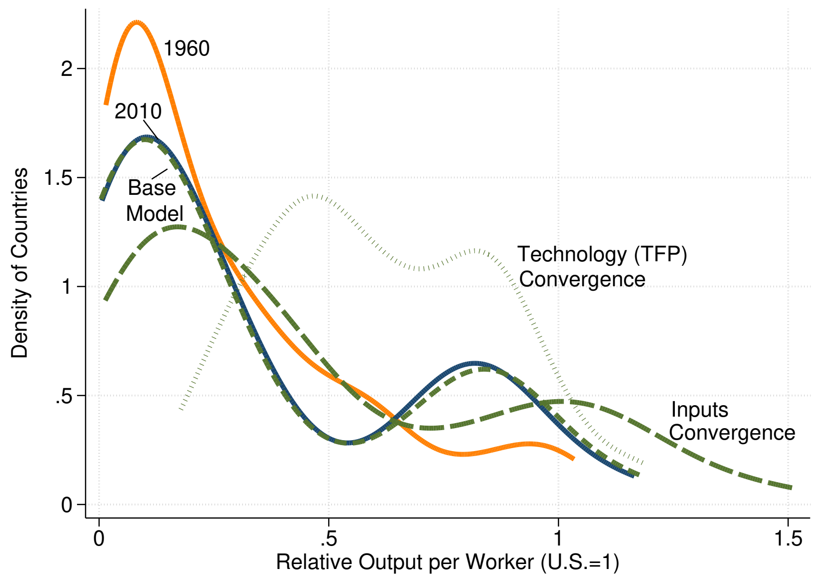
There are also interesting changes at the top of the distribution. South Korea, Australia, and Japan are expected to overtake the United States. The intuition behind the Korean and Japanese case both countries currently have low TFP levels (among industrialized nations) and high physical and human capital stocks. This low TFP level argument, however, might appear puzzling if we consider these countries as current technological leaders in many areas. One interpretation raises from the recent literature on resource misallocation.[12] The main insight of this literature suggests that TFP does not only captures technological development, but also aggregate efficiency losses due to distortions in inputs and goods markets. To support this argument, Baily and Solow (2001) suggests that burdensome regulation might be keeping TFP low in Japan.

Figure 9 summarizes the different shapes of the world productivity distribution for 1960, 2010, and the three forecasted scenarios. Note that overtime the bimodal distribution persist even under input convergence or TFP convergence. The twin-peaks hypothesis and convergence clubs argument appear in the literature as potential explanations for this phenomenon. In the next section, I use the basic tools of this literature to evaluate the probability of persistence of these two peaks.

[11] The exceptions are Netherlands, Ireland, and Italy

[12] See Restuccia and Rogerson (2013) for a survey reference.

Figure 9: World Productivity Distributions



4 Labor Productivity in the Very Long Run

Motivated by the mobility and polarization of countries within the world income distribution, Quah (1993a,b) and Jones (1997) use Markov methods to study the evolution of the world income distribution in a distant time horizon[13]. This section applies similar methods in the context of the 2010 productivity distribution.

Essentially Markov methods compute the evolution of a system based on initial states and transition probabilities. Mathematically, this process is described by

$$d_t \mathrm{M}^s = d_{t+s}, \tag{6}$$

where the vector d_t corresponds to the productivity distribution in the year t, the transition matrix $\mathbf{M}$ contains mobility frequencies from sample data and s represents the number of years into the future.

The first set of columns in Table 2 reports the world productivity distribution, for the years 1960, 1985, and 2010, based on the same seven productivity intervals (states) defined in Table 2. Using Equation 6 for $s = 25$, $s = 50$, and $s \to \infty$, we can compute estimates of the very long-run productivity distribution.

[13]In somewhat more technical jargon, to asymptotically evaluate the evolution of the world income distribution.

