Accounting for Convergence between Countries*

Thomas Schelkle†

January 10, 2014

Abstract

This paper provides an accounting exercise to investigate the proximate sources of convergence and divergence of income per worker between countries during 1970-2010. The first finding is that differences in changes to efficiency and not to factor endowments explain three important facts: Why poor countries do on average not grow faster than rich ones, why income dispersion is rising and why the income distribution becomes more polarized. The second finding is that experiences of successful catch-up to the United States are mainly driven by relatively faster factor accumulation, but experiences of falling behind by relatively slower efficiency improvements. Thus there is an asymmetry between the sources of convergence and divergence to the United States.

JEL codes: O47, O11
Keywords: Convergence, Accounting, Growth, Development

*I thank Francesco Caselli, Alexander Ludwig and seminar participants at the Center for Macroeconomic Research of the University of Cologne for helpful comments.

†University of Cologne; Center for Macroeconomic Research; Albertus-Magnus-Platz; 50923 Köln; Germany; Email: schelkle@wiso.uni-koeln.de

1 Introduction

Divergence is a dominant feature of the cross-country income distribution in recent decades. Poor countries do on average not grow faster than rich ones and the cross-country income distribution is characterized by rising dispersion and polarization. Though these big picture facts are undisputed they also hide a huge heterogeneity. Some poor countries have made enormous progress in catching up with rich countries like the United States. At the same time other poor countries have fallen even further behind.

This paper explains how differences in factor accumulation and efficiency improvements between countries contribute to these patterns of convergence and divergence during 1970-2010. The paper builds on standard decompositions of income levels and growth rates from the literature on growth accounting following Solow (1957) and development accounting exercises like King and Levine (1994), Klenow and Rodríguez-Clare (1997), Hall and Jones (1999), Caselli (2005) and Hsieh and Klenow (2010).

Building on these basic decompositions the paper then conducts "convergence accounting", for which no standard approach exists in the literature yet. Accordingly I present a set of different accounting exercises that are closely related to different concepts of convergence.[1] This reveals the proximate sources of a variety of empirically observed facts related to country and time difference-in-differences and the relative performance of initially poor and rich countries. The analysis consists of two main parts.

In a first set of exercises the relevant object of study is essentially how the whole cross-country income distribution evolves over time. Specifically, I present decompositions of three well known empirical facts on the absence of convergence in large samples of countries.[2] The first fact is that poor countries do on average not grow faster than rich countries or the absence of absolute β-convergence, which is documented by Barro (1991), Barro

[1]Discussions of different convergence concepts can be found in Barro and Sala-i-Martin (1992, 2003) and Sala-i-Martin (1996).

[2]Surveys of the empirical growth literature are provided by Barro and Sala-i-Martin (2003), de la Fuente (1997), Durlauf, Johnson, and Temple (2005) and Temple (1999). Though the framework presented here could in principle be applied at various levels of aggregation, this paper focusses exclusively on countries as the unit of analysis. A discussion and references on convergence between regions or in smaller samples of countries are provided by Barro and Sala-i-Martin (2003). Convergence of the world income distribution of individuals is investigated by Sala-i-Martin (2006).

and Sala-i-Martin (1992), Mankiw, Romer, and Weil (1992) and Sala-i-Martin (1996). The second fact is that income dispersion is rising over time such that there is no σ-convergence as shown by Sala-i-Martin (1996) and Pritchett (1997). The third fact observed by Quah (1993, 1996, 1997) and Jones (1997) is the emergence of twin peaks in the cross-country income distribution, which is often referred to as polarization. This paper provides evidence on the proximate sources of these empirical patterns. The main result is that all these facts of divergence are explained by differences in the rates of efficiency improvements across countries. In contrast factor accumulation is a force towards convergence. However this force is too weak to outweigh the effect of efficiency changes.

It is debatable which of these empirical facts of income divergence is most important for specific theoretical or policy questions. Thus it is an important result that no matter what position one takes on this issue, all these facts are accounted for by differences in efficiency changes between countries. These findings also complement the standard finding of development accounting that differences in factor endowments alone only explain a small fraction of the variation in income levels across countries at a point in time. The results show that in addition the increase in income differences over time is not explained by widening differences in factor endowments, but by the patterns of efficiency changes.

The accounting results for the absence of absolute β-convergence challenge a common interpretation of the influential conditional β-convergence results of Mankiw, Romer, and Weil (1992). These authors found that after controlling for variables reflecting factor accumulation that determine the steady state of the Solow (1956) model poor countries do grow faster than rich ones. Accordingly at first glance their finding seems to suggest that the absence of absolute β-convergence is due to slower factor accumulation in poor countries. This interpretation is inconsistent with the results of this paper. However I argue that one should not interpret the findings of Mankiw, Romer, and Weil (1992) in an accounting sense. The reason is that their analysis rests on the restrictive assumption of common rates of efficiency improvement across countries. This assumption confounds their analysis and effectively prevents it from answering the accounting question on the relative role of factors and efficiency for the absence of absolute

β-convergence.

The second part of the paper is concerned with the sources of convergence and divergence of poor countries to the United States. This means it uses a pairwise convergence concept. Here I focus in more detail on the enormous heterogeneity of convergence experiences by looking separately at the sets of countries that are catching up and falling behind relative to the United States. The first main finding is that experiences of successful convergence to the U.S. are mainly driven by relatively faster factor accumulation. This is consistent with the careful growth accounting exercise of Young (1995) for the high growth episodes of four East Asian countries. The analysis extends the finding of Young by showing that in a much larger sample this is a systematic pattern among countries that successfully catch up to the United States. However I also find that this is not a valid explanation for experiences of falling further behind. Instead the divergence of countries from the U.S. is mainly accounted for by relatively slower efficiency improvements. Thus there is an asymmetry between the sources of convergence and divergence to the United States.

There is an important general theoretical and policy debate on whether factor accumulation or efficiency improvements are key for understanding growth rates, income levels and convergence across countries. The results of this paper support a balanced view on this issue with respect to convergence. Factor accumulation seems to be important for explaining episodes where poor countries successfully catch up to rich countries. But relatively slower and sometimes even negative changes to efficiency in poor countries are key for explaining experiences of falling further behind and the big picture facts of divergence in the cross-country income distribution taken as a whole. These findings highlight the need to better understand both factor accumulation and efficiency changes. They also suggest that the fundamental sources of these two engines of growth may not be completely identical.

The paper is related to prior convergence accounting exercises by Dowrick and Nguyen (1989) and Serrano (1999) for OECD countries, Caselli and Tenreyro (2004) for Europe, de la Fuente (2002) for Spanish regions and Turner, Tamura, and Mulholland (2013) for U.S. states, among others[3].

[3]There is also a small literature building on Kumar and Russell (2002) and Henderson

The contribution of this paper relative to the prior literature is to study several different concepts of convergence within a common framework. The other main difference is that all of these papers are concerned with samples that exhibit convergence. In contrast this paper is focussed on a large sample of countries where divergence is the dominant feature. Furthermore this allows to study the asymmetry between the sources of convergence and divergence of poor countries to a rich country like the United States.

The paper is organized as follows. Section 2 explains the basic accounting framework of income levels and the data. Section 3 analyses how factor accumulation and efficiency changes determine the evolution of the whole cross-country income distribution. Convergence in the sense of catching up with the United States is studied in section 4. Section 5 conducts a sensitivity analysis and section 6 concludes. An online appendix contains further results and robustness checks.

2 Basic Accounting Framework

In this section I present a basic accounting framework that decomposes output levels for many countries and time periods into the contributions of production factors and efficiency levels. The presented approach follows very closely the procedures used in the development accounting literature by Hall and Jones (1999), Caselli (2005) and others. With the information on factors and efficiency in levels and hence in growth rates in hand, I will then conduct convergence accounting exercises in the following main sections.

2.1 Accounting Decomposition in Levels

Development or levels accounting assumes that output per worker y_{it} in country i and period t are determined by a known function F_{it} of factors of production and an unknown efficiency level A_{it} through the production

and Russell (2005) that uses data envelopment techniques to study the sources of growth and polarization. In contrast I follow standard growth and development accounting by decomposing income levels into the two main sources emphasized by theories of growth: factor endowments and efficiency.

function

$$y_{it} = A_{it}F_{it}. \tag{1}$$

The idea of levels accounting is to measure output y_{it} and the factor input contribution F_{it} and then use equation (1) to back out the unobserved efficiency levels A_{it}. I follow this approach to measure F_{it} and A_{it}. These measures are then used in later sections to show how factor accumulation and efficiency improvements account for patterns of convergence and divergence of income per worker between countries during the time period 1970-2010.

In order to implement the accounting decomposition one needs to assume a functional form of F. I follow Hall and Jones (1999) and Caselli (2005) in assuming that aggregate output Y_{it} is given by a constant returns to scale Cobb-Douglas production function $Y_{it} = A_{it}K_{it}^{\alpha}(h_{it}L_{it})^{1-\alpha}$. Here K_{it} is aggregate capital, L_{it} is the number of workers and h_{it} is average human capital per worker. Using this assumption equation (1) for output per worker then reads as

$$y_{it} = A_{it}k_{it}^{\alpha}h_{it}^{1-\alpha} \tag{2}$$

where k_{it} is physical capital per worker. Accordingly, the contribution of factors F_{it} in equation (1) is given by $F_{it} = k_{it}^{\alpha}h_{it}^{1-\alpha}$.

Following the development accounting literature and the macroeconomic literature more generally I calibrate the value of α to 1/3, which is implicitly based on observed factor income shares in the United States. Given data on output, physical capital and human capital per worker one can then measure the contributions of factors F_{it} and efficiency levels A_{it} in many countries and time periods.

2.2 Implications for Growth Rates

Depending on the type of convergence that is investigated, it is sometimes more convenient to work with growth rates and to decompose them into the contributions of factor accumulation and efficiency changes. Growth rates in this paper are computed as log-growth rates. The average annual growth rate between year s and $t > s$ of income per worker y for country i is computed as $g_y^i = \frac{1}{t-s}\left[\log(y_{it}) - \log(y_{is})\right]$ and equivalently for the contribution of factors F and efficiency A. Given the assumed production function of equation (1) income growth rates can then be decomposed according to

$$g_y^i = g_F^i + g_A^i \tag{3}$$

where g_F^i and g_A^i are the growth rates of the contributions of factors and efficiency, respectively. Given information on levels from the accounting decomposition in section 2.1, I then compute the relevant growth rates of equation (3).

2.3 Data

The data sources and variables are standard in the literature and closely follow the procedures used by Caselli (2005). Data on real output per worker and aggregate investment in physical capital in international dollars (PPP adjusted), and the number of workers are taken from the Penn World Tables Version 7.1.[4] A series for the aggregate physical capital stock in each country is computed by the perpetual inventory method which iterates on

$$K_{i,t+1} = (1 - \delta)K_{it} + I_{it} \tag{4}$$

given the time series for aggregate investment I_{it}. It is assumed that the depreciation rate δ is equal to 0.06. The estimate of the initial capital stock is given by $K_{i0} = \frac{I_{i0}}{\delta + g_i}$ where g_i is the geometric average of the growth rate of the investment series during the first 10 years that the country is observed. Since I will analyse convergence between 1970 and 2010, I restrict attention to countries whose investment series starts at the latest in the year 1960. The aggregate physical capital stock is divided by the number of workers to obtain physical capital per worker k_{it}.

The human capital measure is based on observed average years of schooling s_{it} of the population above age 15 obtained from Barro and Lee (2013). Following Hall and Jones (1999) and Caselli (2005) human capital stocks

[4]The variable used for output per worker is RGDPWOK. Aggregate real investment is computed as RGDPL × POP × KI / 100. The number of workers is calculated as RGDPCH × POP / RGDPWOK.

are then computed with a Mincerian method such that

$$h_{it} = \exp(\phi(s_{it})) \tag{5}$$

where $\phi(s_{it})$ is a piece-wise linear step function that reflects a return to schooling for the first four years of 13.4%, 10.1% for the next four years and thereafter 6.8%.[5]

The final data set includes 98 countries and annual observations at a five-year frequency between 1970 and 2010. However for most of the following analysis I simply focus on convergence over the whole time period and only use the observations of 1970 and 2010.

