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# Income per-capita across-countries: stories of catching-up, stagnation, and laggardness

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#### ABSTRACT

The convergence/divergence debate and plausible explanations to the process of catching-up remain highly controversial research areas in growth economics. Recently, these issues have been the subject of questionable predictions with regard future prospect for backward countries, raising concerns about the right direction of macroeconomic policy. To explore these issues, a sample of 131 countries is studied over the 1950s-2010s to identify those that have managed to catching-up, remain stagnant, or keep lagging further behind. Time-distance to the frontier and productivity decompositions, based on non-parametric methods, suggest that some countries have successfully completed already the cachingup, and it would take between 27 and 194 years for others to do so in the most optimistic scenario. But many others would never do. Policy implications drawn from the comparative analysis suggests the need to strengthen local innovation in order to increase the ability to catching-up alongside widespread reliance on technology diffusion from abroad.

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#### **KEYWORDS**

Economic development and economic growth: innovation: technology diffusion; convergence

## 1. Introduction

Whether observed differences in levels of income per capita between rich and poor countries shall disappear or not in the distant future is one of the most intriguing question economists have been faced to since the very beginning of the economics science (Elmslie, 1995). Inconditional income convergence across the world economy has been punctually predicted by Lucas (2000) to occur by the end of the twenty-first century, or within some 340 years - according to more cautious prediction by Patel et al. (2021). But some critics have suggested that substantial divergence will continue to exist instead (Chen & Ravallion, 2010; P. Johnson & Papageorgiou, 2020; Nell, 2020).

Seeking a feasible answer to that question, contributing to the empirical debate on the issues of convergence/divergence and hopefully offering new research perspectives in this

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field, I split the world economies into successful and unsuccessful cases of catching-up and study the roles of technology diffusion from abroad and local innovation in explaining their performance.

In particular, using data from the Penn World Tables, PWT V.10.0 (Feenstra et al., 2015),<sup>1</sup> a sample of 131 countries is classified into those at the frontier and those that over long periods of time show patterns consistent with catching-up, stagnation, or laggardness. The classification is based on records of income per-capita relative to the frontier over the 1950s–2010s and *adjusted growth gaps*, calculated by subtracting the growth rate of the countries at the frontier from the growth rate of other countries.

To provide a plausible explanation of the key determinants of catching-up, productivity decompositions based on well-established non-parametric techniques are used. This approach is aimed to factor productivity changes that are related to technical changes (associated to the diffusion of best practice technologies worldwide) and efficiency changes which are assumed to capture local innovativeness (Coelli et al., 2005; Kumar & Russell, 2002; Los & Timmer, 2005).

A remarkable result of this methodological shift that challenges the conclusions about the future posed by the influential research of some economists (Kremer et al., 2022; Lucas, 2000; Patel et al., 2021; Roy et al., 2016; Spence, 2011) is that even among the select group of succesful catching-up countries, convergence would take not less than three decades, and as much as 200 years in the most optimistic scenario. In turn, countries that are secularly stagnant would take not least that seven decades but as much as 2000 years to get there. And countries that keep lagging behind would need not less than 500 years in the best case, but more probably will never do it.

The paper continues as follows: in Section 2, I provide a brief review of related literature. In Section 3 the proposed four-types of countries classification is introduced. In Section 4, the growth gaps of countries behind the frontier is analyzed. In Section 5, a procedure to calculate the years needed to catching-up is developed. In Section 6, unconditional  $\beta$ -convergence analysis is conducted and related to the *convergence clubs* debate. In Section 7, the relative importance of local innovation and technology diffusion to explain the catching-up performance is studied. Section 8, provides some concluding remarks.

## 2. A review of the literature

Research in the field of growth economics has been marked by two closely interconnected debates: the convergence/divergence issue and the role of technology diffusion and innovation in this context.

The first of these debates is anything but new, yet it remains unsettled. Traced back at least to an old controversy between Hume 1742 and Tucker 1776—regarded in fact as one of the first major doctrinal debates on economic thought well in advance of Adam Smith's inquiry about the Wealth of Nations (Elmslie 1995)—this was also a

<sup>&</sup>lt;sup>1</sup>See https://www.rug.nl/ggdc/productivity/pwt. S. Johnson et al. (2013) show that specific results vary using alternative datasets. Patel et al. (2021), indicate that while PWT tends to favour divergence in earlier decades it does not invalidate convergence patterns in most recent data.

central issue in Veblen's (1915 account of what Gerschenkron (1962 later famously referred to as the "advantage of backwardness".

Throughout the second half of the twentieth century, the Neoclassical model sparked anew controversy that weakened the credibility on the probability of absolute (unconditional) convergence and led instead the issues of *conditional convergence*, *catching-up* and *divergence* to draw research interest from the mid-1980s onwards (Abramovitz, 1986; Barro & Sala-I-Martin, 1997; Baumol, 1986; Fagerberg, 1995; Pritchett, 1997; Romer, 1986). Initially related to differential rates of capital accumulation, the disagreement turned then towards the ability of less developed countries to adopt the technology – namely the inventions and ideas – of the countries at the frontier (Mankiw et al., 1995; Romer, 1993).

From the beginning of the twenty-first century and until recently, some notorious contributions have made it clear that the fundamental disagreement is still open. Lucas (2000) boldly predicted that "*unconditional convergence*" would be a fact of reality by 2100, and his optimistic prediction have received timely support (Kremer et al., 2022; Patel et al., 2021; Roy et al., 2016; Spence, 2011). Barro (2015) also predicts convergence but in the conditional sense (and Nell, 2020 refutes it).

On the other side of the controversy, there are researchers who point out that what has been observed is divergence instead (Chen & Ravallion, 2010; Goldstone, 2002; P. Johnson & Papageorgiou, 2020; Pomeranz, 2000). More in line with the results found below, Pritchett (2000b) suggests that some countries appear to catching-up (hills) while others stagnate (plains) and others show steady declines (valleys).

That there is substantial heterogeneity in cross-country patterns of income and economic growth is generally accepted. What seems much more contentious is the conclusion drawn by some researchers about a "new era of unconditional convergence" which rely on recent trend-shifts in the data. By revisiting the data and focusing on longer periods of time, the findings below support that story for a selected group of catching-up countries. But also give support to alternative stories of stagnation and divergence.

Among other explanations for the substantial heterogeneity that is observed across countries, technology differences (Easterly & Levine, 2000) and differences in efficiency in the use of technology (Clark & Feenstra, 2003) continue to be particularly controversial. A crucial issue in this discussion is whether the technology attribute that allows poor countries to catching-up is made exclusively of the inventions and knowledge developed at the frontier or there is room for endogenous innovation (Fagerberg et al., 2010).

For some economists, the interaction of technology diffusion and indigenous absortive capabilities is the key to explain why there are some countries that manage to catching-up and others that fail to do so (Ayerst et al., 2023; Cai et al., 2022; Comin & Hobijn, 2010; Comin & Nanda, 2019; Park & Dreamson, 2023; Pérez-Trujillo & Lacalle-Calderon, 2020; Sebbesen, 2023; Stokey, 2015). For others, local innovation, and therefore the institutions and incentive structures designed to boost it, is the key mechanism (Kunieda et al., 2021; Malerba & Lee, 2020; Pandey et al., 2022; Perilla, 2019, 2020; Tomizawa et al., 2020). The evidence below appears to favour the latter view.