Table 5: World Productivity Distribution-Using Markov Chains

					Predicted		
States	Interval	1960	1985	2010	2035	2060	Steady State
L	[0, 0.025)	0.08	0.09	0.14	0.17	0.14	0.12
UL	[0.025, 0.05)	0.16	0.15	0.13	0.06	0.05	0.04
LM	[0.05, 0.10)	0.18	0.12	0.13	0.04	0.03	0.03
M	[0.10, 0.20)	0.15	0.12	0.15	0.05	0.05	0.05
UM	[0.20, 0.40)	0.20	0.21	0.15	0.07	0.08	0.08
LH	[0.40, 0.80)	0.16	0.17	0.13	0.21	0.23	0.23
H	[0.80, 1.2)	0.07	0.14	0.16	0.40	0.43	0.45

Before going over the results let us recall the differences and complementarities between the deterministic approach used in Section 3 and the stochastic approach of this section. First, in the previous section, I computed the near-future steady state towards which each country seems to be headed. This section, however, focuses both on a more distant time horizon and seven broad productivity intervals (states). Second, in the previous section, there were not policy changes (recall that relative TFP and human capital are constant in the baseline model SS). This section, however, by the stochastic nature of the Markov process, explicitly recognizes policy changes, which in turn, might shift the position of a country's steady state.

Section 3 ended with an open question: are the twin peaks of the world productivity distribution persistent? Results from Table 5 suggest that the answer of this question has two folds.

First, even in a more distant future (i.e., the steady-state vector of a Markov chain), labor productivity might be characterized by a bimodal distribution. Second, although the world productivity distribution appears to be bimodal, the two peaks are far from being twins: convergence dominates the process in the long run. Consider the following example: in 1960 only 7 percent of countries reported a productive level higher than 80 percent; in the long run, however, almost 50 percent of countries are expected to report a productivity level higher than 80 percent.

When contrasting these results with the early findings of Jones (1997b), the main differences arise at the bottom of the distribution. Jones' analysis defines the lowest interval between 0 and 5 percent and finds continuous convergence in relative income since 1988. The steady-state fraction of countries in this lowest interval is 8 percent— a reduction of 7 percentage points compared to the fraction of countries in the same interval in 1960. This article, however, defines a narrower interval, between 0 and 2.5 percent, and it initially finds continuos divergence from

1960 to 2035 (continuous convergence emerges thereafter). The steady-state fraction of countries in this lowest interval is 12 percent— an increase of 4 percentage points compared to the fraction of countries in the same interval in 1960 (8 percent).

Table 5 also shows that in the long run (steady-state) distribution there is a positive probability of any country spending some time in any interval. The interpretation of this result is that, as the time horizon increases asymptotically, any country might experience a large policy disaster or reform. To illustrate this point, Jones (1997) highlights Japan's reforms, in post world war II period, as a noticeable example of a country moving to the very top of the productivity distribution. In contrast, there is the famous example of Argentina, one of the richest and most productive countries in the world in the early part of the twentieth century that drastically moved backward within the productivity distribution. Other similar examples, described in the introduction of this article include Hong Kong and Venezuela.

Finally, using the transition matrix of Table 2 we can conduct further experiments based on the conditional distribution of labor productivity. For instance, consider the situation of a low productivity country (i.e., $\tilde{y} > 80$ percent in 2010) and a high productivity country (i.e., $\tilde{y} < 10$ percent in 2010). Intuitively, the former has more changes to remain poor, while the latter has more chances to remain rich in the near future.[14] This intuition is consistent with the empirical results reported in the Appendix A. These results predict that, by 2035, a low productivity country has a 45-percent probability to remain poor. In turn, a high productivity country has a 50-percent probability to remain rich.[15] Both distributions, however, asymptotically converge to the world productivity distribution reported in Table 5.

5 Concluding Remarks

The world productivity distribution in the post-World War II period is characterized by four remarkable facts: (1) a large and increasing disparity between the tails of the distribution; (2) this disparity rapidly increased in the mid-1980s, slowed down in the next decade, and stabilized in the mid-2000s; (3) overtime, there has been substantial forward and backward mobility of countries and regions within the distribution; and (4) the upper tail of the distribution is more sensitive to improvements in human capital, while the lower tail is more sensitive to improve-

[14] This is one of the results of Section 3.

