Income per-capita across-countries

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Income per-capita across-countries: Stories of Catching-up, Stagnation, and Laggardness.

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September 13, 2022

Abstract

A sample of 131 countries is classified into those at the frontier (24 OECD countries), and those that over the 1950-2019 period managed to catching-up, remained stagnant, or kept lagging further behind. Time-distance to the frontier suggests that successful catching-up has been already completed by some countries. But it would take no less than 27 years and as much as 194 years in the most optimistic scenario for other countries. The comparative analysis reveals patterns of (unconditional) convergence, secular stagnation and divergence characterized by differences in the approach to local innovation and technology diffusion from abroad, jointly with the ability to take advantage of economies of scale.

Key words: *Economic development and growth, technology change. (JEL: 011, 047, 057)*

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 (Malerba & Lee 2020, Spence 2011, Lucas 2000, Pomeranz 2000, Pritchett 1997, Abramovitz 1986, Baumol 1986).[1]

Below, I attempt to provide and answer to that question. In order to contribute to the debate whether income convergence across the world economy will be reached by the end of the 21st century or not (Pritchett 1997, Lucas 2000, Spence 2011, Rodrick 2011), and hopefully offer new research perspectives in this field, I divise a method to split the world economies into successful and unsuccessful cases of growth and catching up.

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[1] The origin of this discussion goes further back to the Hume-Tucker debate on convergence (Hume 1742) and divergence (Tucker 1776).

In particular, using data from the Penn World Tables (PWT V.10.0)[2] (Feenstra, Inklaar & Timmer 2015) 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.[3] The classification is based on records of income per capita relative to the frontier over 1950-2019. Adjusted growth gaps, which are needed to support the main argument, are calculated by subtracting the growth rate of the countries at the frontier from the growth rate of other countries.

To provide a feasible explanation of the key determinants of catching-up, stagnation and laggardness, a productivity decomposition, based on non parametric techniques is used. This is aimed to factor productivity changes that are related to pure efficiency (local innovation), economies of scale and shifts of the technology frontier. Economies of scale relate to variations in productive factors that might (or not) lead to increase output per worker. Technical change captures the impact of best practice technologies worldwide (Kumar & Russell 2002, Coelli et al., 2005, Los & Timmer 2005). Both of the latter components are assumed to capture the impact of technology diffusion and technology adoption.

A remarkable result from this analysis is that even among the select group of succesful catching-up countries, convergence would take not less than three decades, but as much as 200 years. In turn, countries that are secularly stagnat 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 least than 500 years in the best case. The main determinant of this results attributed to local effort, e.g., after factoring by the impact of best productive practices and scale economies.

This paper continues as follows: in Section 2, the proposed four-types of countries classification is explained along the review of the relevant literature. In Section 3, the growth gaps of countries behind the frontier is analyzed. In Section 4, a procedure to calculate the years needed to catching-up, based on each country historical performance, is developed. In Section 5, an unconditional β-convergence analysis is conducted and related to the *convergence clubs* debate. In Section 6, the country classification is used to study the relative importance of local innovation and technology diffusion/adoption for their catching-up performance. Section 7, provides some concluding remarks.

2 Backward countries' relative levels of income

As it is well known, there are wide disparities in levels of income per capita across countries. The World Bank four-tier classification between Low Income (LICs), Lower Middle Income (LMICs), Upper Middle Income (UMICs) and High Income Countries (HICs), is a well established standard for the interested researcher to gain quick knowledge on this diversity. Unfortunately, this ranking does not allow, *per se*, to judge the ability–and indeed the probability–of

[2]Available from https://www.rug.nl/ggdc/productivity/pwt

[3]See Teuling & Baldwin 2014 on the issue of secular stagnation.

countries behind to shortening the distance to the frontier.

This probability depends positively on the economic performance of countries behind. However, considering the theoretical debate and empirical evidence (Rodrik 2011, Spence 2011, Lucas 2000, Pritchett 1997), it may be positively or inversely related to the economic performance of the leading countries by diverse reasons that shall be discused shortly.

A focus on relative levels of income leads to an alternative classification, and also a different analytical approach that may prove useful to study the world economy. Note, for instance, by 1997, the time India graduated to the LMICs, it had roughly the same income (PPP-adjusted) than in 1975 (8% relative to the richest OECD countries) which was lower than in previous decades (10% on average over 1950-1970). And over 2010-2019 India had more or less the same relative income to the richest OECDs than during the 1950s.