2.4 Discussion of the decomposition

The used levels accounting decomposition resembles very closely the benchmark decomposition of Caselli (2005). However there is an active recent literature on development accounting that attempts to improve on the standard measurements and functional forms. Examples include Caselli and Ciccone (2013) for the contribution of schooling, Lagakos, Moll, Porzio, and Qian (2012) for experience, Weil (2007) for health status and Caselli (2005) for an extensive collection of different effects. In contrast to these studies the contribution of this paper is to conduct the convergence accounting exercises. I thus consider the employed levels accounting framework as a useful benchmark and leave a detailed application of these recent innovations in levels accounting to convergence questions for future research.

However I conduct a simple check to assess whether there is evidence for a strong cumulative effect from omitting all the features mentioned above. Specifically, I compare my estimates of the growth rates of efficiency (TFP) for the East Asian tiger countries to the careful estimates of Young (1995) that are based on detailed disaggregated data of physical capital stocks and the labor force. Young's estimates are for the period 1966-1990. Thus I compare them to the ones I would obtain for the period 1970-1990. My estimates of the annual efficiency growth rate vs. Young's for Hong Kong are 2.3% vs. 2.3%, for South Korea 1.8% vs. 1.7%, for Taiwan 2.2% vs.

[5] Specifically, $\phi(s) = 0.134 \cdot s$ if $s \leq 4$, $\phi(s) = 0.134 \cdot 4 + 0.101 \cdot (s - 4)$ if $4 < s \leq 8$, $\phi(s) = 0.134 \cdot 4 + 0.101 \cdot 4 + 0.068 \cdot (s - 8)$ if $s > 8$.

2.1% and for Singapore 1.9% vs. 0.2%. This shows that with the exception of Singapore, my estimates are extremely close to Young's. I conclude from this comparison that the used decomposition seems to provide reasonable results at least for this group of fast growing countries. Nevertheless I also examine the sensitivity of the main results to the chosen parameter values and the initial estimate of the capital stock in section 5 and online appendix A.

3 Accounting for the Evolution of the Cross-Country Income Distribution

This section explains how factor accumulation and efficiency improvements account for patterns of convergence (or divergence) between countries. In some sense the evolution of the whole cross-country income distribution is the relevant object of study here. Specifically, I provide accounting exercises for why poor countries on average do not grow faster than rich countries (absence of absolute β-convergence), why income dispersion rises (absence of σ-convergence) and why twin peaks in the income distribution emerge.

3.1 Accounting for the Absence β-Convergence

One prominent concept of convergence is absolute β-convergence which is defined as "poor countries grow faster than rich countries". The literature has typically investigated whether this type of convergence is present by regressing income growth rates over a period of time on initial income levels and checking whether this yields a significantly negative coefficient estimate. It is well-known that in large samples of countries there is no evidence for such a pattern as shown by Barro (1991), Barro and Sala-i-Martin (1992), Mankiw, Romer, and Weil (1992) and Sala-i-Martin (1996), among others. The first column of table 1 repeats such a regression exercise for my data set and figure 1(a) plots average annual growth rates against initial log income levels. Consistent with the prior literature poor countries do not grow significantly faster than rich ones in this sample which points towards the absence of β-convergence.

Table 1: Regressions of annual growth rates (in %) on initial log income

	g_y	g_F	g_A
log(y) in 1970	-0.0351	-0.121**	0.0863
	(0.118)	(0.0574)	(0.0884)
Observations	98	98	98
R^2	0.001	0.043	0.010

Robust standard errors in parantheses.

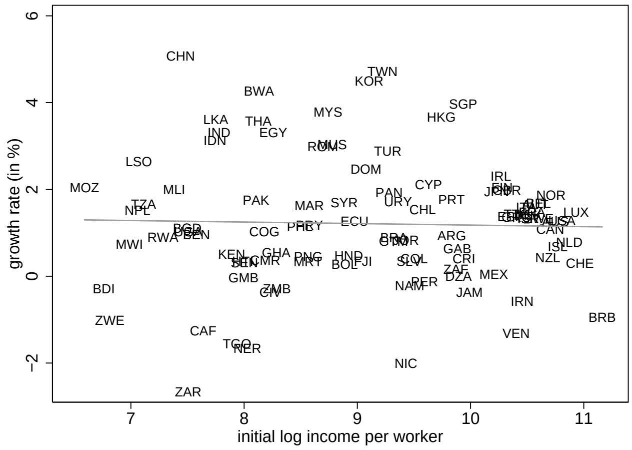
* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

I now investigate the proximate reasons for this pattern. Is the lack of convergence due to the fact that poor countries do not exhibit faster factor accumulation or efficiency improvements than rich ones, or both? The second and third columns of table 1 present regressions of the growth rates of the factor contribution g_F and efficiency g_A on initial log income and figures 1(b) and 1(c) show the associated scatter plots. One observes that poor countries on average exhibit a significantly faster accumulation of factors. These results show that factor accumulation is indeed a force supporting absolute β-convergence during this time period. But efficiency does not improve significantly faster in poor countries. The absence of absolute β-convergence is due to the fact that the force of factor accumulation towards convergence is too weak relative to the diverging force of efficiency changes.

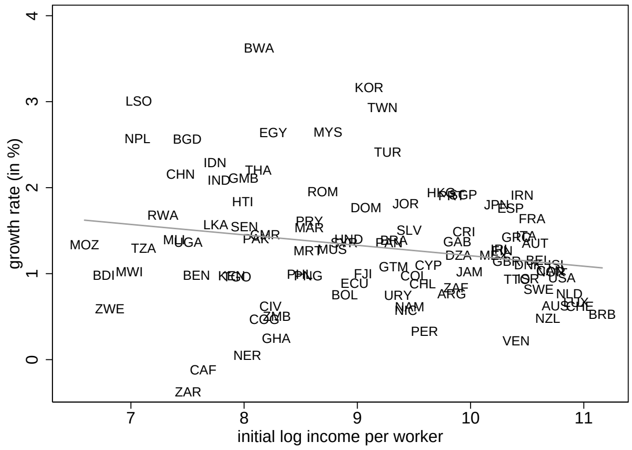
The findings of this section stand in marked contrast to the influential conditional β-convergence results of Mankiw, Romer, and Weil (1992), henceforth MRW. These authors use an estimation instead of a calibration framework and find that after controlling for variables determining the steady state of the Solow (1956) model like saving and population growth rates poor countries do grow faster than rich ones. Accordingly at first glance MRW's finding suggests that the absence of absolute β-convergence is due to slower factor accumulation in poor countries, which is inconsistent with the results of this section. However as I discuss in more detail in online appendix C one should not give an accounting interpretation to MRW's conditional β-convergence result. The basic reason is that MRW

Figure 1: Dependence of Annual Growth Rates during 1970-2010 on Initial Income Levels

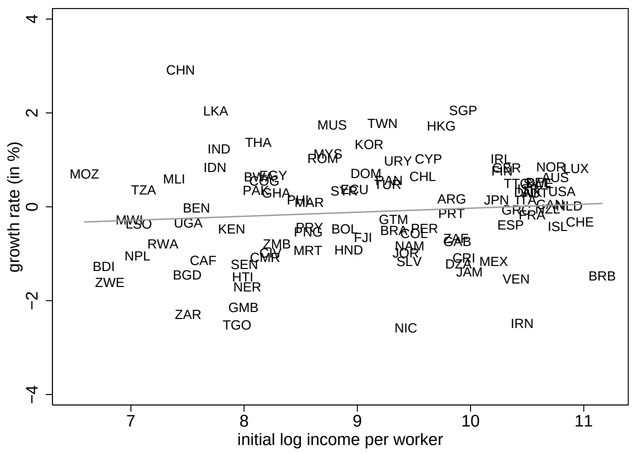
(a) Growth of Output per Worker y



(b) Growth of Factor Contribution F



(c) Growth of Efficiency A



assume common rates of efficiency improvement across countries. This assumption confounds their analysis and prevents it from answering questions on the relative role of factors and efficiency for the absence of absolute β-convergence. In other words their analysis rests on a fact that in an accounting context should not be an element of the assumptions, but instead of the question and answer.

3.2 Accounting for the Absence of σ-Convergence

Another concept of convergence is called σ-convergence. The definition of this concept is that convergence occurs when "income dispersion between countries declines over time". Sala-i-Martin (1996) and Pritchett (1997) among others document that samples consisting of many countries do not exhibit σ-convergence, but rising income dispersion. Figure 2(a) shows that in my data set income dispersion measured by the variance of log income per worker is indeed rising between 1970 and 2010.

I now investigate what accounts for this rise in income dispersion. Using the assumed production function of equation (1) the variance of log income is related to factors and efficiency levels according to

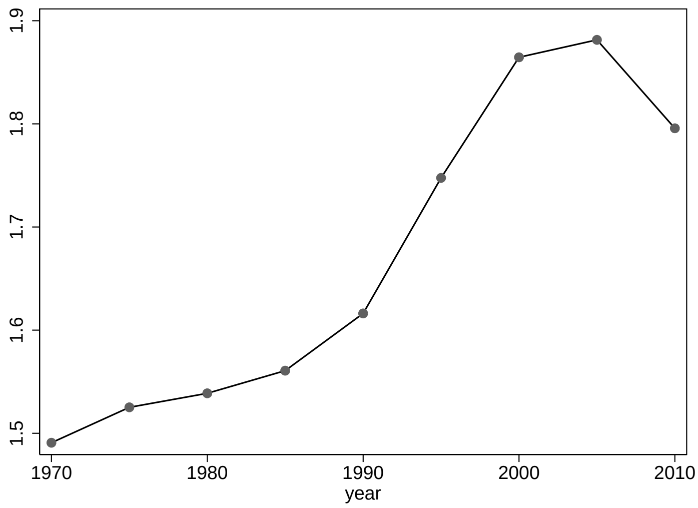
$$\text{Var}[\log(y)] = \text{Var}[\log(F)] + \text{Var}[\log(A)] + 2 \times \text{Cov}[\log(F), \log(A)]. \quad (6)$$

The equation implies that a rising variance of log income over time could be due either to an increase in the variance of factor endowments, the variance of efficiency levels or the covariance between factors and efficiency.

Figure 2(b) plots the time-series of these three objects during 1970-2010 and table 2 reports their values for the years 1970 and 2010 and the difference between these periods. It is evident that the variance of factor endowments remains almost constant and in fact declines slightly during this period. Instead about one third of the rise in income dispersion is due to rising dispersion in efficiency levels. The remaining two thirds are due to a rising covariance between factor endowments and efficiency levels. The correlation coefficient between $\log(F)$ and $\log(A)$ increases between 1970 and 2010 from about 0.76 to 0.93. Thus factor endowments and efficiency levels become more strongly positively related over time such that countries tend to enjoy either high levels on both or low levels on both.