[15] To compute the predicted distribution in each case, the initial distribution is d(2010)=[1,0,0,0,0,0,0] for a low productivity country and d(2010)=[0,0,0,0,0,0,1] for a high productivity country.

ments in efficiency. Overall, the dynamic nature of these facts not only present a challenge to the existing theories of development, but also provide opportunities for the development of new theories and policy initiatives.

Disparities in labor productivity across countries are large, but disparities in technology (broadly defined) are even larger. Improvements in aggregate efficiency in developing countries might drastically affect the distribution of labor productivity and accelerate the process of convergence. If current institutions and policies remain in place, however, the world productivity distribution might be characterized by additional divergence at the bottom, and further convergence and overtaking at the top.

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A Labor Productivity in the Very Long Run: Three Alternative Cases

Table 6: The Case of a Low Productivity Country:

State	Interval	2035	2060	SteadyState
L	[0, 0.025)	0.30	0.17	0.12
UL	[0.025, 0.05)	0.10	0.06	0.04
LM	[0.05, 0.10)	0.05	0.04	0.03
M	[0.10, 0.20)	0.07	0.05	0.05
UM	[0.20, 0.40)	0.07	0.07	0.08
LH	[0.40, 0.80)	0.15	0.21	0.23
H	[0.80, 1.2)	0.27	0.39	0.45

Table 7: The Case of a Middle Productivity Country:

State	Interval	2035	2060	SteadyState
L	[0, 0.025)	0.16	0.13	0.12
UL	[0.025, 0.05)	0.06	0.05	0.04
LM	[0.05, 0.10)	0.03	0.03	0.03
M	[0.10, 0.20)	0.05	0.05	0.05
UM	[0.20, 0.40)	0.07	0.08	0.08
LH	[0.40, 0.80)	0.22	0.23	0.23
H	[0.80, 1.2)	0.41	0.44	0.45

Table 8: The Case of a High Productivity Country

State	Interval	2035	2060	SteadyState
L	[0, 0.025)	0.07	0.11	0.12
UL	[0.025, 0.05)	0.03	0.04	0.04
LM	[0.05, 0.10)	0.03	0.03	0.03
M	[0.10, 0.20)	0.04	0.04	0.05
UM	[0.20, 0.40)	0.08	0.08	0.08
LH	[0.40, 0.80)	0.26	0.24	0.23
H	[0.80, 1.2)	0.50	0.46	0.45

B Data:

This article uses data from Penn World Tables V7.1 (see Heston, Summers, and Aten 1991) to construct annual time series of PPP-adjusted GDP per worker in chained 2005 prices (variable RGDPWOK). Following the criteria of Duarte and Restuccia (2006), the selection of countries was based on the following criteria:

1. Countries that have data for every year from 1960 to 2010

2. Countries that have at least one million in population in 2010.

These restrictions rendered a set of 92 countries. Adding data on educational attainment, which comes from Barro and Lee (2010), the final data set contains complete information for 85 countries.

For every output observation, business-cycle fluctuations are removed using the Hodrick-Prescott filter with a smoothing parameter equal to 100. For the most part of the article, data series on output per worker are reported relative to that of the United States. It is the conventional view in the literature that the United States is a stable technological benchmark against which to measure potential gains in labor productivity in all countries. As a reference, in the post-war period, potential labor productivity in the United States grew at roughly 2 percent per year. .

The capital stock is calculated by summing investments from 1960 to 2010 using a depreciation rate of 6 percent and an initial capital stock determined by the steady-state capital-output ratio of 1960. Given the 51 years of the capital series and the selected depreciation rate, the calculated values of the capital stock are quite insensitive to the initial value.