The Indian performance is contrasting with the experience of Egypt which is also classified among LMICs. This country was roughly stagnant and below the performance of India over 1950-1980 (relative income of 7%). However, the Egyptian economy started to grow and reached a relative income of 16% at the end of the 1990s, and around 25% during the 2010s. The contrary happened to Guinea, a country classified among the LICs which had a relative income averaging 20% over the 1960s-1970s, but fell down steadily to around 10% through the following two decades, and currently is below 5%.

Summing up, economic growth and income trajectories show high dynamism and varying tendencies across countries. Some low income countries have grown richer and show a path to catching-up. While there are other that remain stagnant or even falling farther apart.

To make sense of this diversity, the alternative classification proposed here takes a sample of 131 countries from the PWT V10.[4] The classification is based on 10-year averages of income per capita.[5] The benchmark is made of 24 high-income countries that became members of the OECD before 1990. These are referred now on as frontier countries (FRCs). Based on data coverage, the remaining countries are classified into three clusters: i) a cluster of 35 countries with data coverage for seven decades over 1950s (1950-1959) and 2010s (2010-2019); ii) a cluster of 49 countries with data for six decades over 1960s-2010s; and iii) a cluster of 23 countries with data for five decades over 1970s-2010s.

Cross country comparisons are based on relative income per capita: the ratio between a country's decade average and the average at the frontier. Notice, for instance, that through the 1950s average income per capita was US$3732 in Colombia, US$1208 in South Korea, and US$9843 across the FRCs. Seven decades later, the figures were US$13542, US$38052, and US$48385, respectively. Relative to the FRCs, through the 1950s the Colombian income per capita (38%) was more than three time that of Korea (12%). Through the 2010s, seven decades later, relative income increased to around 80% for Korea,

[4]I use 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.

[5]Ten-year averages are calculated as long as there is data for at least 8 years.

whereas it decreased below 30% for Colombia.

Figure 1 plots relative income for all countries in the sample. 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 diagonal on either side reveal minor progress or even a slight decline in their relative income. For instance, Suriname is located exactly over the diagonal which means that over the 1970s and 2010s it barely improved its position, while for Taiwan the relative income in the 2010s is much larger than in the 1950s, and for Venezuela the relative income in the 2010s is lower than in the 1950s. For the comparison, frontier countries are plotted at the highermost of the diagonal.

The measures of relative income allows for further comparison. For instance, Suriname shows a slight decrease from 30.7% during the 1970s to 30.2% during the 2010s. By taking the ratio between the latter and the former figures it seems evident 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 pattern is observed for Paraguay (1.0), Dominican Republic (1.2), India (1.1), Chile (0.95), Peru (0.92) and Morocco (1.1). The secular stagnation of these countries is in contrast with the evident ability 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 it is in contrast also with the poor performance of countries that kept even falling farther apart: Mexico (0.65), Colombia (0.74), Congo (0.07).

The proposed classification of these variety of cross country experiencies considers an ad-hoc 0.75–1.25 threshold. Countries for which the ratio of income per capita between the last and first decade rises or falls by less than a quarter are classified as stagnant (STCs); countries that are above the upper-point of the threshold are classified as catching-up (CUCs); and countries that are below the lower-point 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. [6]

Clearly, this highly ad-hoc classification may be subject to critic. After all, any wider or tighter threshold may serve the purpose. A country exhibiting an income ratio barely over 1 (like India or Morocco) may, potentially, be able to catching-up at some point in the future. And countries barely below 1 (like Chile or Peru) get away of the frontier even if not as fast as countries that are under the 0.75 threshold. On the other side, a ratio accounting only by changes between the last and first decade may be too restrictive. Many economic shocks may push the economy over or below the threshold between these extremes.

To address these concerns, an additional criterion that seems appropriate is based on growth rates. My focus is on long-run growth trajectories. Unlike short-run events, long-run trends reflect the outcome of policy strategies that are unmistakably able (or unable) to produce sustainable rates of economic growth. Clearly, only countries that exhibit positive growth rates over the long-run should be able to catch-up. In the following section, I show that, factoring

[6] See the Appendix.

by growth rates at the frontier, the STCs in the above classification have long-run average growth rates that are essentially cero, while the CUCs have positive rates and the LGCs show negative rates.