Figure 2: Evolution of Income Dispersion across Countries during 1970-2010

(a) Variance of Log Income



(b) Decomposition of Variance of Log Income

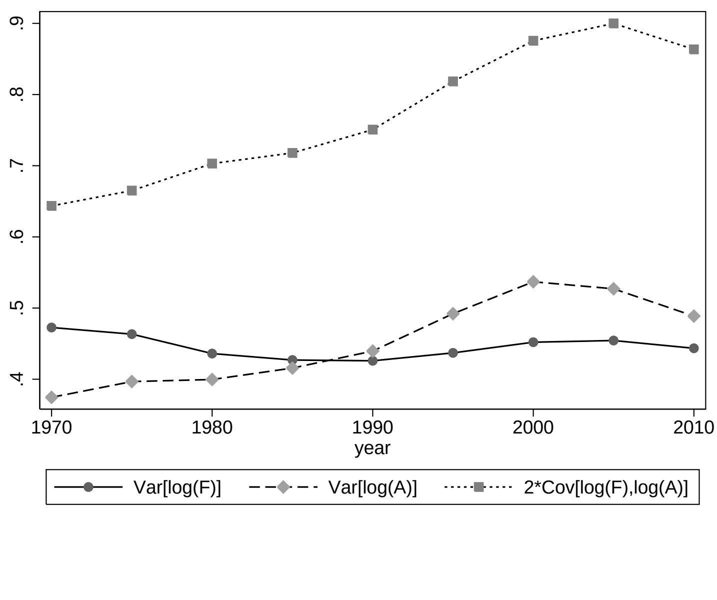


Table 2: Decomposition of Variance of Log Income

Year	$\text{Var}[\log(y)]$	$\text{Var}[\log(F)]$	$\text{Var}[\log(A)]$	$2 \times \text{Cov}[\log(F), \log(A)]$
1970	1.49	0.47	0.37	0.64
2010	1.80	0.44	0.49	0.86
Δ	0.30	-0.03	0.11	0.22

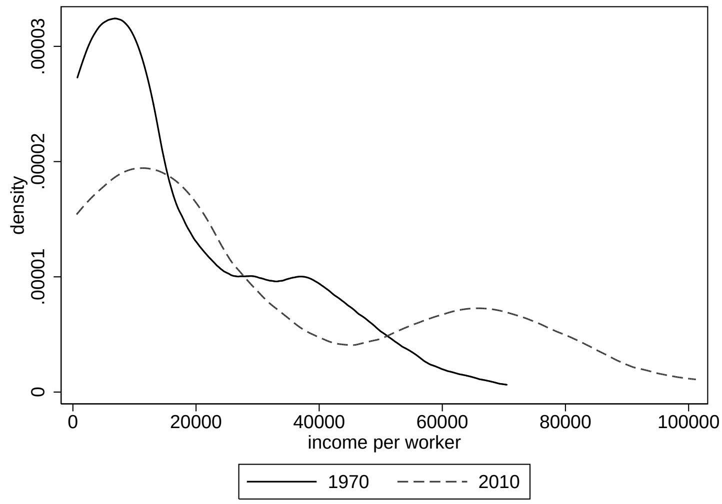
Overall these results show that factor accumulation tends to weakly reduce income dispersion. In contrast the forces of divergence are that efficiency levels become more dispersed over time and more strongly related to factor endowments. The absence of σ-convergence in the world income distribution is due to the fact that the equalising effect of factor accumulation is too weak relative to these forces. These findings complement the standard finding of development accounting that differences in factor endowments alone only explain a small fraction of the variation in income across countries at a point in time. The results show that in addition the increase in income differences over time is not explained by widening differences in factor endowments, but by the patterns of efficiency changes.

3.3 Accounting for the Emergence of Twin Peaks

In a series of papers Quah (1993, 1996, 1997) and Jones (1997) draw attention to the emergence of twin peaks in the cross-country income distribution. Figure 3 shows kernel density estimates of income per worker in the sample used in this paper for the years 1970 and 2010. The cross-country income distribution in 1970 had only one clear peak with many poor countries, a large middle group and very few rich countries. In contrast the 2010 income distribution features two pronounced peaks with a large group of poor countries, a large group of rich countries and a very small group of countries in the middle. This phenomenon is frequently referred to as a polarization of the cross-country income distribution or the existence of convergence clubs.

The question I address next is whether patterns of factor accumulation or efficiency improvements across countries account for these facts. In order

Figure 3: Cross-Country Income Distributions in 1970 and 2010



to investigate this question I compute two counterfactual levels of income per worker in 2010 for each country given by

$$y^F_{i,2010} = A_{i,1970}F_{i,2010} \tag{7}$$

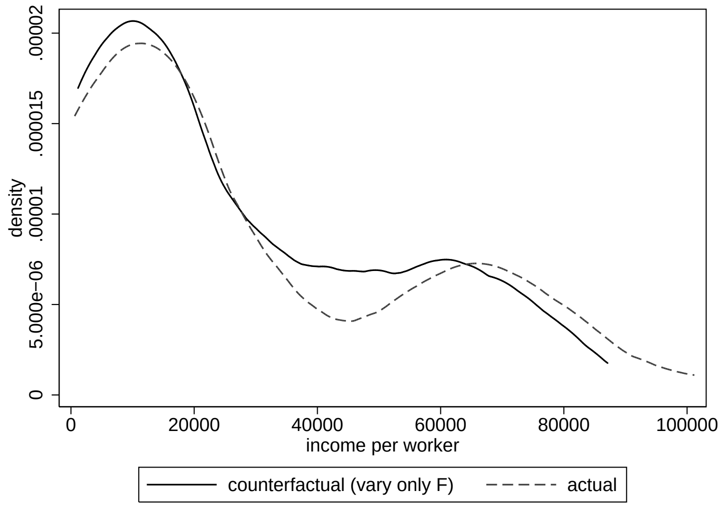
$$y^A_{i,2010} = A_{i,2010}F_{i,1970}. \tag{8}$$

The counterfactual income level $y^F_{i,2010}$ shows what income in 2010 would have been if only factor endowments had changed during 1970-2010, but each country still had its efficiency level from 1970. In contrast $y^A_{i,2010}$ keeps factor endowments at their 1970 level and only varies efficiency levels.

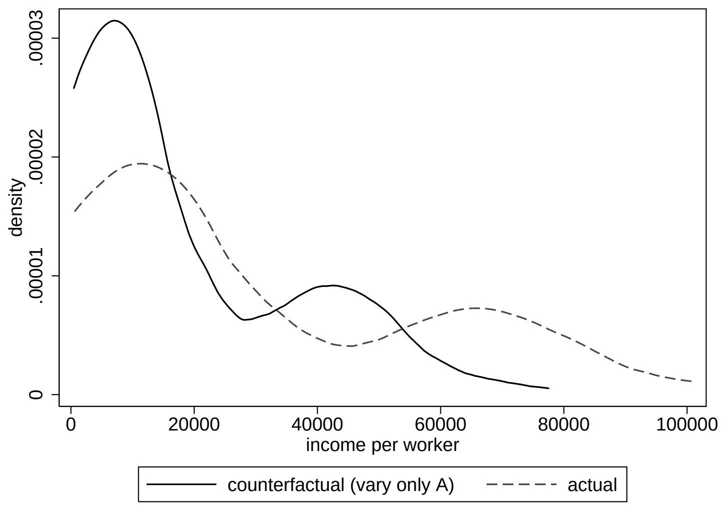
Figure 4 presents kernel density estimates of the income distributions associated with these two counterfactual income levels in comparison to the actual 2010 income distribution that is the result from both factors and efficiency changing. These graphs show that the patterns of factor accumulation across countries alone do not lead to the emergence of a pronounced second peak. In contrast efficiency changes alone are sufficient to account for the emergence of twin peaks.

Figure 4: Actual and Counterfactual Income Distributions in 2010

(a) Only Factors Change (Efficiency kept at 1970 Levels)



(b) Only Efficiency Changes (Factors kept at 1970 Levels)



4 Accounting for Convergence to the United States

There is no general tendency for poor countries to grow faster than rich countries, but figure 1(a) also reveals an enormous heterogeneity in growth experiences during 1970-2010. Some poor countries have grown much faster than rich countries, while others have not. In this section I explore this heterogeneity in more detail and investigate convergence in the sense of catching up with the United States, which represents one of the richest countries in the world. This amounts to a pairwise convergence concept. I ask whether experiences of catching up (falling behind) are accounted for by relatively faster (slower) factor accumulation or efficiency improvements compared to the United States. Furthermore I investigate whether the role of these two underlying forces differs for countries that are catching up versus falling behind during 1970-2010.

A simple measure of catch-up of a poor country to the U.S. is a positive difference in growth rates between the two countries. The decomposition in equation (3) implies that differences in income growth rates between country i and the U.S. are related to differences in growth rates of factors and efficiency according to

$$g_y^i - g_y^{US} = (g_F^i - g_F^{US}) + (g_A^i - g_A^{US}). \tag{9}$$

The income level of country i relative to the one of the U.S., $\frac{y_{it}}{y_{US,t}}$, then evolves between periods s and $t > s$ as

$$\frac{y_{it}}{y_{US,t}} = \exp[(t-s)(g_y^i - g_y^{US})]\frac{y_{is}}{y_{US,s}} \tag{10}$$

such that any growth difference can directly be translated into a change of relative income levels. Equivalent equations apply for relative factor endowments $\frac{F_{it}}{F_{US,t}}$ and efficiency levels $\frac{A_{it}}{A_{US,t}}$.

Table 3 contains for each country and each of the three variables income, factors and efficiency their absolute and relative growth rates over the period 1970-2010 and their levels relative to the U.S. for the years 1970 and 2010. The table shows in detail for each country how its income relative to the U.S. in 1970 and 2010 is accounted for by relative factor endowments and efficiency levels. It also presents how catch-up or falling behind over this period are accounted for by the relative speed of factor accumulation and efficiency improvements.[6] I summarize these results below.

Since the following discussion is focussed on growth differences to the United States, it is worth to first report what my decomposition finds for the growth experience of the United States. During 1970-2010 income per worker in the U.S. grew by 1.28% per year, of which 0.95% are due to factor accumulation and 0.33% are due to efficiency improvements. The value for efficiency improvements may appear to be unexpectedly low. But this finding is consistent with the result of Jorgenson and Yip (2001) who estimate a value of 0.41% during 1973-1995. My estimate for the time period of 1970-1995 would be 0.37% and thus be even closer to their finding.

I simplify the following summary by restricting attention to countries that were poorer than the U.S. in 1970. This ensures that a positive growth difference indeed constitutes a catch-up to the United States. This means that Luxemburg, the Netherlands, Switzerland, Barbados and the United States itself are excluded from the following analysis. The sample then contains 93 countries that were initially poorer than the U.S. and in fact except for Norway were still poorer in 2010.

Summary statistics of the patterns of convergence and divergence to the U.S. are explored in table 4 by considering different country groups. The first two rows present the simplest possible partition of the sample by considering separately the 44 countries that converged towards the U.S. and the 49 countries that diverged from the U.S. during 1970-2010. Converging countries experienced an income growth rate that was on average about 1.16% per year higher than in the United States. On average about two thirds of this income growth difference is accounted for by faster factor accumulation and one third by faster efficiency improvements. In contrast the income growth rate of diverging countries was about -1.1% lower than in the United States. For diverging countries this difference is almost completely accounted for by slower efficiency improvements compared to the

[6]The table contains all necessary information to also study convergence and divergence to a country other than the United States by computing suitable differences or ratios of the reported numbers.

Table 3: Growth Rates and Levels relative to the United States

	Growth Rates (in %)			Growth Differences to U.S. (in %)			Levels relative to U.S.					
Country	g_y	g_F	g_A	$g_y - g_y^{US}$	$g_F - g_F^{US}$	$g_A - g_A^{US}$	$\frac{y_{1970}}{y_{1970}^{US}}$	$\frac{y_{2010}}{y_{2010}^{US}}$	$\frac{F_{1970}}{F_{1970}^{US}}$	$\frac{F_{2010}}{F_{2010}^{US}}$	$\frac{A_{1970}}{A_{1970}^{US}}$	$\frac{A_{2010}}{A_{2010}^{US}}$
Algeria	0.00	1.22	-1.21	-1.28	0.26	-1.54	0.40	0.24	0.49	0.54	0.83	0.45
Argentina	0.94	0.77	0.17	-0.34	-0.18	-0.16	0.38	0.33	0.58	0.54	0.66	0.61
Australia	1.26	0.63	0.63	-0.02	-0.32	0.30	0.94	0.94	1.11	0.97	0.85	0.96
Austria	1.65	1.35	0.30	0.37	0.40	-0.03	0.79	0.92	0.74	0.87	1.07	1.06
Bangladesh	1.11	2.57	-1.45	-0.17	1.61	-1.78	0.04	0.03	0.10	0.19	0.36	0.18
Barbados	-0.94	0.53	-1.47	-2.22	-0.42	-1.80	1.43	0.59	0.94	0.79	1.52	0.74
Belgium	1.68	1.16	0.52	0.40	0.21	0.20	0.81	0.96	0.87	0.94	0.94	1.01
Benin	0.96	0.98	-0.02	-0.32	0.03	-0.34	0.04	0.03	0.18	0.18	0.22	0.19
Bolivia	0.28	0.75	-0.47	-1.00	-0.20	-0.80	0.15	0.10	0.33	0.30	0.45	0.33
Botswana	4.27	3.62	0.64	2.99	2.67	0.32	0.07	0.23	0.21	0.61	0.33	0.37
Brazil	0.89	1.39	-0.50	-0.39	0.44	-0.83	0.23	0.19	0.35	0.42	0.64	0.46
Burundi	-0.29	0.98	-1.27	-1.57	0.03	-1.59	0.02	0.01	0.10	0.10	0.17	0.09
Cameroon	0.37	1.45	-1.08	-0.90	0.50	-1.41	0.07	0.05	0.19	0.23	0.39	0.22
Canada	1.08	1.03	0.05	-0.20	0.08	-0.28	0.90	0.83	0.87	0.90	1.04	0.93
Central African Republic	-1.26	-0.12	-1.14	-2.54	-1.07	-1.47	0.04	0.02	0.16	0.11	0.26	0.14
Chile	1.53	0.89	0.65	0.25	-0.07	0.32	0.29	0.32	0.59	0.58	0.49	0.56
China	5.07	2.16	2.91	3.79	1.21	2.59	0.03	0.16	0.25	0.41	0.14	0.38
Colombia	0.41	0.98	-0.57	-0.87	0.02	-0.89	0.27	0.19	0.41	0.41	0.66	0.46
Congo, Dem. Rep.	-2.66	-0.37	-2.29	-3.94	-1.32	-2.61	0.04	0.01	0.19	0.11	0.19	0.07
Congo, Republic of	1.03	0.47	0.56	-0.25	-0.48	0.23	0.07	0.07	0.34	0.28	0.21	0.23
Costa Rica	0.40	1.49	-1.09	-0.88	0.54	-1.41	0.42	0.30	0.42	0.52	1.01	0.57
Cyprus	2.11	1.10	1.02	0.83	0.14	0.69	0.31	0.43	0.62	0.66	0.50	0.65
Denmark	1.41	1.10	0.31	0.13	0.15	-0.02	0.74	0.78	0.80	0.85	0.93	0.92
Dominican Republic	2.47	1.77	0.71	1.19	0.81	0.38	0.18	0.29	0.31	0.43	0.57	0.67
Ecuador	1.27	0.89	0.38	-0.01	-0.06	0.05	0.16	0.16	0.44	0.43	0.36	0.37