	Determinants				Relative Output per Worker						
Countries	s_K	n	S2010	A2010	1960	2010	(1)	(2)	(3)	(4)	(5)
							Steady-State Prediction				
Algeria(DZA)	0.33	0.01	7.63	0.30	0.35	0.24	0.21	0.30	0.21	0.36	0.69
Argentina(ARG)	0.20	0.01	9.42	0.46	0.36	0.31	0.29	0.45	0.31	0.43	0.65
Australia(AUS)	0.30	0.01	12.12	0.92	0.93	0.93	0.94	0.90	0.94	1.04	1.03
Austria(AUT)	0.24	0.00	9.52	1.23	0.56	0.92	0.94	1.30	0.94	1.34	0.94
Bangladesh(BGD)	0.21	0.02	5.91	0.08	0.05	0.03	0.04	0.07	0.04	0.07	0.46

	Determinants				Relative Output per Worker						
Countries	s_K	n	S2010	A2010	1960	2010	(1)	(2)	(3)	(4)	(5)
Belgium(BEL)	0.26	0.00	10.62	1.13	0.64	0.96	0.99	1.19	0.99	1.27	0.99
Benin(BEN)	0.19	0.03	4.35	0.09	0.04	0.03	0.03	0.08	0.03	0.07	0.34
Bolivia(BOL)	0.11	0.02	9.87	0.17	0.17	0.10	0.08	0.16	0.12	0.11	0.47
Brazil(BRA)	0.21	0.01	7.55	0.31	0.19	0.19	0.17	0.30	0.17	0.29	0.54
Burundi(BDI)	0.12	0.04	3.35	0.03	0.01	0.01	0.01	0.02	0.01	0.02	0.24
Cameroon(CMR)	0.16	0.02	6.21	0.11	0.08	0.05	0.04	0.10	0.05	0.08	0.39
Canada(CAN)	0.24	0.01	12.08	0.89	0.90	0.83	0.83	0.90	0.83	0.92	0.93
Cent. African Rep(CAF)	0.08	0.02	3.68	0.05	0.05	0.01	0.01	0.04	0.02	0.03	0.21
Chile(CHL)	0.26	0.01	10.17	0.44	0.29	0.33	0.35	0.43	0.35	0.46	0.80
China(CH2)	0.35	0.01	8.11	0.26	0.03	0.15	0.20	0.26	0.20	0.33	0.78
Colombia(COL)	0.20	0.01	7.75	0.32	0.26	0.19	0.17	0.31	0.18	0.30	0.54
Congo Dem. Rep.(ZAR)	0.17	0.03	3.26	0.01	0.04	0.01	0.00	0.01	0.01	0.01	0.29
Congo Republic (COG)	0.23	0.03	6.30	0.10	0.06	0.06	0.05	0.09	0.05	0.09	0.46
Costa Rica(CRI)	0.24	0.02	8.74	0.44	0.39	0.29	0.28	0.43	0.28	0.44	0.64
Cote d'Ivoire(CIV)	0.06	0.02	4.60	0.12	0.06	0.04	0.03	0.12	0.05	0.06	0.21
Denmark(DNK)	0.25	0.00	9.97	1.05	0.65	0.79	0.83	1.09	0.83	1.13	0.83
Dominican Rep(DOM)	0.20	0.02	7.33	0.56	0.19	0.27	0.29	0.54	0.31	0.51	0.51
Ecuador(ECU)	0.25	0.02	8.18	0.22	0.16	0.15	0.14	0.21	0.14	0.22	0.62
Egypt(EGY)	0.16	0.02	6.97	0.39	0.08	0.17	0.17	0.36	0.20	0.31	0.43
El Salvador(SLV)	0.16	0.00	7.88	0.35	0.27	0.18	0.18	0.36	0.21	0.30	0.52
Finland(FIN)	0.25	0.00	9.96	1.07	0.47	0.81	0.87	1.12	0.87	1.18	0.87
France(FRA)	0.22	0.01	10.53	1.06	0.60	0.83	0.83	1.09	0.84	1.07	0.83
Ghana(GHA)	0.20	0.02	7.26	0.11	0.08	0.06	0.05	0.10	0.06	0.09	0.49
Greece(GRC)	0.26	0.00	10.68	0.88	0.33	0.73	0.77	0.93	0.77	0.98	0.88
Guatemala(GTM)	0.19	0.02	4.90	0.44	0.20	0.19	0.17	0.41	0.18	0.38	0.38
Haiti(HTI)	0.12	0.01	5.13	0.11	0.08	0.04	0.03	0.10	0.05	0.08	0.32
Honduras(HND)	0.27	0.02	7.30	0.18	0.17	0.11	0.10	0.17	0.10	0.18	0.57
Hong Kong (HKG)	0.31	0.01	10.40	1.01	0.23	0.87	0.93	1.03	0.93	1.21	0.93
India(IND)	0.28	0.02	5.20	0.24	0.05	0.10	0.12	0.23	0.12	0.26	0.49