# 3. Backward countries' relative levels of income

The World Bank four-tier classification between Low Income (LICs), Lower Middle Income (LMICs), Upper Middle Income (UMICs) and High Income Countries (HICs) remains a well-established standard that allows to gain quick knowledge on the diversity of cross-country income per-capita levels. Unfortunately, this ranking does not allow, *per se*, to judge the ability – and indeed the probability – of countries behind to shortening the distance to the frontier. This probability depends positively on the economic performance of countries behind. But, it is inversely related to the economic performance of the leading countries.

It seems staggering, for instance, that by 1997, the year that India graduated to the LMICs, it had roughly the same relative income (PPP-adjusted) than in 1975 (8% relative to the OECD countries). This was lower than the average in previous decades (10% over the 1950s–1970s). And over the 2010s this country had more or less the same relative income than during the 1950s. In contrast, Egypt was roughly stagnant and below the performance of India over the 1950s–1980s (relative income of 7%). But Egypt reached a relative income of 16% by the end of the 1990s, and around 25% during the 2010s. The contrary happened to Guinea whose relative income averaged 20% over the 1960s–1970s, but fell down steadily to around 10% through the following two decades, and over the 2010s fell further below 5%.

To make sense of this diversity in the catching-up experience across countries, below a sample of 131 countries is classified into those at the frontier, and those that over the 1950s–2010s have managed to catching-up, remained stagnant, or kept lagging further behind.<sup>2</sup> Furthermore, depending on data availability, countries are split into time clusters.<sup>3</sup>

The classification is based on 10-year averages.<sup>4</sup> The benchmark is formed by 24 countries members of the OECD since before the 1990s.<sup>5</sup> These are referred now on as frontier countries (FRCs). Relative incomes are calculated as the ratio between a country's average and the average at the FRCs. For instance, through the 1950s average income was US\$3732 in Colombia, US\$1208 in South Korea, and US\$9843 across the FRCs. Throughout the 2010s, the figures were US\$13542, US\$38052, and US\$48385, respectively. Relative to the FRCs, through the 1950s the Colombian income (38%) was more than three times that of Korea (12%). Seven decades later relative income increased to circa 80% for Korea and decreased below 30% for Colombia.

From Figure 1, countries under the 45-degree diagonal have much larger relative income during the 2010s, than at the origin (1950s, 1960s, 1970s). The contrary happens for countries over the diagonal. Countries near the origin and/or close to the diagonal on either side reveal minor progress or even a slight decline in their relative income. Notice, for instance, that over the 1970s–2010s Suriname barely improved its income position,

<sup>&</sup>lt;sup>2</sup>I use PWT V.10.0 output-side real GDP at chained PPPs (in mil. 2017US\$)-*rgdpo*). Rich oil-producing countries, non-OECD high-income countries with relative income per-capita larger than 75% of the frontier at the origin, and countries with data over less than two decades, are excluded.

<sup>&</sup>lt;sup>3</sup>I consider i) a cluster of 35 countries with data over the 1950s-2010s; ii) a cluster of 49 countries with data over 1960s-2010s; and iii) a cluster of 23 countries with data over 1970s-2010s.

<sup>&</sup>lt;sup>4</sup>Decade averages are calculated as long as there is data for at least 8 years.

<sup>&</sup>lt;sup>5</sup>https://www.oecd.org. Using this benchmark rather than a single country (like the U.S.) has the advantage that the OECD represents a wider variety of capitalism and institutional practices (See Hall & Soskice, 2004).



**Figure 1.** Relative levels of income per capita. The big grey circles are FRCs, the big white ones are the CUCs, the big black ones are the STCs and the small ones are the LGCs. Countries below the 45-degree line are better off in the last decade. The position of every country indicates their catching up performance – e.g., at the origin, the relative income of Hong Kong was about 60% off the frontier, in the 2010s it was well over 100%.

while for Taiwan the relative income in the 2010s is much larger and for Venezuela it is lower than at the origin. Even among FRCs, there are some countries that clearly improved their position with respect to the origin and others that failed to do so.

In fact, in the case of Suriname there is a slight decrease between the 1970s (30.7%) and the 2010s (30.2%). By taking the ratio between the latter and the former figures the conclusion is reached that no meaningful change occurred in the position of this country with respect to the frontier ( $30.7\%/30.2\% \cong 1.0$ ). A similar conclusion is reached for Paraguay (1.0), the Dominican Republic (1.2), India (1.1), Chile (0.95), Peru (0.92), and Morocco (1.1). In contrast, there is a group of countries that managed to improve their position: Korea (7.0), Taiwan (4.3), Thailand (3.0), Egypt (3.6), and Romania (2.9); and another group that fell farther apart over the decades: Mexico (0.65), Colombia (0.74), Congo (0.07).

Thus, let's consider an ad-hoc 0.75–1.25 threshold. Countries for which the relative income ratio rises or falls by less than a quarter are classified as stagnant (STCs); countries that are above the upper-bound are classified as catching-up (CUCs); and countries that are below the lower-bound are classified as laggard (LGCs). Based on this criterion, the 131 countries in the sample split into 24 FRCs, 26 CUCs, 27 STCs, and 54 LGCs.<sup>6</sup>

As most classifications are, this is somewhat arbitrary. After all, a relative income ratio barely over 1 implies that a country would be able to catching-up even if in the far distant future. Similarly, a relative income ratio barely under 1 implies that countries are getting away of the frontier even if quite slowly over time. Furthermore, accounting only for changes between the latest decade and the origin may simply indicate that a country was doing well (or bad) in that particular decade. It tell us nothing of what happens in the decades in between.

<sup>6</sup>See the Appendix.





**Figure 2.** Relative levels of income per capita of CUCs (a), STCs (b), and LGCs (c). The upper solid-line is the frontier. The three thick dashed lines below the frontier are 10-year moving averages of relative income for clusters of countries over 1950s–2010s, 1960s–2010s, and 1970s–2010s. The thin dotted lines in (a) show represent the Asian Nics, the thin solid line the HInonOECDs. The dotted and solid lines in (b) and (c) represent the LICs and fragile countries, respectively.

To address the first of these concerns, one may apply different threshold widths. Clearly, a narrower width implies more countries in the extremes (the catching-up and laggard classifications). However, it seems unlikely that countries that are only slightly below (above) unity have performed permanently as bad (well) as those that are farther away. Also, while allowing more countries in the extremes does not appear to be innocuous, it definitively does not invalidate the diverse patterns of convergence/divergence that are argued here for the CUCs, STCs, and LGCs.

To address the second concern, using 10-year moving averages seems more appropriate. This leads to smooth trends that reflect the ability/failure of countries to achieve rates of economic growth consistent with catching-up. In Figure 2, the long-run trends fit well with the proposed four-types of countries classification even after factoring out extreme country cases – which implies that time clusters reflect the performance of middle income and more stable countries.<sup>7</sup>

# 4. Growth gaps

Provided that backward countries grow faster than countries at the frontier, predicting the potential to catching-up amounts to calculate the average gap between these two growth rates.

$$\overline{g}_{gap} = \overline{g}_i - \overline{g}_{FRCs} \mid \overline{g}_i > > \overline{g}_{FRCs}$$

Clearly, the smaller the gap the larger the time needed to catching-up.<sup>8</sup> The condition  $\bar{g}_i > \bar{g}_{FRCs}$  implies that countries exhibiting negative growth gaps will not be able to catching-up at all.