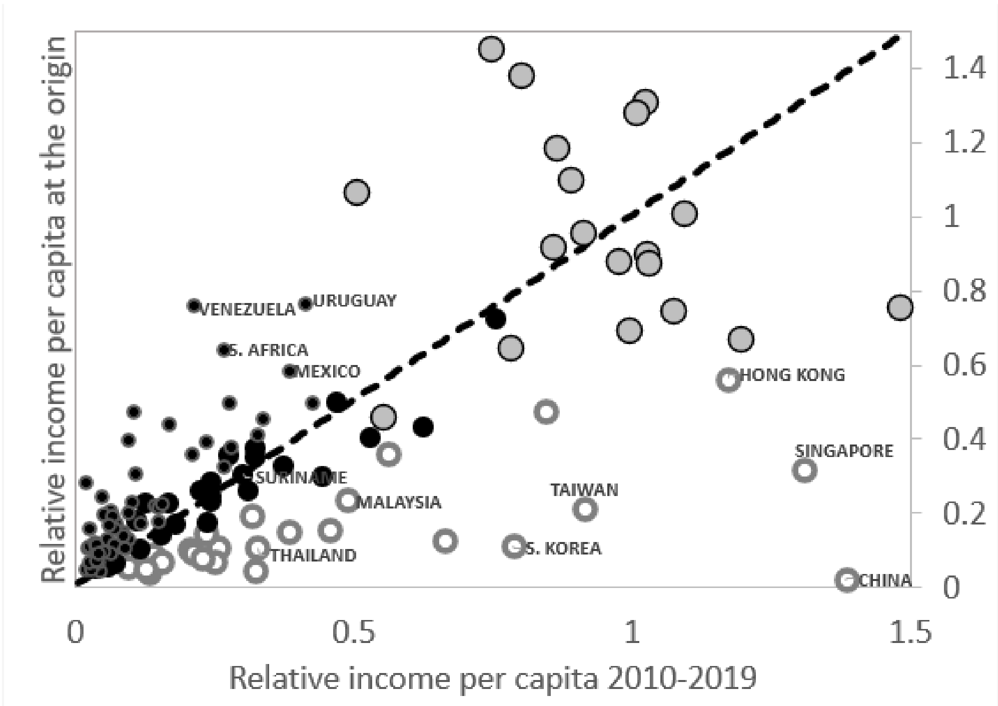


Figure 1: Relative levels of income per capita. The big grey circles are FRCs, the big white ones are the CUCs, the big black ones are the STCs and the small ones are the LGCs. Countries below the 45-degree line are better off in the last decade. The position of every country indicates their catching 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%.

Figure 2 show lon-run trends that fit the proposed four-types of countries classification. In panel (a), there are increasing trends that reflect the catching-up property of the CUCs clusters over the 1950s–2010s, the 1960s–2010s, and the 1970s–2010s. Likewise, in panel (b), the relative stagnation attributed to the STCs is observed. And in panel (c), the decline is consistent with the tendency of the LGCs of getting farther away from the frontier.

Using the coefficient of variation (CV) to measure dispersion within each classification 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 within dispersion increased steadily from 0.27 to 0.42 in the 1990s and remained so with slight variations till 2010s.[7]

[7] Calculations are available from the author.

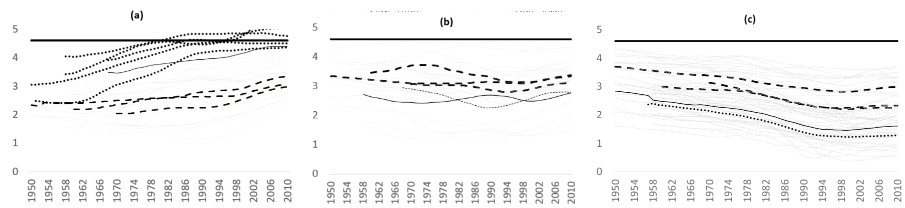


Figure 2: Relative levels of income per capita of CUCs (a), STCs (b), and LGCs (c). The upper solid-line is the frontier. The three thick dashed lines below the frontier are decade averages of relative income for clusters of countries over 1950s–2010s, 1960s–2010s, and 1970s–2010s. The thin dotted lines 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.

Not surprisingly, in the proposed classification one see that 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. Notice that in Figure 2 these specific country cases are depicted apart.

Clearly, among too heterogeneous economies, it is difficult to provide a unique explanation for the success or failure to catching-up. Growth literature contains much discussion about the causes of long-run growth that might be positively related to countries in the proposed classification although not without controversy. For instance, cross-country research that emphasizes the virtues of *accumulation* (Young 1995, Makiw et al., 1995) face the critic from innovation researchers (Nelson & Pack 1999) and economist that give preeminence to *ideas* over *objects* (Romer 1993). Researchers akin to the role of institutions (North 1990) deal with those that give preeminence to trade integration (Sach & Warner 1995), and the role of geography (Baldwin et al., 2001). And some researchers give more credence than others to the role of developmental government intervention (Wade 1996, Lin & Monga 2011).