Table 3 (Continued)

Country	Growth Rates (in %)			Growth Differences to U.S. (in %)			Levels relative to U.S.					
	g_y	g_F	g_A	$g_y - g_y^{US}$	$g_F - g_F^{US}$	$g_A - g_A^{US}$	$\frac{y_{1970}}{y_{1970}^{US}}$	$\frac{y_{2010}}{y_{2010}^{US}}$	$\frac{F_{1970}}{F_{1970}^{US}}$	$\frac{F_{2010}}{F_{2010}^{US}}$	$\frac{A_{1970}}{A_{1970}^{US}}$	$\frac{A_{2010}}{A_{2010}^{US}}$
Egypt	3.32	2.64	0.67	2.04	1.69	0.35	0.08	0.18	0.17	0.33	0.46	0.53
El Salvador	0.35	1.51	-1.16	-0.93	0.55	-1.49	0.26	0.18	0.32	0.40	0.81	0.45
Fiji	0.35	1.00	-0.65	-0.93	0.05	-0.98	0.17	0.12	0.41	0.42	0.42	0.29
Finland	2.04	1.27	0.77	0.76	0.32	0.44	0.59	0.80	0.76	0.86	0.78	0.93
France	1.47	1.64	-0.17	0.19	0.69	-0.50	0.77	0.83	0.64	0.85	1.19	0.98
Gabon	0.64	1.37	-0.73	-0.64	0.42	-1.06	0.40	0.31	0.51	0.61	0.77	0.51
Gambia, The	-0.03	2.11	-2.15	-1.31	1.16	-2.47	0.06	0.04	0.10	0.15	0.62	0.23
Ghana	0.55	0.25	0.30	-0.73	-0.71	-0.03	0.08	0.06	0.34	0.26	0.23	0.23
Greece	1.36	1.42	-0.07	0.08	0.47	-0.39	0.67	0.69	0.70	0.85	0.95	0.81
Guatemala	0.81	1.08	-0.27	-0.47	0.13	-0.60	0.23	0.19	0.32	0.33	0.71	0.56
Haiti	0.35	1.84	-1.49	-0.93	0.88	-1.82	0.06	0.04	0.13	0.18	0.47	0.23
Honduras	0.48	1.40	-0.92	-0.80	0.45	-1.25	0.15	0.11	0.31	0.37	0.50	0.30
Hong Kong	3.67	1.94	1.73	2.39	0.99	1.40	0.34	0.90	0.61	0.90	0.57	0.99
Iceland	0.69	1.11	-0.42	-0.59	0.15	-0.74	0.96	0.76	0.87	0.93	1.11	0.82
India	3.32	2.09	1.23	2.04	1.13	0.90	0.05	0.11	0.18	0.29	0.27	0.38
Indonesia	3.13	2.29	0.84	1.85	1.34	0.51	0.05	0.10	0.17	0.29	0.27	0.34
Iran	-0.57	1.91	-2.49	-1.85	0.96	-2.81	0.70	0.34	0.41	0.60	1.72	0.56
Ireland	2.31	1.28	1.02	1.03	0.33	0.70	0.58	0.88	0.82	0.94	0.71	0.94
Israel	1.33	0.94	0.39	0.05	-0.01	0.06	0.74	0.76	0.82	0.81	0.91	0.93
Italy	1.60	1.44	0.15	0.32	0.49	-0.18	0.73	0.83	0.72	0.87	1.02	0.95
Ivory Coast	-0.36	0.62	-0.98	-1.64	-0.33	-1.31	0.08	0.04	0.17	0.15	0.44	0.26
Jamaica	-0.37	1.02	-1.39	-1.65	0.07	-1.72	0.44	0.23	0.57	0.59	0.77	0.39
Japan	1.96	1.80	0.15	0.68	0.85	-0.17	0.56	0.74	0.69	0.97	0.82	0.76
Jordan	0.84	1.81	-0.98	-0.44	0.86	-1.30	0.25	0.21	0.39	0.54	0.65	0.39

Table 3 (Continued)

Country	Growth Rates (in %)			Growth Differences to U.S. (in %)			Levels relative to U.S.					
	g_y	g_F	g_A	$g_y - g_y^{US}$	$g_F - g_F^{US}$	$g_A - g_A^{US}$	$\frac{y_{1970}}{y_{1970}^{US}}$	$\frac{y_{2010}}{y_{2010}^{US}}$	$\frac{F_{1970}}{F_{1970}^{US}}$	$\frac{F_{2010}}{F_{2010}^{US}}$	$\frac{A_{1970}}{A_{1970}^{US}}$	$\frac{A_{2010}}{A_{2010}^{US}}$
Kenya	0.50	0.98	-0.47	-0.78	0.03	-0.80	0.05	0.04	0.20	0.20	0.27	0.19
Korea, Republic of	4.49	3.16	1.33	3.21	2.21	1.01	0.18	0.66	0.37	0.90	0.49	0.73
Lesotho	2.64	3.01	-0.37	1.36	2.06	-0.69	0.02	0.04	0.12	0.28	0.20	0.15
Luxembourg	1.48	0.67	0.81	0.20	-0.29	0.49	1.13	1.23	1.05	0.93	1.08	1.32
Malawi	0.74	1.02	-0.28	-0.54	0.07	-0.61	0.02	0.02	0.16	0.17	0.13	0.11
Malaysia	3.78	2.65	1.13	2.50	1.70	0.81	0.13	0.34	0.31	0.61	0.41	0.57
Mali	1.99	1.40	0.60	0.72	0.45	0.27	0.03	0.04	0.14	0.16	0.24	0.27
Mauritania	0.34	1.27	-0.93	-0.94	0.32	-1.25	0.11	0.07	0.23	0.26	0.45	0.28
Mauritius	3.04	1.29	1.75	1.76	0.33	1.42	0.13	0.27	0.45	0.52	0.29	0.51
Mexico	0.05	1.21	-1.16	-1.23	0.26	-1.49	0.55	0.34	0.52	0.58	1.05	0.58
Morocco	1.63	1.53	0.09	0.35	0.58	-0.23	0.11	0.12	0.28	0.35	0.39	0.35
Mozambique	2.04	1.34	0.71	0.76	0.39	0.38	0.01	0.02	0.09	0.10	0.16	0.19
Namibia	-0.21	0.62	-0.83	-1.49	-0.34	-1.16	0.26	0.14	0.44	0.39	0.59	0.37
Nepal	1.52	2.57	-1.05	0.24	1.62	-1.38	0.02	0.03	0.09	0.17	0.27	0.15
Netherlands	0.79	0.77	0.02	-0.49	-0.18	-0.31	1.07	0.88	0.93	0.86	1.15	1.02
New Zealand	0.43	0.48	-0.05	-0.85	-0.47	-0.37	0.88	0.63	0.98	0.81	0.90	0.78
Nicaragua	-2.01	0.57	-2.58	-3.29	-0.38	-2.91	0.25	0.07	0.37	0.32	0.68	0.21
Niger	-1.65	0.05	-1.71	-2.93	-0.90	-2.03	0.06	0.02	0.17	0.12	0.36	0.16
Norway	1.88	1.02	0.85	0.60	0.07	0.53	0.91	1.15	1.03	1.06	0.88	1.08
Pakistan	1.76	1.41	0.35	0.48	0.46	0.02	0.07	0.08	0.20	0.24	0.33	0.33
Panama	1.92	1.36	0.56	0.64	0.41	0.24	0.22	0.28	0.42	0.50	0.52	0.57
Papua New Guinea	0.45	0.98	-0.53	-0.83	0.03	-0.86	0.11	0.08	0.22	0.22	0.49	0.35
Paraguay	1.18	1.61	-0.43	-0.10	0.66	-0.76	0.11	0.10	0.26	0.34	0.41	0.31
Peru	-0.13	0.33	-0.46	-1.41	-0.62	-0.79	0.30	0.17	0.54	0.42	0.55	0.40

Table 3 (Continued)

	Growth Rates (in %)			Growth Differences to U.S. (in %)			Levels relative to U.S.					
Country	g_y	g_F	g_A	$g_y - g_y^{US}$	$g_F - g_F^{US}$	$g_A - g_A^{US}$	$\frac{y_{1970}}{y_{1970}^{US}}$	$\frac{y_{2010}}{y_{2010}^{US}}$	$\frac{F_{1970}}{F_{1970}^{US}}$	$\frac{F_{2010}}{F_{2010}^{US}}$	$\frac{A_{1970}}{A_{1970}^{US}}$	$\frac{A_{2010}}{A_{2010}^{US}}$
Philippines	1.14	0.99	0.15	-0.14	0.04	-0.18	0.10	0.09	0.34	0.34	0.29	0.27
Portugal	1.76	1.91	-0.14	0.48	0.95	-0.47	0.38	0.46	0.46	0.68	0.82	0.68
Romania	2.99	1.95	1.03	1.71	1.00	0.71	0.12	0.24	0.38	0.57	0.32	0.42
Rwanda	0.90	1.68	-0.79	-0.38	0.73	-1.11	0.03	0.03	0.10	0.13	0.31	0.20
Senegal	0.32	1.55	-1.23	-0.96	0.59	-1.56	0.06	0.04	0.17	0.21	0.36	0.20
Singapore	3.97	1.92	2.05	2.69	0.96	1.73	0.42	1.23	0.60	0.89	0.69	1.38
South Africa	0.16	0.84	-0.67	-1.12	-0.11	-1.00	0.39	0.25	0.51	0.49	0.76	0.51
Spain	1.38	1.76	-0.38	0.10	0.81	-0.71	0.64	0.66	0.60	0.83	1.05	0.79
Sri Lanka	3.62	1.57	2.05	2.34	0.62	1.72	0.05	0.12	0.32	0.42	0.14	0.29
Sweden	1.32	0.82	0.50	0.04	-0.13	0.18	0.81	0.83	0.87	0.82	0.94	1.01
Switzerland	0.30	0.62	-0.32	-0.98	-0.33	-0.64	1.17	0.79	0.99	0.87	1.19	0.92
Syria	1.69	1.36	0.34	0.42	0.41	0.01	0.15	0.17	0.26	0.30	0.57	0.57
Taiwan	4.72	2.93	1.78	3.44	1.98	1.46	0.21	0.81	0.37	0.82	0.55	0.98
Tanzania	1.66	1.30	0.36	0.38	0.35	0.04	0.02	0.03	0.16	0.19	0.15	0.16
Thailand	3.58	2.21	1.37	2.30	1.25	1.05	0.07	0.17	0.27	0.45	0.25	0.39
Togo	-1.56	0.96	-2.52	-2.84	0.01	-2.85	0.06	0.02	0.16	0.16	0.36	0.11
Trinidad and Tobago	1.43	0.93	0.50	0.15	-0.02	0.17	0.67	0.71	0.71	0.71	0.94	1.01
Turkey	2.89	2.41	0.48	1.61	1.46	0.15	0.21	0.41	0.27	0.49	0.79	0.84
Uganda	1.02	1.36	-0.34	-0.25	0.41	-0.67	0.04	0.03	0.14	0.16	0.27	0.21
United Kingdom	1.98	1.15	0.83	0.70	0.19	0.51	0.61	0.81	0.68	0.73	0.90	1.11
United States	1.28	0.95	0.33	0.00	0.00	0.00	1.00	1.00	1.00	1.00	1.00	1.00
Uruguay	1.72	0.75	0.98	0.44	-0.21	0.65	0.24	0.28	0.55	0.51	0.43	0.56
Venezuela	-1.31	0.22	-1.53	-2.59	-0.73	-1.86	0.67	0.24	0.62	0.46	1.09	0.52
Zambia	-0.28	0.51	-0.79	-1.56	-0.45	-1.11	0.08	0.04	0.26	0.21	0.32	0.20
Zimbabwe	-1.02	0.59	-1.61	-2.30	-0.36	-1.94	0.02	0.01	0.11	0.09	0.17	0.08

U.S., while factor endowments grew about as fast as in the United States. These are striking results. They suggest that on average countries converge to the U.S. to a large part due to faster factor accumulation. This extends the finding of Young (1995) for the high growth episodes of four East Asian tiger countries to a much larger sample of countries. However factor accumulation is not a valid explanation for experiences of falling further behind. Instead countries fail to converge to the U.S. due to slower efficiency improvements. Thus there is an asymmetry between the sources of convergence and divergence to the United States.