In Figure 3, growth gaps are calculated yearly and depicted as 10-year moving averages over relevant country classifications and time clusters. Again, extreme country cases are plotted apart. Despite cyclical fluctuations, the growth gaps in panel (a) are generally

<sup>&</sup>lt;sup>7</sup>Most Low Income Countries (LICs) and many countries characterized as having weak institutions and poor governance, so-called fragile states (Frags), classify as LGCs. Likewise, all of the so-called New Industrialized Asian Economies-NICs (Hong Kong, Singapore, Taiwan, South Korea), and most of the High Income Countries that are not part of the OECD (HINOECDs) classify as CUCS. To prevent a misleading influence on long-run trajectories, in Figure 2 these specific country cases are depicted apart.

<sup>&</sup>lt;sup>8</sup>A gap of 1 pp for a country that has half the FRC's income indicates that catch-up will take 70 years; but with a gap of 0.1 pp it will take 700 years.



**Figure 3.** Growth gaps CUCs (a), STCs (b) and LGCs (c). The zero line is the frontier. The other three thick lines are time clusters over 1950s–2010s, 1960s–2010s, and 1970s–2010s. Thin dotted and dashed lines in (a) are the Nics and HInonOECDs, in (b) are the LICs and fragile states.

positive, consistent with the fact that the CUCs have grown permanently faster than countries at the frontier regardless the excepcional performance attributed to Asian Nics and other HInonOECDs.

By contrast, in panel (b) growth gaps for the STCs fluctuate around the zero-cutoff. The sequencial periods of faster and slower growth of these countries with respect to the frontier offer a possible explanation why these countries have failed to close their income gaps. Finally, in panel (c), growth gaps for the LGCs are generally below the zero-cutoff which is the likely reason why these countries have been diverging from the frontier over time.

Notice, however, the increasing trends in the data for the STCs and LGCs after the 1990s. The tendency shown by the countries in these groups to close their growth gaps with the frontier is what gave a cause for optimism to researchers that have taken it as an indication of a new path of unconditional convergence in the world economy (Patel et al., 2021; Roy et al., 2016). Unfortunately after the 2000s, the evidence appears less clear cut. Apparently, the well-known crisis at the end of the latter decade affected all countries, and was particularly adverse to LGCs.

# 5. Distance to the frontier

Combining both, relative income and *growth gaps*, allows for some interesting predictions about the time that it would take backward countries to reach the frontier. For instance, a country with relative income of 10% and a growth gap of +1 pp would reach the frontier in around 230 years; using the same growth gap, a country with relative income of 50% would reach the frontier in 70 years; and with a growth gap of +5 pp the first country would reach the frontier in less than 50 years.

This is a simple application of the "*Rule of 70*". Consider a country *i* with average income  $\bar{y}_i$  which grows steadily at the rate  $\bar{g}_i$ . The time that it would take to catching-up with the frontier's income  $\bar{y}_{FRCs}$  which grows at the rate  $\bar{g}_{FRCs}$ , is given by the solution to the following problem

$$\overline{y}_i * e^{\overline{g}_i N} = \overline{y}_{FRCs} * e^{\overline{g}_{FRCs} N}$$

Taking natural logs on both sides and solving for N, the following conditions are obtained

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$$N = -LN(\bar{y}_{i/FRCs}) * (\bar{g}_i - \bar{g}_{FRCs})^{-1} |\bar{g}_{FRCs} < \bar{g}_i$$
(1)

$$N = \infty \qquad |\bar{g}_{FRCs} \ge \bar{g}_i$$
 (2)

where  $\bar{y}_{i/F}$  is relative income and  $\bar{g}_i - \bar{g}_F$  is the growth gap. Equation (1) indicates the time to catching-up when the growth gap is positive. Equation (2) shows that no catching-up is possible when a country grows at a rate that is equal or less than the frontier's.

Figure 4 plots this relationship for the 131 countries in the sample taking the average of relative income over the 2010s and the average growth rate for every country over the whole sample period. Panel (a) plots a *fixed target* scenario, assuming  $\bar{g}_{FRCs} = 0\%$ . Panel (b) plots the *actual target* scenario, using  $\bar{g}_{FRCs} = 2.74\%$ .

The *fixed target* scenario shows the FRCs grouped around the *average* (2.74%) at zero years to catching-up. The CUCs, the STCs and many LGCs are over the zero-pp line – and even over the minimum growth rate at the frontier. This implies, obviously, that when the frontier is a fixed target almost all countries have some probability to catching-up.

However, even under this optimistic scenario, a large number of LGCs would fail to reach the frontier at any time.<sup>9</sup> In particular, under the *fixed target* scenario the CUCs would need on average 27 years to catching-up. Some countries (Singapore, Macao, Taiwan, Hong Kong, South Korea) are near fulfillment or already fulfilled the process, while others are farther away (Cape Verde, Cyprus). By comparison, the STCs would need on average 69 years, and the LGCs 246 years. But there are many countries with negative growth gaps that, consequently, will never even hope to catching-up. Excluding them, the LGCs would need 483 years.



**Figure 4.** Time-distance to catching-up. FRCs (white), CUCs (grey), STCs (black bordered grey) and LGCs (black). Panel (a) assumes  $\bar{g}_{FRCs}$ =0%. Panel (b) uses  $\bar{g}_{FRCs}$ =2.74%, the average across frontier countries. Other horizontal lines depict the maximum and minimum growth in countries at the frontier.

<sup>&</sup>lt;sup>9</sup>Countries as Burundi or Algeria would need more that 300 years to catching-up. But Central African Republic, Djibouti, and Congo would not be able to catching-up at all. As a rule of thumb, countries falling behind far beyond 300 years are plotted at –300 (these countries are even behind the starting gate of modern economic growth initiated with the onset of the *industrial revolution* – see Lucas, 2000).

The *actual target* scenario, panel (b), shows the FRCs grouped around the zero pp line. Now, only the CUCs show positive growth gaps. In turn, only three STCs (Bulgaria, the Dominican Republic, and India), and no LGCs show catching-up probabilities. In this scenario, the CUCs are, on average, at a distance of 194 years to the frontier. But there are large disparities in the predictions for individual countries: there are again the countries that are near or already fulfilled the process (Taiwan, South Korea, Singapore). But, there are others falling farther apart of the limit of 300 years: Albania (1374 years), Cape Verde (831), Tunisia (522), Argentine (470), and Myanmar (380). Among the STCs, Bulgaria shows the smallest distance to the frontier (234 years), while the Dominican Republic (619) and India (2242) are far apart.

Notice that time-distance to the frontier depends on the level of income considered the appropriate measure of richness. In Figure 4, the reference income of the FRCs was US\$48385 (PPP adjusted real GDP at 2017US\$). This might be too high a standard for many countries. The minimum level of income and the lowest growth rate across FRCs are US\$24437 and 1.8%. Using these measures, the average distance to the frontier is 20 years for the CUCs and 370 years for the STCs (excluding countries that would never make the catching-up). But even in this type of straightforward scenario only four countries in the LGCs show catching-up probabilities: Ethiopia (296), Mexico (287), Colombia (267) and Costa Rica (74).<sup>10</sup>

Summing up, the time-distance analysis shows than only the CUCs have been or may be able to fulfilled the catching-up process in feasible times. The weakness of the STCs to generate growth rates that are consistently above the frontier's average, and the even worse growth performance of the LGCs, show why these countries remain stagnant or diverging farther away. Interestingly, the latter group includes several of the best examples of countries with a reasonable record of economic performance in other well-known classifications (see Spence, 2011).