Some of the above debates are ideological and other are a subject of empirical research. Not surprisingly, the data shows that the CUCs, the STCs and LGCs, includes countries with pretty high and very low records for any given standard. Among the CUCs, for instance, one finds countries ranking high in trade openess (Hong Kong, Singapore) and countries ranking relatively low (Brazil, Indonesia); countries ranking well in the role of institutions and governance (South Korea) and countries ranking poorly (Egypt); and some countries that are catching-up are landlocked (Botswana, Bhutan) while others are not (Singapore, Hong-Kong).

The proposed four-types of countries classification is not deemed to provide any answer to the above mentioned debates. However, I argue that such classification may contribute to the convergence / divergence debate famously represented by Baumol 1986, Lucas 2000 and Pritchett 1997, among many others. Specifically, I suggest that the long-run declining trends in income gaps and within convergence shown by the CUCs, the relative stagnation shown by the STCs, and the evident dispersion across the LGCs which also keep getting apart of the frontier seems to supports the idea of *convergence clubs* in earlier literature (Baumol 1986). This is in contrast to the prediction of 21st end of century convergence across the world economy suggested by Lucas 2000, or the view that convergence is registered only for the most advanced countries in the world economy, as suggested by Pritchett 1997.

In line with this debate, below I suggest that a fundamental difference in the ability to catching-up among countries behind the frontier seems to be characterized more by local innovation efficiency along the diffusion / adoption of technology from abroad.

3 Growth gaps

As mentioned in the last section, Catching-up requires of backward countries to grow permanently faster than those at the frontier. Thus, predicting the potential to catching-up amounts to calculate the percentage points (pp) of the difference between these two growth rates. The smaller the gap, the larger the time needed to catching-up. For instance, a positive gap of 1 pp for a country that has a relative income which is half of the income at the frontier, indicates that catch-up will take a period of 70 years; with a gap of 0.5 pp it will take 140 years; and with a gap of 0.1 pp 700 years. Obviously, a country with a negative growth gap will not be able to catching-up at all.

To calculate growth gaps yearly growth rates and decade averages are calculated for every country and the frontier's average is subtracted from every other country. Growth gaps are aggregated over relevant country classifications and time clusters: FRCs, CUCs, STCs LGCs, Nics, HInonOECDs, LICs, and Fragile countries over 1950s-2010s, 1960s-2010s, 1970s-2010s. A plot of the outcomes is presented in Figure 3. The Nics and HInonOECDs are plotted apart, and LICs and Fragile countries are excluded. Thus, time clusters focus on the performance of middle income countries (Lower and Upper Middle Income Countries). This has the advantage of relying in the analysis of rather stable economies.[8]

Notice that in panel (a), growth rates for the CUCs generally exceeds the average at the frontier which is consistent with the fact that these countries have grown permanently faster than countries at the frontier. This outcome holds for the countries in every time cluster, as well as the Asian Nics and other HInonOECDs.

In panel (b), growth rates for the STCs fluctuate around the zero-cutoff, reflecting the fact that these countries exhibit sequencial periods of rapid and slow or even negative growth. In panel (c), growth rates for the LGCs are generally below the zero-cutoff, consistent with the failure of these countries to keep growth at all.

[8]A full analysis is available from the author.

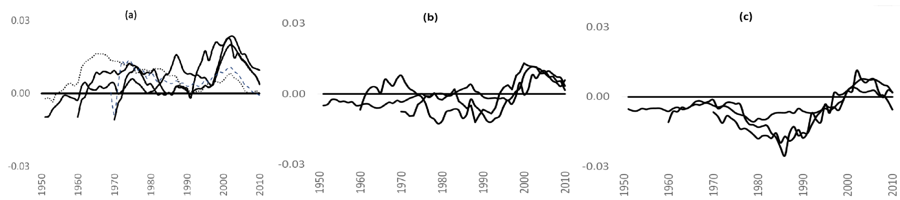


Figure 3: Growth gaps CUCs (a), STCs (b) and LGCs (c). The zero line is the frontier. The other three thick lines represent the average of countries over time clusters 1950s-2010s, 1960s-2010s and 1970s-2010s. Thin dotted and dashed lines in (a) are the average of the Nics and HInonOECDs. LICs and fragile states have been excluded.