Table 4: Growth Rates relative to the United States during 1970-2010

		Growth Differences to U.S. (in %)		
Country Group	Obs	$g_y - g_y^{US}$	$g_F - g_F^{US}$	$g_A - g_A^{US}$
Converging	44	1.16	0.77	0.39
Diverging	49	-1.10	0.07	-1.17
Miracles	13	2.56	1.39	1.17
Successes	31	0.56	0.50	0.06
Failures	41	-0.78	0.17	-0.95
Disasters	8	-2.78	-0.47	-2.31
All	93	-0.04	0.40	-0.43

In order to check whether there are further important differences within these two groups, I also look at a finer partition. I define a country to be a "miracle" if it has at least doubled its relative income compared to the U.S. during 1970-2010. This requires a growth rate that is at least about 1.73% per year higher than in the U.S. over this period. Within the group of 44 converging countries there are then 13 miracle countries and a remaining 31 countries that I term "successes". Rows 3 and 4 of table 4 show that there seems to be a bit of heterogeneity within the group of converging countries. Relative to the whole group of converging countries the catch-up of miracle countries to the U.S. features a stronger relative role for faster efficiency improvements. For the convergence of these countries to the U.S. the two forces contribute almost equally to catch-up. In contrast the catch-up of the non-miracle successful countries is on average almost entirely driven by faster factor accumulation.

The sizeable contribution of relatively faster efficiency improvements for the catch-up of growth miracles does not contradict the finding of Young (1995), but only requires a careful interpretation of his result. As discussed in section 2.4 my accounting decomposition yields efficiency growth rates for high growth East Asian countries that are comparable to the ones of Young and that are not excessively high by historical standards. However the United States had quite low rates of efficiency growth during 1970-2010 as discussed above and as in fact Young reports in his paper himself. This explains why relatively faster efficiency improvements have also contributed to the catch-up of growth miracles to the United States during this time period.

I also divide the diverging countries into two groups and define the convergence experience of a country to be a "disaster" if the relative income in 2010 was less than half of what it was in 1970. In terms of growth rates this requires that growth was on average more than 1.73% per year lower than in the United States. There are then 8 such disasters and 41 remaining countries that I call "failures". Rows 5 and 6 document that for these two groups the conclusion that divergence is mainly accounted for by falling behind on efficiency relative to the U.S. is essentially unchanged.

5 Sensitivity Analysis

In this section I investigate the sensitivity of the results to some of the basic assumptions of the levels accounting decomposition. In particular I first show how the results are affected when alternative parameter values are used and then discuss the role of the estimate of the initial capital stock.

5.1 Parameter Values

First I explore whether the results are sensitive to the parameter values used in the basic levels accounting decomposition. The first check concerns the used share parameter of physical capital α in the production function. The benchmark value was 1/3, but I now consider the alternative values of 0.23 and 0.43. Second instead of using a depreciation rate of physical capital δ of 6% in the benchmark, I experiment with values of 4% and 8%. Lastly I investigate the role of the returns to schooling that were used to construct measures of human capital stocks. Here I consider lower returns by reducing each of the used returns in the function $\phi(s)$ by 3 percentage points and higher returns by adding 3 percentage points to each of these returns. Detailed results for these alternative parameter values are provided in online appendix A (along with further checks described in section 5.2) and can be summarized as follows.

Across all parameterizations measured factor accumulation is faster in poor countries than in rich countries, while efficiency does not improve significantly faster (appendix table A.1). Thus the absence of β-convergence is in all these cases explained by the effect of factor accumulation being too weak relative to the diverging force of efficiency improvements.

Concerning the absence of σ-convergence the increase in income dispersion is for all specifications driven by an increase in efficiency dispersion and the covariance between factors and efficiency (appendix table A.2). Only the relative contribution of these two effects varies a bit across specifications and seems to be most sensitive to the choice of α. For the benchmark value of $\alpha = 1/3$ the increase in the variance of efficiency accounts for one third and the increase in the covariance between factor and efficiency for two thirds of the increase in income dispersion. In contrast for a lower value of $\alpha = 0.23$ each of these two effects plays an equal role and for the higher value of $\alpha = 0.43$ the share of increased efficiency dispersion is about one fifth and the one of the covariance about four fifths.

Across all parameterizations the patterns of efficiency changes are sufficient to account for the emergence of a pronounced second peak in the cross-country income distribution, but the patterns of changes to factor endowments are not (appendix figure A.1).

Finally, my results on convergence to the United States and the asymmetry between the sources of catching up and falling behind are very similar to the benchmark results in all the considered specifications (appendix table A.3).

Overall these checks show that the main results of the paper are remarkably robust to using alternative reasonable parameter values.

5.2 Initial Capital Stock

Another potential concern are the used estimates of the initial physical capital stock. These are based on a steady-state assumption that may not be accurate for all countries. A failure of this assumption is relevant because for some countries the investment series starts only in 1960 such that the constructed capital stock for 1970 may still contain a substantial part of the initial estimate. Indeed the fraction of the constructed capital stock in 1970 that is due to the initial estimate takes an average value of 17%. However it varies considerably across countries with the lowest value being 1.4% and the highest value being 60%. If the physical capital stock in 1970 and subsequent years is measured with error then the factor contribution F and efficiency level A in those years will also be measured with error. These errors could potentially confound the analysis.

Though there is no way to assess how well measured the initial capital stock is, I take two steps to address these concerns. First I formally derive and quantify how much an initial measurement error of a given size affects the key measurements of the paper. This provides prima facie evidence on the involved quantitative magnitudes. This quantitative error analysis may also be useful in a wide set of other applications that are based on capital stocks generated by the perpetual inventory method. Second I conduct a set of experiments where I make assumptions on the measurement error inherent in my benchmark estimates and check how the main results are affected if one corrects for the assumed measurement error.

First one needs to distinguish between the estimate of the aggregate capital stock $\widehat{K}_t$ and the true value K_t in period t for a particular country. For convenience I drop country subscripts i. The measurement error of the estimate can then be quantified by a positive number ψ_t defined by $\widehat{K}_t = \psi_t K_t$. Here $\psi_t = 1$ implies no measurement error, $\psi_t < 1$ implies that the capital stock is underestimated and $\psi_t > 1$ that it is overestimated.

The ultimate aim is to determine how measurement error of the capital stock in the first year the country is observed, say ψ_0, translates into measurement error of F and A in the years 1970 and 2010 and their growth rate during 1970-2010. The following derivation is more general, but can be applied for this purpose. Here I restrict attention to measurement error of the initial capital stock and assume that the investment series and all parameters are measured accurately. As shown in appendix section B, measurement error of the capital stock in period s of a given size ψ_s affects measurement error ψ_t in a subsequent period $t > s$ by

$$\psi_t = \frac{\psi_s}{p_{st} + \psi_s(1 - p_{st})} \tag{11}$$

where

$$p_{st} = \frac{(1-\delta)^{t-s}\widehat{K}_s}{(1-\delta)^{t-s}\widehat{K}_s + \sum_{j=1}^{t-s}(1-\delta)^{j-1}I_{t-j}} \tag{12}$$

is the share of the period s capital stock estimate that is still present in the estimate of the capital stock in period t. For each country and time period the number p_{st} can be readily computed from the observed investment series, the period s capital stock estimate and the assumed value of δ. This implies that for any exogenously given value of ψ_s one can compute ψ_t. Equation (11) shows that if the capital stock is underestimated in period s it will also be underestimated in period $t > s$, and vice versa. The more ψ_s deviates from 1 the more will ψ_t deviate from 1 for a given p_{st}. The lower is p_{st} the closer will ψ_t be to 1 for any given $\psi_s \neq 1$.

If one is interested in an accurate measurement of the capital stock itself then ψ_t is the relevant number to look at. However here the main interest is in accurately measuring the contribution of factors and efficiency to output. The functional form of the production function in equation (2) implies that $\widehat{F}_t = \psi_t^\alpha F_t$ such that the multiplicative measurement error of F_t takes the form ψ_t^α. Conversely, the multiplicative measurement error of A_t takes the form $\psi_t^{-\alpha}$ such that $\widehat{A}_t = \psi_t^{-\alpha} A_t$. Accordingly, an overestimation of the capital stock in period s (and hence in t) leads to an overestimation of F_t and an underestimation of A_t, and vice versa.

It directly follows from these results that the growth rate of the factor contribution between period s and $t > s$ then exhibits an additive measurement error of αg_ψ such that $g_{\widehat{F}} = g_F + \alpha g_\psi$. Conversely the growth rate of efficiency is measured with an additive error of $-\alpha g_\psi$ such that $g_{\widehat{A}} = g_A - \alpha g_\psi$. Equation (11) implies that the growth rate of measurement error g_ψ between period s and $t > s$ is given by

$$g_\psi = \frac{1}{t-s} \log\left(\frac{1}{p_{st} + \psi_s(1-p_{st})}\right). \tag{13}$$

This shows that g_ψ is negative if ψ_s is larger than 1 such that an overestimation of the period s capital stock leads to an underestimation of the subsequent growth rate of the capital stock and hence the growth rate of the factor contribution, and vice versa. The more ψ_s deviates from 1 the more will g_ψ deviate from 0 for any given p_{st}. The lower is p_{st} the more will g_ψ deviate from 0 for any given $\psi_s \neq 1$.

Accordingly there are two effects that mitigate any measurement error of the initial capital stock of size ψ_0 on the measured levels of F and A in 1970. The first is that observed investment between the first year that a country is observed and 1970 increases the signal relative to the noise as captured by the number $p_{0,1970}$. The second is that the capital stock enters production with an exponent equal to the capital share parameter α. These two mitigating effects are quantitatively important. Appendix table B.1 reports statistics of the distribution of measurement error in the sample for different values of ψ_0. There is a distribution of measurement error because countries differ in their values of $p_{0,1970}$. The table shows that even sizable measurement error of the initial capital stock like a 20% overestimate compared to the true value ($\psi_0 = 1.2$) has only a minor effect on the measurement of F and A in 1970 for all countries. Only extreme values of initial measurement error like a 50% overestimate ($\psi_0 = 1.5$) has a bit more substantial effects, but even then only for a small number of countries. The calculations also show that underestimating the initial capital stock has more severe consequences than overestimating it. Furthermore appendix table B.2 also shows that by 2010 the capital stock is very well measured for all countries and all values of ψ_0 used here.

The effect of initial measurement error on the measured growth rates during the period 1970-2010 is mitigated by similar effects. The first is that ψ_{1970} will already be closer to 1 than ψ_0 as explained above and the second is again due to the weighting with the share parameter α of capital in production. Appendix table B.3 reports statistics on the distribution of the additive measurement error of the growth rate of the factor contribution in percentage points for different values of ψ_0. Except for a severe underestimate of the initial capital stock these errors are quite modest. These calculations suggest that even large deviations of the estimated initial capital stock from the true value are unlikely to have major effects on the key measurements.