#### 6. Conventional convergence revisited

In this section, I run conventional  $\beta$ -convergence OLS-pooled regressions for countries within the FRCs classification and countries in each couple FRCs-CUCs, FRCs-STCs, and FRCs-LGCs with and without controlling for extreme country cases. As long as there are no further conditions, this may be consider an analysis of *"unconditional convergence"*.<sup>11</sup>

In Figure 5, the negatively sloped relationship between the rate of growth and the level of income for the FRCs highlights the well-known convergence pattern documented elsewhere for advanced countries. There are also negatively sloped and steep trends for the couple FRCs-CUCs, and much flatter trends for the FRCs-STCs, whereas for the FRCs-LGCs the data suggest positively sloped trends instead. In other words, the evidence suggests a pattern

<sup>&</sup>lt;sup>10</sup>Interestingly, the distance to the frontier, and indeed the decline in relative income of the three Latin American countries in the latter group between the 1950s and the 2010s (Colombia from 38% to 28%, Costa Rica from 46% to 33%, and Mexico from 59% to 38%) is in strong contrast with the optimism on their economic performance in other country classifications. For instance, these countries belong to the World Bank UMICs: Mexico since 1990, Costa Rica since 2000, and Colombia since 2008, and all of them are among the latest members of the OECDs: Mexico 1994, Colombia 2020, and Costa Rica 2021).

<sup>&</sup>lt;sup>11</sup>Alternatively, a "conditional convergence" test can be run based on the fact that countries belong to distinct convergence clubs.



**Figure 5.** Relative income per-capita in the 1970s and growth gaps over 1970s-2010s. The thicker black line and grey circles are the FRCs. The dotted lines on the top and white circles are the CUCs before (black line) and after subtracting the Nics and HInOECDs (grey line). The dashed lines in the middle correspond to the STCs before (black line) and after subtracting LICs, HInOECDs, and Frags (grey line). The bottom-most dash-dotted lines correspond to the LGCs before and after subtracting LICs and Frags.

of convergence between the CUCs and the FRCs but not between the STCs and FRCs, and suggests a process of divergence between the LGCs and the FRCs.

The  $\beta$ -convergence estimates in Table 1 are obtained from the following regression

$$\overline{g}_{i,\tau} = \alpha + \beta \overline{y}_{i/FRCs,1970s} + D_{\tau} + DZ_{\tau} + \varepsilon_{\tau}$$

the dependent variable is the growth gap for the country over 1970s-2010s (5 observations per country),  $\bar{y}_{i/FRCs,1970s}$  is the relative income per capita between a country and the frontier in the 1970s.  $D_{\tau}$  denotes decade specific dummies and *DZ* denote dummies to control for extreme country cases.

As expected, coefficient estimates suggest a significant convergence effect for the CUCs. The coefficient for the CUCs-1 (-0.008) is statistically significant and robust after controlling for the Nics and HInOECDs. In the case of the STCs, the convergence effect is not statistically significant. In the case of the LGCs-1, the positive sign of the coefficient suggests a statistically significant pattern of divergence. But this result is not robust, as may be seen for the regression of the LGCs-2.

The so-called *half-life of adjustment* reveals patterns that are roughly consistent with the findings in the previous section. On average, it would take around 115 years for the CUCs and 518 years for the STCs to eliminate half of their initial income gap with the FRCs, while for the LGCs the evidence suggests no convergence possibilities.

Interestingly, the data suggests also the possibility of  $\sigma$ -convergence within every group of countries other than the LGCs. In particular, using the coefficient

**Table 1.** Estimates of  $\beta$ -convergence. The regressions are based on OLS-pooled regressions, the dependent variable is the growth gap over 1970s–2010s. The explanatory variable is relative income per capita in the 1970s. Decade dummies are included over 1980s-2010s. X-1 and X-2 denote regressions before and after controlling for the Nics, HINOECDs, LICs, and Frags. Sandwich-robust standard errors reported in parentheses. The *half-life of adjustment* denotes the years needed to eliminate a half of the income gap with the frontier,  $HLA = \frac{1}{2n} \sum_{i} ln(y_i/y_{FRCs})/(\beta_{xs})$ . This is 115 years for the CUCs and 518 for the STCs. The positive  $\beta_{x}$  of the LGCs implies that the HLA goes to infinity.

|                   |           |           | • 15     |          |           |          |          |
|-------------------|-----------|-----------|----------|----------|-----------|----------|----------|
|                   | FRCs      | CUCs-1    | STCs-1   | LGCs-1   | CUCs-2    | STCs-2   | LGCs-2   |
| а                 | 0.05***   | 0.04***   | 0.023    | 0.028*** | 0.04***   | 0.005    | -0.01    |
|                   | (0.017)   | (0.005)   | (0.007)  | (0.007)  | (0.006)   | (0.008)  | (0.011)  |
| β                 | -0.011*** | -0.008*** | -0.002   | 0.004*** | -0.008*** | -0.002   | 0.0002   |
|                   | (0.004)   | (0.001)   | (0.002)  | (0.002)  | (0.001)   | (0.002)  | (0.002)  |
| D <sub>1980</sub> | -0.00     | -0.004    | -0.003   | -0.009   | -0.004    | -0.003   | -0.009   |
|                   | (0.00)    | (0.004)   | (0.005)  | (0.006)  | (0.004)   | (0.005)  | (0.006)  |
| D <sub>1990</sub> | -0.00     | -0.007*   | -0.0002  | -0.011** | -0.007*   | -0.0002  | -0.011** |
|                   | (0.00)    | (0.004)   | (0.005)  | (0.006)  | (0.004)   | (0.005)  | (0.006)  |
| D <sub>2000</sub> | -0.00     | 0.007*    | 0.016*** | 0.019*** | 0.007*    | 0.016*** | 0.019*** |
|                   | (0.00)    | (0.004)   | (0.005)  | (0.006)  | (0.004)   | (0.005)  | (0.006)  |
| D <sub>2010</sub> | -0.00     | -0.004    | -0.008*  | 0.013**  | -0.004    | 0.008*   | 0.013**  |
|                   | (0.00)    | (0.004)   | (0.005)  | (0.006)  | (0.004)   | (0.005)  | (0.006)  |
| DNics             |           |           |          |          | 0.018***  |          |          |
|                   |           |           |          |          | (0.005)   |          |          |
| DHInonOECDs       |           |           |          |          | 0.009**   | -0.002   | 0.003    |
|                   |           |           |          |          | (0.004)   | (0.008)  | (0.016)  |
| DLICs             |           |           |          |          |           | 0.003    | -0.006   |
|                   |           |           |          |          |           | (0.009)  | (0.005)  |
| DFrags            |           |           |          |          | -0.003    | -0.009*  | -0.009*  |
|                   |           |           |          |          | (0.007)   | (0.005)  | (0.005)  |
| r2 <sub>a</sub>   | 0.03      | 0.15      | 0.06     | 0.10     | 0.19      | 0.06     | 0.11     |
| Ν                 | 120       | 265       | 240      | 390      | 265       | 240      | 390      |
| HLA               |           | 115       | 518      | $\infty$ | 115       | 518      | $\infty$ |
|                   |           |           |          |          |           |          |          |