Note that, even along similar cycles of growth in the world economy, there are clear differences in the patterns followed by the four-types of countries that are examined. For instance, there was more rapid growth in the CUCs than in any other group over 1950s-1960s–a period termed the *Golden Age* in which advanced countries experienced unparalleled rapid rates of growth (Snowdon & Vane 2005). And there was a much stronger deceleration in the LGCs over the 1970s-1980s–a period when growth decelerated worldwide due to various well known events which are not in the focus to be examined here (stagflation, persistent unemployment, debt crisis). Since then, growth accelerated again everywhere, though more rapidly in the CUCs. Finally, the expansion over 1990s-2000s that led to the crisis at the end of the latter decade affected all countries. But it was particularly adverse to LGCs.

To sum up, complementing the analysis focused on relative income using adjusted growth rates leads to a systematic analysis on the ability of countries to catching-up. While the ad-hoc 0.75–1.25 may be open to critic, the adjusted growth rates suggests that catching-up, stagnation and laggardness stems on the ability (or failure) of countries to generate positive growth rates permanently (factoring by the performance at the frontier). Under this condition, the data shows that the 0.75-1.25 threshold is equivalent to a +/- 1% rate of adjusted growth. More specifically, while the long-run adjusted growth rate of STCs is, on average, cero, it is over 1% for the CUCs and -1% for the LGCs. Stagnant countries close to the lower bound would need 50 years to get to the upper bound if they grow at the 1% adjusted growth rate.

4 Distance to the frontier

Time-distance to the frontier relates to both, relative income and *growth gaps*. A country with relative income of 10% and a growth gap of +1 pp would reach the frontier in 233 years. With the same 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.

More in general, for a given country i with average income (per-capita) Y_i which grows steadily at the rate g_i, the time needed to catching-up with the frontier's income Y_F which grows at the rate g_F, is given by the solution to the following problem

$$Y_i * e^{g_i N} = Y_F * e^{g_F N}$$

Taking natural logs on both sides and solving for N, the time needed to catching-up, the following conditions are obtained

$$N = -LN(Y_{i/F}) * (g_i - g_F)^{-1} | \ g_F < g_i \quad (1)$$
$$N = \infty \quad | \ g_F \geq g_i \quad (2)$$

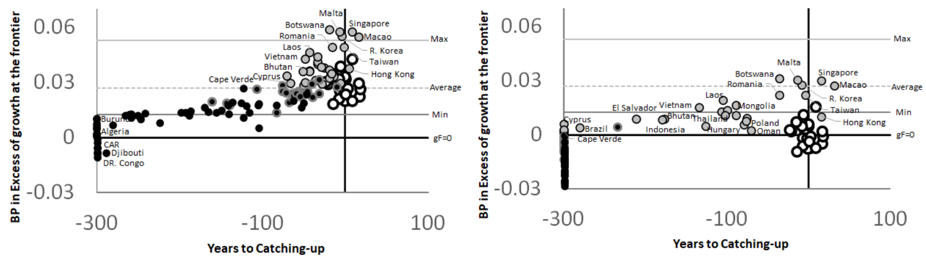
where $Y_{i/F}$ is relative income and $g_i - g_F$ is the growth gap. Eq. (1) indicates the time to catching-up when the growth gap is positive. Eq. (2) implies that no catching-up is possible when the growth rate is equal or less than the frontier's. Note that g_F=0% implies that the frontier is a fixed target. But, given g_i, distance to the frontier is inversely related to the growth rate at the frontier.

Figure 4 plots this relationship for the 131 countries in the sample taking the average of relative income over 2010s and the whole time average of growth rates for every country. Panel (a) plots a *fixed target* scenario, growth gaps (BP in excess of growth at the frontier) are obtained assuming g_F=0%. Panel (b) plots the *actual target* scenario, the gaps are obtained using g_F=2.74%–the whole time average across frontier countries.

The *fixed target* scenario shows the FRCs (white balls) grouped around the *average* (2.74%) and zero years to catching-up. All countries belonging to the CUCs (grey balls) and the STCs (grey bordered black balls) are found over the zero-pp line, which implies that they have catching-up probabilities. Many of the LGCs (black balls) fail to do so.

More specifically, in the *fixed target* scenario the CUCs growth gaps (4.03% on average) are generally over the average or even the maximum at the frontier. The STCs growth gaps (2.35% on average), by contrast, are slightly below the frontier's average, and the LGCs growth gaps (0.84% on average) are close to the minimum at the frontier or even below it. Some countries in the latter group (Burundi and Algeria among other) would need more that 300 years to catching-up and other (Central African Republic, Djibouti, and Congo, among other) will not be able to catching-up at all (having average growth rates below zero even without the proposed adjustment). Notice that, as a rule of thumb, countries that are far beyond 300 years to catching-up are plotted at -300 (meaning that they are currently at the starting gate of modern economic growth initiated with the onset of the *industrial revolution*–see Lucas 2000).