However I also conduct further robustness checks where I make specific assumptions on the measurement error inherent in my benchmark estimates, then correct them and repeat my analysis using these alternative estimates. This correction is very simple. The benchmark estimate of the initial capital stock $\widehat{K}_{i0}$ is just replaced by the alternative estimate $\widetilde{K}_{i0} = \widehat{K}_{i0}/\widehat{\psi}_{i0}$ where $\widehat{\psi}_{i0}$ is the assumed measurement error in the benchmark estimate. All other procedures are then the same as in the benchmark.

In one set of exercises I assume that $\widehat{\psi}_{i0}$ is common across countries and consider values of 0.5, 0.8, 1.2 and 1.5. In a second set I assume that measurement error is more severe in poor countries. Here I assume that initial measurement error is linear in log income per worker in 1970 such that the richest country has a value of $\widehat{\psi}_{i0}$ equal to 1 and the poorest a value of 0.5, 0.8, 1.2 or 1.5.

Detailed results for all these alternative specifications are reported in appendix tables A.1, A.2 and A.3 and figure A.1 (along with the checks of section 5.1). These show that the results of the paper are remarkably robust to measurement error of the initial capital stock. The only exception is that the result of section 3.1 that poor countries accumulate factors significantly faster than rich countries vanishes if one assumes that the benchmark initial capital estimate severely underestimates the true capital stock. In other words this would require that either all countries or just the poor countries have a true initial capital stock that is substantially above their steady state level of capital. However this seems like a unlikely scenario. Instead it seems more plausible that all countries were below their steady state levels and poor countries probably even more so. In such a situation the finding of section 3.1 would in fact be strengthened. But in any case, all other results of the paper are not sensitive to this issue.

6 Conclusions

This paper has provided accounting exercises to investigate the role of factor accumulation and efficiency changes for convergence and divergence between countries during 1970-2010. The prior literature has documented three important facts of divergence in the cross-country income distribution. These are that poor countries do on average not grow faster than rich ones, that income dispersion is rising over time and that the income distribution becomes more polarized. The first main finding is that patterns of efficiency changes account for all of these facts. In contrast factor accumulation is a force towards convergence, but one that is too weak to outweigh the effect of efficiency changes.

The second part of the analysis concerns pairwise convergence to the United States and investigates why individual countries catch up or fall behind relative to the U.S. Here I find that experiences of successful catch-up are mainly driven by relatively faster factor accumulation, though the most successful countries also outpace the U.S. with respect to efficiency improvements. In contrast countries fall behind the U.S. because they experience relatively slower efficiency improvements. Thus there is an asymmetry between the sources of catch-up and falling behind.

There is a theoretical and policy debate on whether factor accumulation or efficiency improvements are key for understanding cross-country income dynamics. The results of this paper support a balanced view on this question in the area of convergence. Factor accumulation seems to be important for explaining episodes where poor countries successfully catch up to rich countries. But relatively slower and sometimes even negative changes to efficiency in poor countries are key for explaining experiences of falling further behind and the big picture facts of divergence in the cross-country income distribution. These findings highlight the need to better understand both factor accumulation and efficiency changes and suggest that the fundamental sources of these two engines of growth may not be completely identical.

References

Barro, R. J. (1991). Economic Growth in a Cross Section of Countries. *Quarterly Journal of Economics 106*(2), 407–443.

Barro, R. J. and J.-W. Lee (2013). A new Data Set of Educational Attainment in the World, 1950-2010. *Journal of Development Economics 104*, 184–198.

Barro, R. J. and X. Sala-i-Martin (1992). Convergence. *Journal of Political Economy 100*(2), 223–251.

Barro, R. J. and X. Sala-i-Martin (2003). *Economic Growth* (2nd ed.). MIT Press.

Caselli, F. (2005). Accounting for Cross-Country Income Differences. In P. Aghion and S. N. Durlauf (Eds.), *Handbook of Economic Growth*, pp. 679–741. Amsterdam: Elsevier.

Caselli, F. and A. Ciccone (2013). The Contribution of Schooling in Development Accounting: Results from a Nonparametric Upper Bound. *Journal of Development Economics 104*, 199–211.

Caselli, F. and S. Tenreyro (2004). Is Poland the Next Spain? In R. H. Clarida, J. Frankel, F. Giavazzi, and K. D. West (Eds.), *NBER International Seminar on Macroeconomics*, pp. 459–533. MIT Press.

de la Fuente, A. (1997). The Empirics of Growth and Convergence: A Selective Review. *Journal of Economic Dynamics and Control 21*(1), 23–73.

de la Fuente, A. (2002). On the Sources of Convergence: A closer Look at the Spanish Regions. *European Economic Review 46*(3), 569–599.

Dowrick, S. and D.-T. Nguyen (1989). OECD Comparative Economic Growth 1950-85: Catch-Up and Convergence. *American Economic Review 79*(5), 1010–1030.

Durlauf, S. N., P. A. Johnson, and J. R. W. Temple (2005). Growth Econometrics. In P. Aghion and S. N. Durlauf (Eds.), *Handbook of Economic Growth*, pp. 555–677. Amsterdam: Elsevier.

Hall, R. E. and C. I. Jones (1999). Why do some Countries produce so much more Output per Worker than Others? *Quarterly Journal of Economics 114*(1), 83–116.

Henderson, D. J. and R. R. Russell (2005). Human Capital and Convergence: A Production-Frontier Approach. *International Economic Review 46*(4), 1167–1205.

Hsieh, C.-T. and P. J. Klenow (2010). Development Accounting. *American Economic Journal: Macroeconomics 2*(1), 207–223.

Islam, N. (1995). Growth Empirics: A Panel Data Approach. *Quarterly Journal of Economics 110*(4), 1127–1170.

Jones, C. I. (1997). On the Evolution of the World Income Distribution. *Journal of Economic Perspectives 11*(3), 19–36.

Jorgenson, D. W. and E. Yip (2001). Whatever happened to Productivity Growth? In C. R. Hulten, E. R. Dean, and M. J. Harper (Eds.), *New Developments in Productivity Analysis*, pp. 509–540. University of Chicago Press.

King, R. G. and R. Levine (1994). Capital Fundamentalism, Economic Development, and Economic Growth. *Carnegie-Rochester Conference Series on Public Policy 40*, 259–292.

Klenow, P. J. and A. Rodríguez-Clare (1997). The Neoclassical Revival in Growth Economics: Has It Gone Too Far? In B. S. Bernanke and J. J. Rotenberg (Eds.), *NBER Macroeconomics Annual*, Volume 12, pp. 73–103. MIT Press.

Kumar, S. and R. R. Russell (2002). Technological Change, Technological Catch-up, and Capital Deepening: Relative Contributions to Growth and Convergence. *American Economic Review 92*(3), 527–548.

Lagakos, D., B. Moll, T. Porzio, and N. Qian (2012). Experience Matters: Human Capital and Development Accounting. *NBER Working Paper 18602*.

Mankiw, N. G., D. Romer, and D. N. Weil (1992). A Contribution to the Empirics of Economic Growth. *Quarterly Journal of Economics 107*(2), 407–437.

Pritchett, L. (1997). Divergence, Big Time. *Journal of Economic Perspectives 11*(3), 3–17.

Quah, D. T. (1993). Galton's Fallacy and Tests of the Convergence Hypothesis. *Scandinavian Journal of Economics 95*(4), 427–443.

Quah, D. T. (1996). Twin Peaks: Growth and Convergence in Models of Distribution Dynamics. *Economic Journal 106*(437), 1045–1055.

Quah, D. T. (1997). Empirics for Growth and Distribution: Stratification, Polarization, and Convergence Clubs. *Journal of Economic Growth 2*(1), 27–59.

Sala-i-Martin, X. (1996). The Classical Approach to Convergence Analysis. *Economic Journal 106*(437), 1019–1036.

Sala-i-Martin, X. (2006). The World Distribution of Income: Falling Poverty and ... Convergence, Period. *Quarterly Journal of Economics 121*(2), 351–397.

Serrano, L. (1999). On Convergence Accounting. *Applied Economics Letters 6*(4), 219–221.

Solow, R. M. (1956). A Contribution to the Theory of Economic Growth. *Quarterly Journal of Economics 70*(1), 65–94.

Solow, R. M. (1957). Technical Change and the Aggregate Production Function. *Review of Economics and Statistics 39*(3), 312–320.

Temple, J. (1999). The New Growth Evidence. *Journal of Economic Literature 37*(1), 112–156.

Turner, C., R. Tamura, and S. E. Mulholland (2013). How important are Human Capital, Physical Capital and Total Factor Productivity for determining State Economic Growth in the United States, 1840-2000? *Journal of Economic Growth 18*(4), 319–371.

Weil, D. N. (2007). Accounting for the Effect of Health on Economic Growth. *Quarterly Journal of Economics 122*(3), 1265–1306.

Young, A. (1995). The Tyranny of Numbers: Confronting the Statistical Realities of the East Asian Growth Experience. *Quarterly Journal of Economics 110*(3), 641–680.

Appendix (Only For Online Publication)

A Detailed Results for Robustness Checks

This section contains detailed results of the robustness checks discussed and summarized in sections 5.1 and 5.2 of the main text. Table A.1 reports estimated coefficients of regressions of the growth rates of income, factors and efficiency during 1970-2010 on log income per worker in 1970 for the different specifications. Table A.2 decomposes the increase in the variance of log income per worker between 1970-2010 into the changes to the variances of the factor contributions and efficiency and the covariance between them. Figure A.1 compares the actual and counterfactual income distributions in 2010 for the alternative specifications. Finally, table A.3 provides for each specification the summary statistics of convergence and divergence to the U.S. for different country groups.

Table A.1: Estimated Coefficients in Regressions of Annual Growth Rates (in %) on $\log(y)$ in 1970 for different Specifications

Specification	g_y	g_F	g_A
Benchmark	-0.0351	-0.121**	0.0863
	(0.118)	(0.0574)	(0.0884)
$\alpha = 0.23$	-0.0351	-0.115**	0.0800
	(0.118)	(0.0443)	(0.0966)
$\alpha = 0.43$	-0.0351	-0.127*	0.0921
	(0.118)	(0.0710)	(0.0830)
$\delta = 0.04$	-0.0351	-0.110*	0.0746
	(0.118)	(0.0595)	(0.0887)
$\delta = 0.08$	-0.0351	-0.127**	0.0915
	(0.118)	(0.0566)	(0.0879)
R.t.S. -3%	-0.0351	-0.121**	0.0855
	(0.118)	(0.0552)	(0.0882)
R.t.S. $+3\%$	-0.0351	-0.122**	0.0870
	(0.118)	(0.0601)	(0.0889)
Common $\psi_0 = 0.5$	-0.0351	-0.0984	0.0633
	(0.118)	(0.0606)	(0.0867)
Common $\psi_0 = 0.8$	-0.0351	-0.115*	0.0796
	(0.118)	(0.0583)	(0.0878)
Common $\psi_0 = 1.2$	-0.0351	-0.126**	0.0911
	(0.118)	(0.0568)	(0.0888)
Common $\psi_0 = 1.5$	-0.0351	-0.132**	0.0964
	(0.118)	(0.0561)	(0.0893)
Variable $\psi_0 \in [0.5, 1]$	-0.0351	-0.0846	0.0494
	(0.118)	(0.0597)	(0.0872)
Variable $\psi_0 \in [0.8, 1]$	-0.0351	-0.111*	0.0754
	(0.118)	(0.0580)	(0.0880)
Variable $\psi_0 \in [1, 1.2]$	-0.0351	-0.129**	0.0943
	(0.118)	(0.0569)	(0.0887)
Variable $\psi_0 \in [1, 1.5]$	-0.0351	-0.138**	0.103
	(0.118)	(0.0564)	(0.0891)

Robust standard errors in parantheses.