\*, \*\*, \*\*\* denote statistical significance at 10%, 5% and 1%.

of variation (CV) to normalize the dispersion, over 1970s-2010s the data suggests a decline for the FRCs from (0.11 to 0.07), the CUCs (from 0.31 to 0.21) and the STCs (from 0.28 to 0.22). By contrast, for the LGCs the dispersion increases steadily from 0.27 to 0.42 in the 1990s and remained stable till 2010s.<sup>12</sup>

It remains to be seen whether countries off the frontier are able to rectify the relatively large periods of time needed to catching-up that are suggested by the above calculations. Among a much larger list of feasible explanations, too large to be discussed here, the extensive literature relating to the causes and consequences of underdevelopment with a focus on cross-country settings has questioned whether convergence hinges on the virtues of accumulation (Mankiw et al., 1995; Young, 1995), technological diffusion and the ability of countries to use the received technology/replicate the conditions that allowed the technologies developed at the frontier (Baldwin et al., 2001; Clark & Feenstra, 2003; Easterly & Levine, 2000; Lin & Monga, 2011; Mankiw et al., 1995; Rodrik, 2011; Romer, 1993; Sachs & Warner, 1995), or on their ability to assimilate and innovate (Nelson & Pack, 1999; Perilla, 2019, 2020; Wade, 1996). An analysis of these issues is presented in the next section.

<sup>&</sup>lt;sup>12</sup>Calculations are available from the author.

## 7. Cross-country differences in technology

A relative consensus in growth economics is that cross-country income differences are closely related to differences in productivity which, in turn, are associated with differences in technology.<sup>13</sup>

Below, I show that while income differences appear to mirror productivity differences across countries, the decomposition of productivity into local efficiency – a measure or indication of the impact of innovation – and technical change – a measure of the impact of technology diffusion/adoption – suggests that catching-up strongly depends on innovation.

#### 7.1. Productivity performance and catching-up

Following Caselli (2005), I use *development accounting* techniques to assessing to what extent differences in income (per worker) are explained by productivity differences across countries. The question to answer is how much of the differences in relative income between a country and the frontier is explained by differences in the endowment of productive factors and, by subtraction, how much by differences in productivity.

Consider the standard production function in per-worker terms of country i at time t relative to the frontier,

$$\tilde{y}_i = y_i / \bar{y}_{FRCs} = \frac{A_i}{\bar{A}_{FRCs}} \left(\frac{k_i}{\bar{k}_{FRCs}}\right)^{\alpha} \left(\frac{h_i}{\bar{h}_{FRCs}}\right)^{1-\alpha} = \tilde{A}_i \tilde{q}_i \tag{3}$$

where  $x_i$ ,  $\bar{x}_{FRCs}$  are yearly figures and the latter denotes the average at the frontier (time subscripts dropped for simplicity). k is the capital stock and h is the "quality adjusted" workforce (the number of workers times their average human capital). The capital-share,  $\alpha = 1/3$  is assumed to be country and time invariant.<sup>14</sup>

the log-variance decomposition of the above equation is

$$var(ln\tilde{y}) = var(ln\tilde{A}) + var(ln\tilde{q}) + 2cov(ln\tilde{A}, ln\tilde{q})$$

if there are no productivity differences across countries, the second and fourth term of the last equation are both equal to zero. In such a situation, the *factors-only share* of the difference in income per worker is

$$Z_{kh} = \frac{var(ln\tilde{q})}{var(ln\tilde{\gamma})}$$

thus, the productivity share of income differences is given by

$$Z_A = 1 - \frac{var(ln\tilde{q})}{var(ln\tilde{y})} \tag{4}$$

To emphasize the distance to the frontier, the variances in the last expression are calculated with respect to the average at the frontier

<sup>&</sup>lt;sup>13</sup>See Dougherty and Jorgenson (1996), and Jorgenson and Vu (2005) for counter arguments.

 $<sup>^{14}</sup>a = 1/3$  is a standard value in growth literature. Alternatively, one may use country specific and time varying statistics on factors shares. However, Gollin (2002), and Pritchett (2000a), provide solid arguments to be cautious on the reliability of official statistics in this regard.

$$var(x_i^X) = \frac{1}{N} \sum_{i}^{N} (x_i^X - \bar{x}_{FRCs})^2$$

where  $X \in \{FRCs, CUCs, STCs, LGCs\}$ . Thus, the *factors-only share* for each country classification are calculated in the following way

$$Z_{kh,t}^{X} = \frac{var(ln\tilde{q}_{t}^{X})}{var(ln\tilde{y}_{t}^{X})}$$

Clearly,  $Z_{kh,t}^X = 1$  when income differences are fully explained by differences in factor endowments. Otherwise,  $1-Z_{kh,t}^X$  gives an indication of the share of income difference that are explained by productivity. I apply this decomposition to a sample of 110 countries with complete information on relevant variables over 1970–2019 (24 FRCs, 21 CUCs, 25 STCs, 40 LGCs).<sup>15</sup> From Figure 6, panel (a), the median of the distribution across all countries is 0.37 (std = 0.08, min = 0.30, max = 0.53) which is wholly consistent with results found in other studies that usually focus on either a single year or shorter time periods, using different versions of the data and different country samples (Caselli, 2005; King & Levine, 1994).

Surprisingly, as one would expect productivity to play a more powerful and systematic influence in income differences at the frontier, in panel (a) the median and variability of the *factors-only share* is much larger for the FRCs (median = 0.71, std = 0.24) than for other country classifications: the LGCs (median = 0.34, std = 0.09), the CUCs (median = 0.42, std = 0.08), and the STCs (median = 0.46, std = 0.06). However, the data suggests



**Figure 6.** Dispersion of the *factors-only share* and productivity conditional on the average at the frontier. The thick grey line depicts all countries, the thick black line the FRCs, the dashed line the CUCs, the dotted line the STCs, and the thin line the LGCs. Panel (a) shows the distribution based on a sample of 110 countries over 1970–2019 (24 FRCs, 21 CUCs, 25 STCs, 40 LGCs), panels (b) and (c) are based on an adjusted sample of 59 countries (20 FRCs, 11 CUCs, 12 STCs, 16 LGCs, excluding extreme country cases and adjusting the distribution at the frontier to remain between the 10th-90th percentiles). Panel (c) shows productivity share differences.

<sup>&</sup>lt;sup>15</sup>I use the following data from PWT V.10.0: Output-side real GDP (cgdpo) and capital stock (cn) at current PPPs in millions of 2017US\$, number of persons engaged (emp) and the human capital index (h). The smaller sample size is because some countries in the original sample of 131 countries lack the data on factor inputs that is needed in this section.

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a consistent pattern of income per capita differences that are explained largely by differences in productivity.

The sensitivity of development accounting to extreme values has led some researchers to consider alternative scenarios, e.g., the 90th-10th percentile ratio of the distribution of the factors-only share (Caselli, 2005). I follow that procedure for the FRCs but consider a different approach for other country groups taking into account the wide diversity in the performance of relevant economic variables across low-income countries (LIC), fragile democracies (Frags) and high-income countries that are not part of the OECD (HINOECDs) as well as the NICs. Basically, by excluding those extreme country cases, a more stable sample is obtained that is better suited for the analysis, including a rather compact distribution at the frontier and middle-income countries that have enjoyed good economic performance over long periods of time. The new sample accounts for 59 countries (20 FRCs, 11 CUCs, 12 STCs, 16 LGCs).