Time-distance to the frontier under the *fixed target* scenario suggests that the CUCs would need on average 27 years to catching-up (CV of 0.8). 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 (CV=0.5), and the LGCs–without negative growth cases–483 years (CV=2)



(a) Fixed target scenario

(b) Average growth scenario

Figure 4: Time-distance to catching-up. FRCs (white), CUCs (grey), STCs (black bordered grey) and LGCs (black). Panel (a) assumes g_F=0%. Panel (b) uses g_F=2.74%, the average across frontier countries. Other horizontal lines depict the maximun and minimun growth in countries at the frontier.

As would be expected, the *actual target* scenario plotted in panel (b) shows the FRCs grouped around the zero pp line. In contrast with the more optimistic probabilities in panel (a) only the CUCs show positive growth gaps, although many countries are now below the mimimun at the frontier. In turn, only three STCs (Bulgaria, Dominican Republic and India), and no LGCs, show catching-up probabilities.

In the new scenario, the CUCs are, on average, at a distance of 194 years to the frontier and the disperion is higher (CV=1.5). This is explained because although there are still countries that fulfill the process, there are others falling now farther appart of the limit of 300 years: Albania (1374 years), Cape Verde (831), Tunisia (522), Argentine (470), and Myanmar (380). Among the few STCs exhibiting positive growth gaps Bulgaria shows the smallest distance to the frontier (234 years), while Dominican Republic (619) and India (2242) are far apart.

Clearly, the probability to catching-up depends on the level of income per-capita to be considered a fair measure of richness. The calculations in Figure 4 are based on 2010s measures of relative income. Over this decade the average income at the frontier is US$48385 (PPP adjusted real GDP at 2017US$). If one considers instead the minimum income and the lowest growth rate across frontier countries (US$24437 and 1.8%), the average distance to the frontier is 20 years for the CUCs (CV=2) and 370 years for the STCs (CV= 2.2). But still only four countries in the LGCs would show catching-up probabilities: Ethiopia (296), Mexico (287), Colombia (267) and Costa Rica (74). 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.[9]

[9]The three 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

Summing up, the time-distance analysis shows than only the CUCs may be able to fulfilled the catching-up process, and indeed that some countries already did so. The weakness of the STCs to generate growth rates above the average at the frontier implies that countries in this group would not be able to catching-up–at least not in feasible times. In turn, the LGCs growth rates generally near the minimum at the frontier, or in many cases below it, explains why these countries tend to fall farther away over time. What is rather interesting is that the latter group includes several of the best examples of countries with a reasonable record of economic performance in other well-known classifications.

5 Conventional convergence revisited

The dispersion found in the last two sections using the coefficient of variation (CV) across countries in each classification provides some support to the *convergence clubs* hypothesis in Baumol 1986. Those clubs would be determined by the four types of countries classification in this paper.

In this section, I evaluate whether there is a statistically significant negative association between the countries in every classification and the FRCs. In particular, I consider a five decades period over the 1970s-2010s and run conventional β-convergence OLS-pooled regressions for the FRCs and for countries in each couple FRCs-CUCs, FRCs-STCs and FRCs-LGCs with and without controlling for the Nics, HInOECDs, LICs, and Frags. As long as there are no further conditions, this may be consider an analysis of *"unconditional convergence"*.

Figure 5 plots the relationship between relative income in the 1970s and growth gaps over the 1970s-2010s. The negative slope in the case of the FRCs highlights the well know convergence pattern documented 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 suggests positively sloped trends instead. In other words, the evidence suggests a pattern 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 β-convergence estimates in Table 1 are obtained from the following regression

$$gg_{i,\tau} = \alpha + \beta y_{i/\bar{F},1970s} + D_\tau + DZ_\tau + \epsilon_\tau$$

the dependent variable is the growth gap for the country over 1970s-2010s (5 observations per country), $y_{i/\bar{F},1970s}$ is the relative income per capita between a country and the frontier in the 1970s. D_τ denotes decade specific dummies and DZ denote dummies that control for extreme country cases (Nics, HInOECDs, LICs, and Frags).

As expected, coefficient estimates suggest a significant convergence effect for the CUCs. The coefficient for the CUCs-1 (-0.008) is negative, statistically

OECDs: Mexico 1994, Colombia 2020 and Costa Rica 2021.