	Determinants				Relative Output per Worker						
Countries	s_K	n	S2010	A2010	1960	2010	(1)	(2)	(3)	(4)	(5)
Indonesia(IDN)	0.20	0.01	5.95	0.20	0.04	0.09	0.09	0.19	0.09	0.18	0.45
Iran(IRN)	0.27	0.01	8.64	0.41	0.37	0.33	0.29	0.41	0.29	0.45	0.70
Ireland(IRL)	0.26	0.02	11.62	1.00	0.46	0.93	0.88	0.95	0.88	1.02	0.88
Israel(ISR)	0.23	0.02	11.36	0.83	0.54	0.74	0.67	0.78	0.67	0.79	0.81
Italy(ITA)	0.26	0.00	9.46	1.07	0.51	0.83	0.82	1.11	0.82	1.18	0.82
Jamaica(JAM)	0.26	0.01	9.75	0.27	0.40	0.23	0.21	0.28	0.21	0.30	0.77
Japan(JPN)	0.27	0.00	11.59	0.73	0.30	0.73	0.73	0.77	0.73	0.85	1.00
Kenya(KEN)	0.16	0.03	6.65	0.08	0.06	0.04	0.03	0.08	0.04	0.06	0.40
Korea Rep.(KOR)	0.36	0.00	11.94	0.62	0.13	0.63	0.72	0.64	0.72	0.81	1.17
Malawi(MWI)	0.30	0.03	4.69	0.03	0.02	0.02	0.01	0.03	0.01	0.03	0.45
Malaysia(MYS)	0.27	0.02	10.16	0.42	0.11	0.34	0.32	0.40	0.32	0.43	0.76
Mali(MLI)	0.19	0.03	2.38	0.14	0.04	0.04	0.04	0.12	0.04	0.11	0.29
Mauritania(MRT)	0.30	0.03	4.51	0.15	0.05	0.07	0.07	0.14	0.07	0.16	0.45
Mexico(MEX)	0.23	0.01	9.06	0.46	0.48	0.34	0.30	0.45	0.30	0.45	0.66
Morocco(MAR)	0.37	0.01	5.01	0.22	0.07	0.12	0.13	0.22	0.13	0.28	0.56
Mozambique(MOZ)	0.17	0.02	1.81	0.09	0.02	0.02	0.02	0.08	0.03	0.07	0.26
Nepal(NPL)	0.25	0.02	4.02	0.06	0.03	0.03	0.03	0.06	0.03	0.06	0.41
Netherlands(NLD)	0.21	0.01	11.02	1.04	0.88	0.86	0.84	1.07	0.87	1.03	0.84
New Zealand(NZL)	0.21	0.01	12.68	0.66	1.00	0.63	0.61	0.66	0.63	0.64	0.93
Nicaragua(NIC)	0.29	0.01	6.66	0.10	0.23	0.07	0.05	0.09	0.05	0.10	0.58
Niger(NGA)	0.08	0.02	1.84	0.33	0.11	0.07	0.06	0.31	0.10	0.18	0.18
Norway(NOR)	0.25	0.00	12.26	1.17	0.79	1.16	1.18	1.21	1.18	1.28	1.18
Pakistan(PAK)	0.15	0.02	5.53	0.19	0.05	0.08	0.07	0.18	0.08	0.15	0.37
Panama(PAN)	0.23	0.02	9.60	0.41	0.18	0.27	0.28	0.39	0.28	0.39	0.69
Papua(PNG)	0.17	0.02	4.08	0.19	0.09	0.07	0.06	0.17	0.07	0.15	0.33
Paraguay(PRY)	0.15	0.02	8.51	0.15	0.12	0.10	0.08	0.15	0.09	0.12	0.50
Peru(PER)	0.23	0.01	8.93	0.24	0.26	0.16	0.15	0.23	0.15	0.23	0.65
Philippines(PHL)	0.20	0.02	8.95	0.14	0.10	0.09	0.08	0.13	0.09	0.13	0.58
Portugal(PRT)	0.28	0.00	8.03	0.66	0.27	0.45	0.46	0.68	0.46	0.76	0.70