From Figure 6 panel (b), the new sample leads to a significant reduction in the overall distribution of the *factors-only share* (median = 0.34, std = 0.08). The most meaningful reduction occurs at the frontier (median = 0.25, std = 0.05), followed by the CUCs (median = 0.34, std = 0.08), the STCs (median = 0.36, std = 0.09), and only a minor reduction in the LGCs (median = 0.33, std = 0.09).

Remarkably, the ability of the *factors-only share* to explain income differences has been reducing over time (e.g., for the FRCs it goes from 0.39 in 1970 to 0.10 in 2019), thereby indicating that productivity has become increasingly more important over time as the fundamental explanation of differences in income between backward countries and the frontier.

Using Equation (4), Figure 6 panel (c) shows that productivity differences explain between 61% (1970) and 90% (2019) of the differences in income across the FRCs (median = 75%), and they have a relatively larger influence on the CUCs and LGCs differences with respect to FRCs (the LGCs slightly to the right) than the STCs. In particular, in terms of productivity the CUCs, 59%  $< Z_A^{CUCs} < 79\%$  (median = 66%), and the LGCs, 45%  $< Z_A^{LGCs} < 74\%$  (median = 67%) were moving faster in the direction of the frontier than the STCs,  $43\% < Z_A^{STCs} < 73\%$  (median = 64%). Z-test statistics support the null hypothesis that the STCs are significantly behind the FRCs and the CUCs. But not from the LGCs. Also, the CUCs and LGCs are significantly distributed to the left of the FRCs, and the LGCs are significantly to the right of the CUCs.<sup>16</sup>

Summing up, despite overlaps, income differences with the frontier appear dominated by the substantial contribution of productivity differences over the 1970-2019. But still the STCs appear to have been relatively more affected by their failure to accumulate productive factors than the LGCs and the CUCs, which in turn appear to have been mostly affected by productivity weaknesses. The preeminence of productivity is consistent with earlier findings in the development accounting tradition (Caselli, 2005; King & Levine, 1994), the distinct results found for the country classifications above suggest that

- $(\mu, \sigma^2, N)_{FRCs} = (0.76, 0.01, 50)$  and  $(\mu, \sigma^2, N)_{STCs} = (0.64, 0.01, 50)$ Thus,  $(0.76, 0.01, 50)_{FRCs}$ - $(0.64, 0.01, 50)_{STCs} = -6.55$  (P < |z| = 2.92E-11).

<sup>&</sup>lt;sup>16</sup>The Z-mean test is runned for every pair of country classifications, e.g., for the FRCs and STCs, the null hypothesis is.  $Ho: \mu_{FRCs} - \mu_{STCs} = 0$ 

which is distributed at the 99% as follows:

the exclusive focus on productivity is insufficient to gain perspective on the apparently complex interactions that are important to understand the ability of backward countries to catching-up.

#### 7.2. Diffusion or innovation, which matters the most?

Productivity decomposition has become instrumental to break down total factor productivity into *technical changes*-indicating shifts in the technology frontier – and *efficiency changes*-indicating the distance of a particular economy to the frontier (Fare et al., 1994; Farrell, 1957; Kumar & Russell, 2002; Los & Timmer, 2005). Below, this approach is used to identify the influence of technology diffusion and local innovation on the ability of countries to catching-up.

In particular, it seems acceptable to view technology diffusion from abroad as inexorably related to the concept of *"technical change"* which is essentially associated to new inventions/ideas that spread worldwide. In turn, *"efficiency changes"* may be reasonably associated to technology adoption and indigenous innovation to the extent that it reflects the ability to put the received inventions/ideas to commercial purpose through new products and production processes. In fact, a large consensus in growth economics appears to subscribe now to the view that technical changes are exogenously determined by the most productive countries in the world, while "efficiency" depends basically on local efforts (Benhabib et al., 2014; Coe & Helpman, 1995; Gault, 2023; Keller, 2002, 2004; Kumar & Russell, 2002).<sup>17</sup>

From a methodological point of view, *"technical changes"* are calculated with reference to countries able to produce more output out of a given set of inputs. One shortcoming of this approach is that resource abundant economies or countries enjoying some sort of advantage of backwardness may become part of the frontier even if they are not regarded the actual technology leaders. As there is no obvious solution to this problem in the literature, results referring to the *"technical change"* should be taken with caution to the extent that they do not necessarily take the FRCs as the benchmark.<sup>18</sup>

Let the non-parametric Farrell (output based) efficiency problem for country *i* at time *t* be defined in the following way

$$E(\tilde{y}_i, k_i, h_i) = max\{\theta | (\theta \tilde{y}_i, k_i, h_i) \in \tau_{CRS}\}$$

Where  $\tilde{y}, \tilde{k}, \tilde{h}$  are the measures of relative income and production factors defined in Equation (3),  $1 \le \theta < \infty$  is an expansion factor and  $\theta - 1$  represents the maximal increase in output that is feasible given the actual amounts of factor inputs and technology  $\tau$  in the reference period.

The Farrell efficiency index is the result of solving the following linear program for each country i

$$\underset{\theta,\lambda}{Max} \quad \theta: \{ (\theta \tilde{y}_i, \tilde{x}_i) \in \tau \}, \ \tilde{x}_i = (\tilde{k}_i, \tilde{h}_i)$$

<sup>&</sup>lt;sup>17</sup>Fare et al. (1994) associate *changes in efficiency* to *catching-up* and *technical changes* to *innovation* instead. The different use of the terms is because they think of "innovation" as technology produced at the frontier, and "catching-up" as local efforts to reach the frontier.

<sup>&</sup>lt;sup>18</sup>I have forced the model to use only FRCs as the benchmark. But this approach leads to minor variation in the results.

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s.t. 
$$\theta \tilde{y}_i \leq \sum_i \lambda_i \tilde{y}_i; \quad \tilde{x}_i \geq \sum_i \lambda_i \tilde{x}_i; \quad \theta, \lambda_i \geq 0; \quad i = 1, 2, \dots N$$

Note that  $0 \le 1/\theta \le 1$  represents the *technical efficiency score* of this problem.  $\theta = 1$  implies that the country is part of the technological frontier under a constant returns to scale level of operation. The Variable Returns to Scale (VRS) technology requires the additional restriction  $\sum_i \lambda_i \le 1$ . The ratio between the CRS and the VRS score reflects scale efficiency (Coelli et al., 2005).

$$SE = \frac{\tau_{CRS}}{\tau_{VRS}}$$

Where

$$\tau_X = (\tilde{y}_i, \tilde{x}_i) \in \mathcal{R}^3_+ | \ \tilde{y}_i \le \sum_i \lambda_i \tilde{y}_i, \tilde{x}_i \ge \sum_i \lambda_i \tilde{x}_i, \ \lambda_i^X \ge 0$$

for X=(CRS, VRS).

By construction, the CRS efficiency index may be obtained by multiplying scale efficiency and the VRS efficiency index,

$$au_{CRS} = SE imes au_{VRS}$$

In multi-time periods efficiency measures may be obtained using the Malmquist index approach using chained indices based on the linear program introduced above. In this case, a decomposition is possible of TFP into technical changes, scale efficiency changes, and *local innovation* changes (Coelli et al., 2005; Malmquist, 1953).<sup>19</sup>

Figure 7 illustrates this approach in the two-dimensional space for one output (Y) and one input (X) over two periods – X(0) and X(1). This seems adequate to illustrate the differences between VRS and CRS.