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Table A.2: Changes to Variances between 1970 and 2010 for different Specifications

Specification	ΔVar[log(y)]	ΔVar[log(F)]	ΔVar[log(A)]	$2 \times \Delta$Cov
Benchmark	0.30	-0.03	0.11	0.22
$\alpha = 0.23$	0.30	-0.03	0.17	0.17
$\alpha = 0.43$	0.30	-0.02	0.06	0.26
$\delta = 0.04$	0.30	-0.03	0.11	0.23
$\delta = 0.08$	0.30	-0.03	0.12	0.22
R.t.S. 3% lower	0.30	-0.03	0.13	0.20
R.t.S. 3% higher	0.30	-0.03	0.09	0.24
Common $\psi_0 = 0.5$	0.30	-0.02	0.10	0.22
Common $\psi_0 = 0.8$	0.30	-0.03	0.11	0.22
Common $\psi_0 = 1.2$	0.30	-0.03	0.12	0.22
Common $\psi_0 = 1.5$	0.30	-0.04	0.12	0.22
Variable $\psi_0 \in [0.5, 1]$	0.30	-0.01	0.09	0.22
Variable $\psi_0 \in [0.8, 1]$	0.30	-0.02	0.11	0.22
Variable $\psi_0 \in [1, 1.2]$	0.30	-0.03	0.12	0.22
Variable $\psi_0 \in [1, 1.5]$	0.30	-0.04	0.12	0.22

Figure A.1: Actual and Counterfactual Income Distributions in 2010 for different Specifications

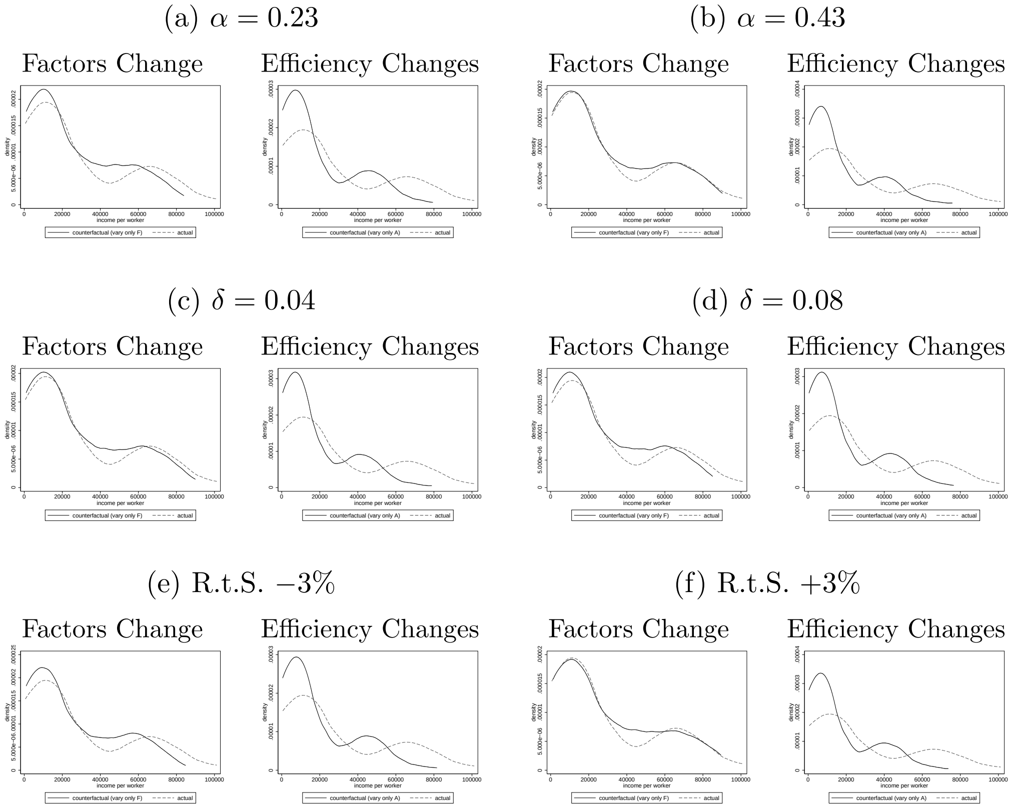
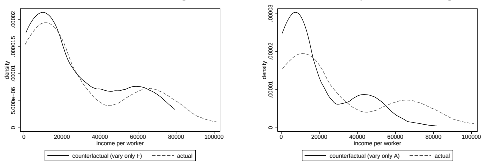


Figure A.1 (Continued)

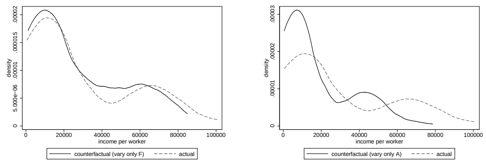
(g) Common $\psi_0 = 0.5$

Factors Change Efficiency Changes



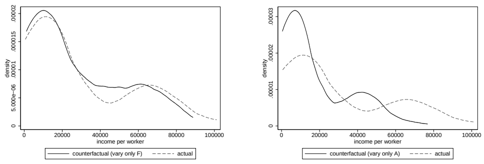
(h) Common $\psi_0 = 0.8$

Factors Change Efficiency Changes



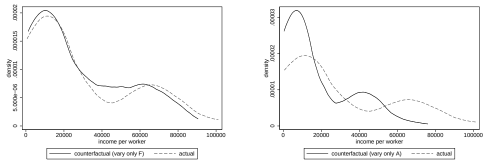
(i) Common $\psi_0 = 1.2$

Factors Change Efficiency Changes



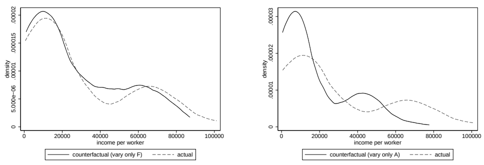
(j) Common $\psi_0 = 1.5$

Factors Change Efficiency Changes



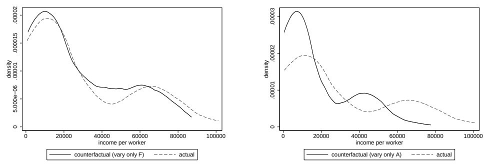
(k) Variable $\psi_0 \in [0.5, 1]$

Factors Change Efficiency Changes



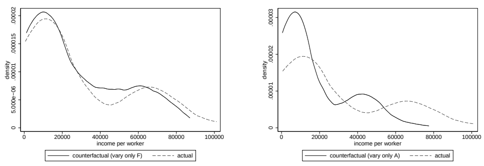
(l) Variable $\psi_0 \in [0.8, 1]$

Factors Change Efficiency Changes



(m) Variable $\psi_0 \in [1, 1.2]$

Factors Change Efficiency Changes



(n) Variable $\psi_0 \in [1, 1.5]$

Factors Change Efficiency Changes

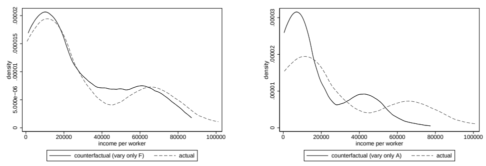


Table A.3: Growth Differences to the United States (in %) for different Specifications

			Benchmark		$\alpha = 0.23$		$\alpha = 0.43$		$\delta = 0.04$		$\delta = 0.08$		R.t.S -3%		R.t.S $+3\%$	
Country Group	Obs	Δg_y	Δg_F	Δg_A	Δg_F	Δg_A	Δg_F	Δg_A	Δg_F	Δg_A	Δg_F	Δg_A	Δg_F	Δg_A	Δg_F	Δg_A
Converging	44	1.16	0.77	0.39	0.69	0.47	0.84	0.31	0.83	0.33	0.72	0.43	0.69	0.46	0.84	0.31
Diverging	49	-1.10	0.07	-1.17	0.25	-1.35	-0.10	-1.00	0.14	-1.24	0.03	-1.13	-0.01	-1.09	0.15	-1.25
Miracles	13	2.56	1.39	1.17	1.18	1.38	1.59	0.98	1.46	1.11	1.35	1.21	1.28	1.29	1.51	1.06
Successes	31	0.56	0.50	0.06	0.48	0.09	0.53	0.03	0.56	-0.00	0.46	0.10	0.44	0.12	0.56	0.00
Failures	41	-0.78	0.17	-0.95	0.32	-1.10	0.03	-0.81	0.24	-1.02	0.14	-0.92	0.09	-0.87	0.25	-1.03
Disasters	8	-2.78	-0.47	-2.31	-0.12	-2.67	-0.81	-1.98	-0.39	-2.39	-0.54	-2.25	-0.54	-2.24	-0.41	-2.38
All	93	-0.04	0.40	-0.43	0.46	-0.49	0.34	-0.38	0.46	-0.50	0.36	-0.39	0.32	-0.36	0.47	-0.51

	$\psi_0 = 0.5$		$\psi_0 = 0.8$		$\psi_0 = 1.2$		$\psi_0 = 1.5$		$\psi_0 \in [0.5, 1]$		$\psi_0 \in [0.8, 1]$		$\psi_0 \in [1, 1.2]$		$\psi_0 \in [1, 1.5]$	
Country Group	Δg_F	Δg_A	Δg_F	Δg_A	Δg_F	Δg_A	Δg_F	Δg_A	Δg_F	Δg_A	Δg_F	Δg_A	Δg_F	Δg_A	Δg_F	Δg_A
Converging	0.81	0.34	0.78	0.38	0.76	0.40	0.75	0.41	0.73	0.42	0.76	0.40	0.77	0.38	0.78	0.37
Diverging	0.07	-1.17	0.07	-1.17	0.07	-1.17	0.07	-1.18	0.01	-1.11	0.05	-1.15	0.08	-1.19	0.10	-1.20
Miracles	1.44	1.13	1.40	1.16	1.38	1.18	1.37	1.19	1.36	1.21	1.38	1.18	1.40	1.17	1.41	1.16
Successes	0.55	0.01	0.52	0.05	0.50	0.07	0.49	0.08	0.47	0.09	0.49	0.07	0.51	0.05	0.52	0.05
Failures	0.17	-0.95	0.17	-0.95	0.17	-0.95	0.18	-0.95	0.12	-0.89	0.16	-0.93	0.19	-0.96	0.20	-0.98
Disasters	-0.48	-2.30	-0.48	-2.31	-0.47	-2.31	-0.47	-2.32	-0.56	-2.22	-0.50	-2.28	-0.46	-2.33	-0.43	-2.35
All	0.42	-0.45	0.40	-0.44	0.39	-0.43	0.39	-0.43	0.35	-0.39	0.38	-0.42	0.41	-0.44	0.42	-0.46

B Further Details on Measurement Error

This section derives equation (11) in section 5.2 of the main text. The section also contains a quantitative illustration how measurement error of the initial capital stock of a given size affects the key measurements of the main analysis. Using equation (4) first observe that the true capital stock K_t in period t as a function of the true capital stock in period $s < t$ is given by

$$K_t = (1-\delta)^{t-s} K_s + \sum_{j=1}^{t-s} (1-\delta)^{j-1} I_{t-j} \tag{14}$$

and the estimated capital stock $\widehat{K}_t$ as a function of the estimate in period $s < t$ reads as

$$\widehat{K}_t = (1-\delta)^{t-s} \widehat{K}_s + \sum_{j=1}^{t-s} (1-\delta)^{j-1} I_{t-j}. \tag{15}$$

The period t measurement error ψ_t as a function of ψ_s is then derived from equations (14) and (15) with a few steps of algebra according to

$$\begin{aligned}
\psi_t \equiv \frac{\widehat{K}_t}{K_t} &= \frac{(1-\delta)^{t-s}\widehat{K}_s + \sum_{j=1}^{t-s}(1-\delta)^{j-1}I_{t-j}}{(1-\delta)^{t-s}K_s + \sum_{j=1}^{t-s}(1-\delta)^{j-1}I_{t-j}} \\
&= \frac{(1-\delta)^{t-s}\widehat{K}_s + \sum_{j=1}^{t-s}(1-\delta)^{j-1}I_{t-j}}{(1-\delta)^{t-s}\frac{\widehat{K}_s}{\psi_s} + \sum_{j=1}^{t-s}(1-\delta)^{j-1}I_{t-j}} \\
&= \psi_s \frac{(1-\delta)^{t-s}\widehat{K}_s + \sum_{j=1}^{t-s}(1-\delta)^{j-1}I_{t-j}}{(1-\delta)^{t-s}\widehat{K}_s + \psi_s\sum_{j=1}^{t-s}(1-\delta)^{j-1}I_{t-j}} \\
&= \psi_s \left[\frac{(1-\delta)^{t-s}\widehat{K}_s + \psi_s\sum_{j=1}^{t-s}(1-\delta)^{j-1}I_{t-j}}{(1-\delta)^{t-s}\widehat{K}_s + \sum_{j=1}^{t-s}(1-\delta)^{j-1}I_{t-j}}\right]^{-1} \\
&= \psi_s \left[p_{st} + \psi_s(1-p_{st})\right]^{-1} \\
&= \frac{\psi_s}{p_{st} + \psi_s(1-p_{st})} \qquad (16)
\end{aligned}$$

which is equation (11) of the main text.