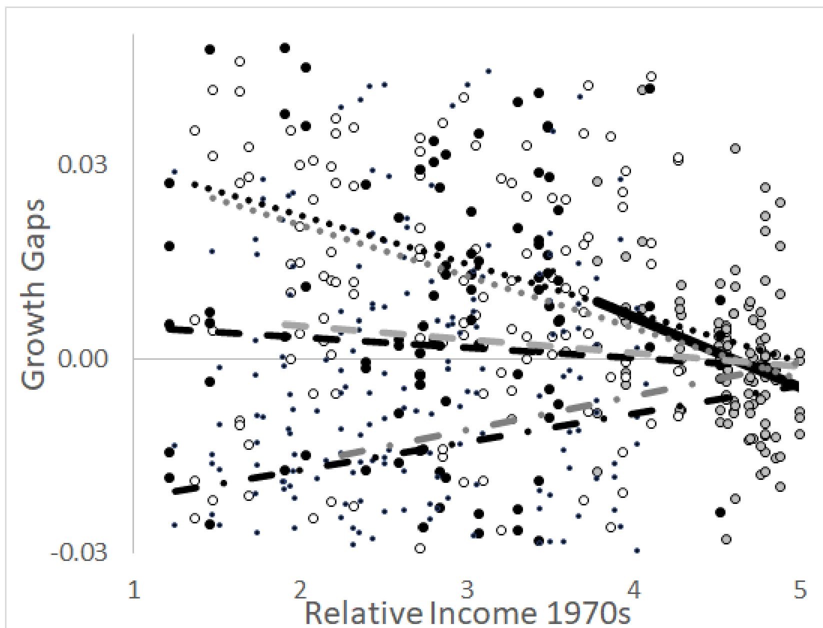


Figure 5: Relative income per-capita in the 1970s and growth gaps over 1970s-2010s. The thicker black line and grey circles are the FRCs. The dotted lines on the top and white circles are the CUCs before (black line) and after subtracting the Nics and HInOECDs (grey line). The dashed lines in the middle 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.

	FRCs	CUCs-1	STCs-1	LGCs-1	CUCs-2	STCs-2	LGCs-2
α	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_{1980}	-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_{1990}	-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_{2000}	-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_{2010}	-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)
$r2_a$	0.03	0.15	0.06	0.10	0.19	0.06	0.11
N	120	265	240	390	265	240	390
HLA		115	518	∞	115	518	∞

Table 1: Estimates of β-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, $HLA = \frac{1}{2n}\sum_i ln(y_i/y_F)/(\beta_{X_s})$. This is 115 years for the CUCs and 518 for the STCs. The positive β_{X_s}) of the LGCs implies that the HLA goes to infinity.

significant and robust after controlling for the impact of the Nics, and the HI-nOECDs. 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*, $HLA = -ln(y_i/y_F)/2\beta$, which measures the time that it would take a country to eliminate half of the income gap at origin, taking into account the speed of convergence, suggests a pattern 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 gap with the FRCs, while for the LGCs the evidence suggests no convergence possibilities (the positive sign of the coefficient implies a negative *HLA* value).

It remains to be seen whether countries off the frontier are able to rectify the relatively large periods of time needed to catching-up suggested by the above calculations. To a large extent, the debate in this front has motivated increasing research relating to the different impacts of diffusion and innovation in explaining the ability of countries to catching-up (Barro & Sala-I-Martin 1997, Kumar & Russell 2002, Clark & Feenstra 2003, Jorgenson 2009, Perilla 2019, 2020).[10] An analysis of these issues is presented in the next section.

6 Cross-Country Differences in Technology

The accepted wisdom 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.[11]

In reviewing some of the essential features of this argument, below I show that indeed income differences seem to mirror productivity differences across the country classifications in this paper. In particular, the decomposition of productivity into local efficiency–which I assimilate to innovation efficiency–and technical change–which I assimilate to technology diffusion/adoption–suggests that catching-up strongly depends on innovation.

6.1 Productivity performance and catching-up

Following Caselli 2005, I use so-called *development accounting* techniques to assessing to what extent income per worker differences across countries are explained by differences in the availability of productive factors. By subtraction, this approach allows to gauge the importance of productivity differences in explaining differences in income.

[10]There is a more open an extended debate as to whether convergence hinges on the ability of countries to replicate the institutions along the technologies developed at the frontier, or on their ability to assimilate and innovate (Romer 1993, Mankiw et al., 1995, Sachs & Warner 1995, Pritchett 1997, 2000a, Nelson & Pack 1999, Rodrik 2011, Spence 2011).

[11]See Dougherty & Jorgenson 1996, and Jorgenson & Vu 2005 for the counter argument.