Under VRS, the technical change component – shifts in the frontier associated to technology diffusion/adoption – is measured by the ratio Yf/Yd when the technology is X (1), and the ratio Yc/Yb when the technology is X(0). The Malmquist index approach is based on the geometric mean of these two measures

$$\Delta tech | VRS = \left(\frac{Yf}{Yd} \times \frac{Yc}{Yb}\right)^{1/2}$$

Under CRS the index is

$$\Delta tech | CRS = \left(\frac{Yf'}{Yd'} \times \frac{Yc'}{Yb'}\right)^{1/2}$$

Likewise, the scale efficiency change – the distance between the CRS and VRS frontiers – is measured by the ratio  $Yd'/Yd \times Yf'/Yf$  when the technology is X(1), and  $Yb'/Yb \times Yc'/Yc$  when the technology is X(0). The geometric mean of these quantities is

<sup>&</sup>lt;sup>19</sup>In this case, the linear program must be calculated for each country and time period, e.g., if there are N countries and T time periods a total of  $N \times (3T-2)$  programs need to be calculated.



Figure 7. Productivity decomposition.

$$\Delta seff = \frac{\Delta tech | CRS}{\Delta tech | VRS} = \left(\frac{Yf'/Yc'}{Yf/Yc} \times \frac{Yd'/Yb'}{Yd/Yb}\right)^{1/2} \begin{pmatrix} = 1, & CRS \\ < 1, & IRS, DRS \end{pmatrix}$$
(5)

where Yf/Yc and Yd/Yb capture de productivity effect of factor increases (therefore the adoption of new technology) between X(0) and X(1) along the VRS-based frontier and Yf'/Yc' and Yd'/Yb' do it along the CRS-based frontier.

Notice that when  $\Delta tech|VRS = \Delta tech|CRS$  production takes place at the *technically* optimal productive scale under a CRS technology, therefore, the scale efficiency is equal to unity. Otherwise, the economy exhibits scale inefficiencies due to increasing or decreasing returns to scale.

Lastly, the distance of the economy to the VRS-based frontier is measured by the ratio  $\frac{Ye/Yf}{Ya/Yb}$ . This captures the ability of the economy to short the distance to the frontier after accounting for technical changes (shifts in the frontier) and scale (in)efficiencies. Thus, it is a measure of *local innovative efficiency*,

$$\Delta inneff = \frac{Ye/Yf}{Ya/Yb}$$

Total factor productivity changes are obtained by multiplying the above three components:

$$\Delta tfp = \Delta tech \times \Delta seff \times \Delta inneff$$

For comparison purposes, following Inklaar and Timmer (2013), a conventional growth accounting parametric estimate of TFP is based on the following representation.

$$ctfp_i = \tilde{A}_i = \tilde{y}_i/\tilde{q}_i$$

where  $A, \tilde{y}, \tilde{q}$  are defined in Equation (3), and the relevant capital share is assumed to be country and time invariant ( $\alpha = 1/3$ ).<sup>20</sup>

<sup>&</sup>lt;sup>20</sup>In spite that PWT V.10 report statistics for *ctfp* using USA as the benchmark and country specific factor shares, I rely on the average across FRCs as the benchmark and constant factor shares.

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|       | Whole sample    |        |            |       |               |                            | Adjusted sample |       |       |              |
|-------|-----------------|--------|------------|-------|---------------|----------------------------|-----------------|-------|-------|--------------|
|       | (110 countries) |        |            |       |               |                            | (59 countries)  |       |       |              |
|       | $\Delta tech^*$ | ∆ineff | ∆seff      | ∆tfp  | <b>∆</b> ctfp | $\overline{\Delta tech}^*$ | ∆inff           | ∆seff | Δtfp  | <u>∆ctfp</u> |
| FRCs  |                 | 2      | 4 countrie | s     |               | 20 cou                     | Intries         |       |       |              |
| 1970s | -8.48           | -1.14  | 9.69       | -0.83 | -0.38         | 2.11                       | -0.92           | -1.28 | -0.14 | -0.04        |
| 1980s | -8.66           | 4.35   | 4.60       | -0.38 | -0.16         | -4.73                      | 2.57            | 2.12  | -0.24 | -0.11        |
| 1990s | -1.17           | 1.31   | 0.42       | 0.53  | 0.37          | 0.66                       | 0.11            | -0.22 | 0.53  | 0.41         |
| 2000s | -0.42           | -1.95  | 2.06       | -0.39 | 0.01          | 0.31                       | -0.43           | 0.17  | 0.05  | 0.13         |
| 2010s | -4.08           | 1.39   | 2.78       | -0.08 | -0.01         | 1.02                       | -1.14           | 0.09  | -0.04 | -0.17        |
| Mean  | -4.56           | 0.79   | 3.91       | -0.23 | -0.03         | -0.12                      | 0.04            | 0.18  | 0.03  | 0.04         |
| CUCs  | 21 countries    |        |            |       | 11 countries  |                            |                 |       |       |              |
| 1970s | -6.89           | 4.01   | 4.09       | 0.68  | 1.33          | -0.88                      | 0.84            | 0.71  | 0.62  | 1.04         |
| 1980s | -3.73           | 2.24   | 0.41       | -1.25 | -0.54         | -0.37                      | 0.31            | -1.48 | -1.54 | -0.97        |
| 1990s | -0.67           | -0.17  | -0.24      | -1.07 | -0.16         | -3.43                      | 0.07            | 1.77  | -1.71 | -0.70        |
| 2000s | -0.66           | -1.12  | 1.00       | -0.82 | 0.85          | -1.75                      | 0.61            | 0.99  | -0.16 | 1.13         |
| 2010s | -3.42           | 1.10   | 2.24       | -0.23 | 0.35          | 0.85                       | 0.14            | -0.48 | 0.50  | 0.79         |
| Mean  | -3.07           | 1.21   | 1.50       | -0.54 | 0.37          | -1.11                      | 0.39            | 0.30  | -0.46 | 0.26         |
| STCs  | 25 countries    |        |            |       | 12 countries  |                            |                 |       |       |              |
| 1970s | -7.36           | 2.12   | 3.73       | -2.02 | -1.81         | -0.77                      | -1.28           | 0.54  | -1.52 | -1.77        |
| 1980s | -4.61           | 1.85   | -0.10      | -2.98 | -3.00         | -0.48                      | 0.41            | -0.93 | -1.04 | -0.88        |
| 1990s | -0.57           | -0.24  | -0.21      | -1.06 | -1.10         | -4.20                      | 0.92            | 1.17  | -2.20 | -2.31        |
| 2000s | -0.46           | -0.23  | 0.40       | -0.26 | 1.10          | -1.71                      | 1.38            | 0.33  | -0.04 | 0.97         |
| 2010s | -2.76           | 1.70   | 0.48       | -0.64 | -0.38         | 0.71                       | 0.10            | -0.36 | 0.44  | 1.00         |
| Mean  | -3.15           | 1.04   | 0.86       | -1.39 | -1.04         | -1.29                      | 0.31            | 0.15  | -0.87 | -0.60        |
| LGCs  | 40 countries    |        |            |       | 16 countries  |                            |                 |       |       |              |
| 1970s | -6.96           | 2.64   | 3.25       | -1.53 | -1.82         | 0.14                       | -1.03           | -0.33 | -1.20 | -1.53        |
| 1980s | -3.50           | 0.66   | 0.25       | -2.66 | -2.64         | -1.49                      | -0.36           | -0.78 | -2.64 | -2.32        |
| 1990s | -1.27           | -1.19  | -0.25      | -2.71 | -3.03         | -4.12                      | 1.22            | 1.02  | -2.01 | -1.99        |
| 2000s | -0.25           | 0.11   | -0.02      | -0.15 | 0.55          | -1.59                      | 0.55            | 0.24  | -0.85 | -0.30        |
| 2010s | -1.56           | 1.36   | 0.48       | 0.27  | -0.58         | 0.65                       | 0.81            | -0.86 | 0.59  | -0.22        |
| Mean  | -2.71           | 0.72   | 0.74       | -1.36 | -1.50         | -1.28                      | 0.24            | -0.14 | -1.22 | -1.27        |