Tables B.1, B.2 and B.3 report statistics of the distribution of measurement error of F in 1970 and 2010 and g_F during 1970-2010 resulting from initial capital measurement error of different sizes ψ_0.

Table B.1: Measurement error of F in 1970 (ψ^{α}_{1970}) for different ψ_0

Deviation from 1	$\psi_0 = 0.5$	$\psi_0 = 0.8$	$\psi_0 = 1$	$\psi_0 = 1.2$	$\psi_0 = 1.5$
Smallest	1.00	1.00	1.00	1.00	1.00
10th-Percentile	0.98	1.00	1.00	1.00	1.01
25th-Percentile	0.98	0.99	1.00	1.00	1.01
Median	0.96	0.99	1.00	1.01	1.01
75th-Percentile	0.93	0.98	1.00	1.01	1.03
90th-Percentile	0.91	0.97	1.00	1.02	1.04
Largest	0.85	0.95	1.00	1.04	1.08

Table B.2: Measurement error of F in 2010 (ψ^{α}_{2010}) for different ψ_0

Deviation from 1	$\psi_0 = 0.5$	$\psi_0 = 0.8$	$\psi_0 = 1$	$\psi_0 = 1.2$	$\psi_0 = 1.5$
Smallest	1.00	1.00	1.00	1.00	1.00
10th-Percentile	1.00	1.00	1.00	1.00	1.00
25th-Percentile	1.00	1.00	1.00	1.00	1.00
Median	1.00	1.00	1.00	1.00	1.00
75th-Percentile	1.00	1.00	1.00	1.00	1.00
90th-Percentile	1.00	1.00	1.00	1.00	1.00
Largest	0.99	1.00	1.00	1.00	1.00

Table B.3: Measurement error of g_F (αg_{ψ} in %-points) for different ψ_0

Deviation from 0	$\psi_0 = 0.5$	$\psi_0 = 0.8$	$\psi_0 = 1$	$\psi_0 = 1.2$	$\psi_0 = 1.5$
Smallest	0.01	0.00	0.00	-0.00	-0.00
10th-Percentile	0.04	0.01	0.00	-0.01	-0.01
25th-Percentile	0.06	0.02	0.00	-0.01	-0.02
Median	0.09	0.02	0.00	-0.02	-0.03
75th-Percentile	0.17	0.05	0.00	-0.03	-0.07
90th-Percentile	0.24	0.07	0.00	-0.05	-0.10
Largest	0.37	0.11	0.00	-0.08	-0.18

C Discussion of the Relationship to the Conditional β-Convergence Result of Mankiw, Romer and Weil (1992)

The findings of section 3.1 stand in marked contrast to the influential conditional β-convergence results of Mankiw, Romer, and Weil (1992), henceforth MRW. These authors found that after controlling for variables determining the steady state of the Solow (1956) model like saving and population growth rates poor countries do grow faster than rich ones. Accordingly at first glance their finding suggests that the absence of absolute β-convergence is due to slower factor accumulation in poor countries, which is inconsistent with the results of section 3.1.

In this section I discuss how these conflicting findings can be reconciled and argue that one needs to be very careful in giving an accounting interpretation to MRW's conditional β-convergence result. The basic reason is that MRW assume common rates of efficiency improvement across countries. This assumption confounds their analysis and prevents it from answering questions on the relative role of factors and efficiency.

First I discuss the theoretical differences between the approach of MRW and this paper. It is important to note that the key difference between the papers are only the identifying assumptions. However the basic model assumptions are essentially the same in both papers with two minor exceptions that are without consequence. The first one is that MRW assume that efficiency enters production in a labor augmenting form. However for Cobb-Douglas production functions this is essentially just a relabeling where MRW's efficiency term B_t is related to the one used in equation (1) of this paper by $B_t = A_t^{\frac{1}{1-\alpha}}$. The second difference is how human capital enters production. In this paper human capital is modelled as a factor that directly augments the number of workers. In contrast MRW either abstract completely from human capital in their "textbook" Solow model or model human capital as an endogenous variable which is separated from labor in their augmented model.[7] In the following analysis I continue to

[7] The way MRW model and measure human capital is not key for my argument. These issues have for example been discussed by Klenow and Rodríguez-Clare (1997).

assume that human capital directly augments labor as in the rest of this paper. But to focus on the key points I assume that human capital evolves exogenously. The production function of this paper can then equivalently be written as $Y_t = K_t^{\alpha}(B_t\widetilde{L}_t)^{1-\alpha}$ where B_t is efficiency and $\widetilde{L}_t = h_t L_t$ is labor in human capital units. This function is identical to the one used in the textbook model of MRW with the small modification on how "labor" is measured.[8] The other main equation of the Solow model is the capital accumulation equation, but there is no substantial difference between equation (4) in this paper and the one used by MRW. This implies that it is straightforward to apply the MRW methodology in its textbook version to the theoretical framework of this paper. This also means that differences in results between MRW and this paper cannot come from basic model assumptions, but only from the way the model is investigated and compared to the data.

I now apply MRW's methodology and derivations to this model. In such a textbook Solow model output per efficiency unit of labor $\widehat{y}_t \equiv \frac{Y_t}{B_t\widetilde{L}_t}$ is constant in the steady state with a value given by $\widehat{y}^* = \left(\frac{S}{\widetilde{n}+g_B+\delta}\right)^{\frac{\alpha}{1-\alpha}}$ where S is the investment rate in physical capital, $\widetilde{n}$ is the growth rate of labor in human capital units $\widetilde{L}_t$, g_B is the rate of efficiency improvements and δ is the depreciation rate. MRW's convergence analysis is then based on a log-linear approximation around the steady state, which yields an equation of the form

$$\log \widehat{y}_t - \log \widehat{y}_s = \left(1 - e^{-\lambda(t-s)}\right) \frac{\alpha}{1-\alpha} \log\left(\frac{S}{\widetilde{n}+g_B+\delta}\right) - \left(1 - e^{-\lambda(t-s)}\right) \log \widehat{y}_s \tag{17}$$

where λ is a parameter representing the convergence rate. This equation motivates the empirical analysis of MRW. However in the actual regressions MRW replace output per efficiency unit of labor $\widehat{y}$ by output per units of human capital $\widetilde{y} = \frac{Y}{\widetilde{L}}$ (in their actual paper they use output per worker because there is no h_t in their textbook model). This is the basic source of the inconsistency between their results and the ones of this paper. In

[8]All the following substantive points are identical if one simply abstracts from human capital h_t in production and just considers the number of workers L_t as MRW do it in their textbook model version.

order to see this more clearly rewrite equation (17) in terms of $\widetilde{y}$ as

$$\log \widetilde{y}_t - \log \widetilde{y}_s = (t-s)g_B + \left(1 - e^{-\lambda(t-s)}\right) \frac{\alpha}{1-\alpha} \log \left(\frac{S}{\widetilde{n} + g_B + \delta} \right) - \left(1 - e^{-\lambda(t-s)}\right) [\log \widetilde{y}_s - \log B_s] \quad (18)$$

where $g_B = \frac{1}{t-s}[\log B_t - \log B_s]$ is the growth rate of efficiency B between periods s and t. MRW make two important identifying assumptions. The first one is that initial TFP satisfies $\log B_s = a + \varepsilon$ where a is a constant common in all countries and ε is an iid error term. The limitation of this assumption has been discussed before for example by Islam (1995). However they also make a second assumption that has not received sufficient attention, which is that the growth rate of efficiency g_B is constant across countries. Only when both of these assumptions hold will the efficiency terms be captured by the constant of the regression such that equation (18) can be consistently estimated by OLS. MRW then first regress $\Delta \log \widetilde{y}$ only on initial income $\log \widetilde{y}_s$ and do not find a significantly negative coefficient in this regression. However they do find a significantly negative coefficient on initial income once they also include the control for the steady state level. This is their famous conditional β-convergence result.

However one should not interpret these regression results as saying that poor countries do not grow faster than rich countries because they have lower Solow steady states. Such an interpretation rests completely on the restrictive assumption of common rates of technological progress. If rates of technological progress are not common across countries then omitting this factor will lead to biased and inconsistent estimates of the coefficients of both initial income and the steady state level. Instead one needs to separately control for these differences in efficiency growth rates. In other words one needs to regress $\Delta \log \widehat{y}$ on initial $\log \widehat{y}_s$ and the control for the steady state. One could then again estimate regressions that first exclude and then include the control for the Solow steady state. The problem is of course that strictly within MRW's estimation framework such equations cannot be estimated because $\widehat{y}$ is unobservable and only $\widetilde{y}$ can be observed. Only if the regressions that control for differences in efficiency growth rates exhibited the same pattern as originally found by MRW then one could draw conclusions on what accounts for the absence of absolute convergence.

In contrast to the MRW framework this paper employs a calibration approach that admittedly makes strong assumptions on the value of α (and conducts sensitivity checks on the used parameter value). This leaves the rates of efficiency growth completely unrestricted. When the purpose is one of accounting, then this is a key advantage. In fact this seems to be a necessary ingredient of an accounting analysis because otherwise the assumptions include an element that belongs in the question and answer.

As mentioned before it is not possible to strictly stay within the MRW estimation framework and address the discussed concerns. Thus I now provide an empirical illustration that the MRW estimation may indeed be misleading using estimates of efficiency growth rates obtained from the accounting framework of this paper. There are obviously caveats to this approach, but it can still help to illustrate the involved points.

First I repeat the original MRW regressions for my data set. As in MRW it is here assumed that $g_B + \delta = 0.05$ for all countries and S is the average investment rate during 1970-2010. The results for the regression involving only $\widetilde{y}$ terms are reported in the first two columns of table C.1. It turns out that one finds exactly the same pattern in this data as MRW. In the regression without the steady state control the coefficient of initial income is insignificant, but with the control it is negative and significant.

In the next step I use the estimates of B_t based on the calibration approach of this paper to calculate $\widehat{y}$ terms and then run the regressions involving these terms. The results are reported in column 3 and 4 of table C.1 along with the ones of the original MRW method. Column 3 shows that after controlling only for differences in efficiency growth rates poor countries do already grow faster than rich ones. This is another conditional convergence result, but here “conditional” refers to conditioning on efficiency growth rates. Column 4 then controls for differences in efficiency growth and the steady state of the Solow model relating to factor accumulation.[9] The coefficient of initial income becomes even larger now in absolute magnitude compared to columns 2 and 3 which implies stronger

[9] In the control for the steady state I also include the estimate of g_B and use the depreciation rate δ assumed in section 2.3. However the results are very similar if one continues to assume $g_B + \delta = 0.05$ for all countries in the steady state term.

conditional convergence.

Looking at all columns one observes that either controlling for factor accumulation or efficiency growth or both yields conditional convergence. Thus a regression analysis in the spirit of MRW does not provide a clear answer to the question of what accounts for the absence of absolute β-convergence unless one makes very restrictive assumptions.

Table C.1: Regressions in the spirit of Mankiw, Romer and Weil (1992)

	$\Delta\log(\widetilde{y})$	$\Delta\log(\widetilde{y})$	$\Delta\log(\widehat{y})$	$\Delta\log(\widehat{y})$
$\log(\widetilde{y})$ in 1970	-0.031	-0.189***		
	(0.063)	(0.058)		
$\log(\widehat{y})$ in 1970			-0.651***	-0.937***
			(0.064)	(0.026)
$\log\left(\frac{S}{\widetilde{n}+0.05}\right)$		0.939***		
		(0.116)		
$\log\left(\frac{S}{\widetilde{n}+g_B+\delta}\right)$				0.452***
				(0.022)
Implied λ	0.001	0.005***	0.026***	0.069***
	(0.002)	(0.002)	(0.005)	(0.010)
Implied α		0.832***		0.325***
		(0.035)		(0.009)
Observations	98	98	98	98
R^2	0.00	0.35	0.59	0.93

Robust standard errors in parantheses.

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$