	Determinants				Relative Output per Worker						
Countries	s_K	n	S2010	A2010	1960	2010	(1)	(2)	(3)	(4)	(5)
Romania(ROM)	0.22	0.00	10.34	0.36	0.07	0.26	0.29	0.39	0.29	0.38	0.81
Rwanda(RWA)	0.13	0.03	3.96	0.09	0.04	0.02	0.02	0.08	0.03	0.06	0.27
Senegal(SEN)	0.25	0.03	5.20	0.09	0.08	0.04	0.04	0.08	0.04	0.09	0.44
Singapore(SGP)	0.30	0.02	9.13	1.57	0.32	1.17	1.18	1.52	1.18	1.76	1.18
South Africa(ZAF)	0.22	0.01	8.48	0.38	0.36	0.24	0.23	0.38	0.24	0.37	0.62
Spain(ESP)	0.29	0.01	10.40	0.76	0.43	0.67	0.64	0.74	0.64	0.84	0.85
Sri Lanka(LKA)	0.24	0.01	11.10	0.15	0.04	0.11	0.12	0.15	0.12	0.15	0.83
Sweden(SWE)	0.18	0.00	11.48	1.07	0.76	0.83	0.86	1.13	0.96	1.01	0.86
Switzerland(CHE)	0.25	0.00	9.92	0.94	1.03	0.78	0.74	0.97	0.74	1.02	0.79
Syrian (SYR)	0.16	0.03	5.21	0.45	0.15	0.17	0.15	0.41	0.18	0.34	0.34
Taiwan(TWN)	0.24	0.00	11.34	0.96	0.13	0.78	0.86	0.99	0.86	1.03	0.90
Tanzania(TZA)	0.23	0.02	5.78	0.06	0.02	0.03	0.03	0.06	0.03	0.06	0.45
Thailand(THA)	0.28	0.01	7.41	0.27	0.05	0.17	0.17	0.27	0.17	0.30	0.64
Togo(TGO)	0.15	0.03	5.77	0.03	0.04	0.02	0.01	0.03	0.01	0.02	0.35
Turkey(TUR)	0.18	0.01	7.18	0.91	0.16	0.40	0.44	0.88	0.49	0.79	0.49
Uganda(UGA)	0.14	0.03	5.46	0.10	0.04	0.03	0.03	0.09	0.04	0.07	0.33
United Kingdom(GBR)	0.18	0.01	9.44	1.34	0.60	0.82	0.86	1.38	0.96	1.23	0.86
United States(USA)	0.23	0.01	13.09	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Uruguay(URY)	0.21	0.00	8.56	0.42	0.28	0.26	0.27	0.44	0.28	0.43	0.65
Venezuela.(VEN)	0.21	0.01	7.13	0.39	0.60	0.25	0.20	0.38	0.21	0.36	0.51
Zambia(ZMB)	0.21	0.03	6.68	0.09	0.07	0.04	0.04	0.08	0.04	0.08	0.47
Zimbabwe(ZWE)	0.04	0.00	7.70	0.02	0.02	0.01	0.00	0.02	0.01	0.01	0.25

Notes: The determinants of steady-state output are: s_K investment share, last decade average, trended data; n population growth, decade average; $S2010$ average years of schooling in 2010; and $A2010$ relative level of technology (TFP) in 2010. Simulations: (1) Base Model, (2) $s_{K_i} = s_{K_{USA}}$ and $h_i = h_{USA}$, (3) $s_{K_i} \geq s_{K_{USA}}$, (4) $h_i = h_{USA}$, (5) $A_i \geq A_{USA}$. Data on output per worker is also available for the following countries: Burkina Faso(BFA), Ethiopia(ETH), Guinea(GIN), Madagascar(MDG), Niger(NER), Puerto Rico(PRI), Chad(TCD).

This countries, however, are not including in Section 2 of this paper due to lack of data on educational attainment