**Table 2.** Decade-averages of cross-country TFP changes and their components (for the FRCs (1970s):  $\overline{\Delta tfp} = (1 - 0.0848) \times (1 - 0.0114) \times (1 + 0.0969) = (0.992 - 1))$ . Results obtained from the software DEAP (Coelli et al., 2005.).

\* Technical change wrt VRS technology:  $\Delta tech | VRS$ .

Table 2 shows decade-averages of the parametric and non-parametric measures of productivity and relevant decompositions. The estimates are based on yearly calculations of the linear program for the sample of 110 countries with complete information over 1970–2019 (left panel), and the sample of 59 countries after exclusion of extreme country cases and the 10th-90th percentiles adjustment of the FRCs (right panel).

Obviously, the non-parametric ( $\Delta tfp$ ) and conventional ( $\Delta ctfp$ ) estimates of productivity are different in magnitude. However, despite the methodological differences, these measures display roughly procyclical patterns which support the relevance of the non-parametric approach to capture the essencial features of productivity for the sample of countries in this research. The Pearson's correlation coefficient between both productivity approaches is quite high in all cases (generally over 0.9). Particularly, after excluding extreme country cases. The exception is the CUCs when the whole sample is used (correlation coefficient of 0.83).

There are three issues worth highlighting from the results in Table 2

(1) The CUCs are the only countries that appear to have been unaffected by the widespread productivity slowdown of the 1970s, and appear to have been more

successful to cope with the decline that followed through the 1980s and 1990s which, on the contrary, was particularly severe for STCs and LGCs. As a result, despite some underperformance in later decades, the CUCs exhibit more favourable productivity records than the STCs and LGCs when the focus is on the overall mean of the nonparametric measure of productivity,  $\overline{\Delta tfp}$  (-0.54 on the left and -0.46 on the right panel).<sup>21</sup>

- (2) The CUC's success is explained by a stronger combination of innovation and scale efficiency compared to other backward countries. This group exhibits the highest *∆ineff* overall mean rates even after the exclusion of extreme country cases (1.21 on the left and 0.39 on the right hand panel), and also the highest rates of *∆seff* (only surpassed by the FRCs in the panel on the left).
- (3) With focus on the overall mean, technical change ( $\Delta tech|VRS$ ) was decreasing in general for all groups of countries and in both panels. However, by excluding extreme country cases, the superior performance of the FRCs seems apparent in all decades but the 1980s. This seems consistent with well-established stylized facts according to which the pattern of worldwide technical change is led by a few countries at the frontier which account for most of the international creation of new technology (Keller, 2002, 2004).

It seems evident, from the above analysis, that the average growth of productivity across the four-types of countries does not support the expectations of "*unconditional convergence*" discussed earlier in this paper. The evidence in the table seems more accurately described as complex fluctuations around long-run trends that are clearly determined and consistent with the patterns of catching-up, stagnation and laggardness defined above and well supported by empirical evidence emerging from cross country comparisons. In particular, the good performance of the CUCs relative to the FRCs is in sharp contrast with the poor performance of the STCs and LGCs, and the latter's is much more dissapointing despite the evident improvement in the 2010s.

Notice also, from the results in the table, that substantial productivity benefits (from the  $\Delta tfp$  perspective) accrue through the effective combination of innovation efficiency ( $\Delta ineff$ ) and scale efficiency ( $\Delta seff$ ). In fact, leaving aside the negative contribution of technical change, it seems apparent that productivity differences between the CUCs and other country groups, including the FRCs, are well explained by differences in the magnitude and correspondence between changes in innovation and scale efficiency.

Firstly, as mentioned before, the high rate of innovation combined with increasing scale efficiency shows up as the most salient fact in the CUCs performance whether one focus on the more heterogeneous group of countries in the left hand panel or the more stable middle-income economies in the right hand panel. Secondly, in contrast with the CUCs and FRCs, the STCs and LGCs major weaknesses are associated with a much lower increase in both components, and even a decline in scale efficiency (in the case of the LGCs). These two aspects are very important to understand the convergence probabilities of these countries in the distant future.

<sup>&</sup>lt;sup>21</sup>Notice that when the focus is on the overall mean of the conventional measure of productivity, Δ*ctfp*, the CUCs are even more successful than the FRCs.

Remarkably, over the 2010s, the LGCs appear to perform so much better than any other group in productivity, and this can be explained by a large increase in innovation efficiency whether one focus on the right of the left hand side panel. This behavior is consistent with the distribution of the LGCs to the right of other groups but the FRCs in Figure 6 panel (c), and provides support to the convergence optimism of some researchers as was discussed in a previous section. But, clearly, it seems too early to derive the likely implications of this performance over the longrun.

Summing up, the productivity outcomes discussed above give support to the fourtypes of countries classification introduced in this paper, and provide suggestive evidence that catching-up hinges critically on the factors determining local innovation along the diffusion/adoption of technology from abroad.

#### 8. Concluding remarks

I have tried to build a picture of the world economy upon the observation that, contrary to the optimistic claim in recent research that foresees a path of unconditional convergence, over long periods of time only a few countries have been successfully catching-up, whereas many other remain stagnant or keep lagging behind. Catching-up is a dynamic phenomenon that hinges upon the performance of both backward and leading countries. Thus, relative levels of income and adjusted growth rates are needed to say something about the speed and progress of the convergence process.

Using that approach, I have shown above that countries that exhibit consistent patterns of catching-up are at a distance of at least 27 years to reach the frontier in the most optimistic scenario. But they are to as much as 194 years if the frontier keeps growing at the historical pace. In turn, STCs countries are between 69 and more than two thousand years (India 2242 years) and LGCs between 483 but only when countries with negative growth rates are excluded.

Productivity decompositions provide another piece of suggesting evidence supporting the view that successful catching-up accrues through the effective combination of domestic innovation efficiency alongside the adoption of technology from abroad. This outcome is consistent with conclusions from recent research on the complex feedback effects that exist between technology diffusion/adoption and indigenous innovation in recipient countries. The policy implications for the design and implementation of macroeconomic policy highlight the importance of innovation incentives as the driving force of economic growth and catching-up (Malerba & Lee, 2020; Nelson & Pack, 1999; Perilla, 2019, 2020).

A worthwhile avenue for future research under this framework would be to investigate the fundamental determinants and cross-country differences in the approach to innovation policy, and the likely macroeconomic and environmental implications of getting all countries in the four-types framework to reach the income standards of the countries at the frontier.

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