A convenient way to grasp this problem is by measuring income and productive factors in relative terms. The question to answer is how much of the differences in relative income of a country to the frontier is explained by differences in relative endowment of factors, and how much by differences in relative productivity.

Consider the standard production function in per-worker terms of country i at time t relative to the average at the frontier, $\bar{F}$

$$\tilde{y}_i = y_i/y_{\bar{F}} = \frac{A_i}{A_{\bar{F}}}\left(\frac{k_i}{k_{\bar{F}}}\right)^{\alpha}\left(\frac{h_i}{h_{\bar{F}}}\right)^{1-\alpha} = \tilde{A}_i\tilde{q}_i \tag{3}$$

where $x_i, x_{\bar{F}}$ denote country time varying quantities (time subscripts dropped for simplicity). The capital-share, $\alpha = 1/3$ is assumed to be country and time invariant, equal to its most standard value in growth literature.[12]

Using natural logs, the log-variance decomposition of the above equation is

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

Development accounting goes by assuming that if there are no technology differences across countries the second and third term of the last equation vanish away. In that case, the *factors-only share* of the difference in income per worker across countries is

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

This implies that the productivity share of income differences, accounted by $var(ln\tilde{A}) + 2cov(ln\tilde{A}, ln\tilde{q})$ are

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

To emphasize the importance of the distance to the frontier in my approach, I calculate the variances in the last expression conditional on the average at the frontier. This means that for $X \in \{FRCs, CUCs, STCs, LGCs\}$

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

Thus, I calculate the *factors-only share* year over year for each country classification in the following way

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

[12]Country specific and time varying statistics about factors shares of income may be deducted from the labor share in PWT10. However, Gollin 2002, and Pritchett 2000b, provide solid arguments to be cautios on the reliability of official statistics in this regard. In general, using them leads to much more extreme cross country variation.

I apply this decomposition to a sample of 110 countries with complete information on all variables over 1970-2019 (24 FRCs, 21 CUCs, 25 STCs, 40 LGCs).[13] Notice that this is a more general analysis than usually found in the literature.[14] From Figure 6, panel (a), the median of the distribution across all 110 countries is 0.37 (std=0.08, min=0.30, max=0.53). This average value is nicely consistent with results found in other studies that usually focus on a single year or shorter time periods, using different versions of the data and different country samples (King & Levine 1994, Caselli 2005).

Surprisingly enough, in panel (a) the median (0.71) and variability (std=0.24, min=0.17, max=0.99) of the *factors-only share* is quite large for the 24 countries in the FRCs. This extreme variation originates in a few of countries below the median (Turkey, Portugal, Ireland, Spain) and a few other with extreme good performance (Switzerland, Luxembourg, Canada). This is in contrast with the more compact distributions found for 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), which are distributed toward the left of the FRCs.

Caselli (2005) acknowledges the sensitivity of development accounting to extreme values in some countries and introduce an alternative 90th-10th percentile ratio of the distribution of the *factors-only share* to account for this possibility. I follow a different approach. As mentioned earlier, the 110 countries in the original sample includes low income countries (LIC), fragile democracies (Frags) and high income countries that are not part of the OECD (HInOECDs) as well as the so-called NICs. In addition, I have noted the extreme variation originated in a few of FRCs countries.

Excluding these specific country cases from every other group, and excluding also the countries over the 90th percentile and under the 10th percentile among FRCs, leads to a sample better suited for analysis.[15]The new sample is formed by a rather compact distribution at the frontier, and middle income countries which, to a certain extent, are also stable economies. In particular, the sample accounts for 59 countries (20 FRCs, 11 CUCs, 12 STCs, 16 LGCs).

Compared to panel (a), using the new sample, panel (b) shows a meaningful reduction in factor differences across countries at the frontier. The median of the FRCs falls from 0.71 to 0.25 and the dispersion reduces from 0.24 to 0.05. The overall median for all 59 countries falls from 0.37 to 0.34 (std=0.08). There is a minor reduction in the median across LGCs from 0.34 to 0.33 (std=0.09); and meaningul reductions across CUCs, from 0.42 to 0.34 (std=0.08), and the STCs from 0.46 to 0.36 (std=0.09).

It is worth noting that in all cases, the ability of factor differences to explain income differences is actually reducing over time (e.g., for the FRCs it goes

[13]Some countries in the earlier sample of 131 countries has data on labor, physical and human capital needed in this section.

[14]I use the following data from PWT V.10: Output-side real GDP at current PPPs in mil. 2017US$(cgdpo), number of persons engaged (emp), capital stock at current PPPs in mil. 2017US$ (cn), and human capital index (h).

[15]Sweeping out countries under 10th- over 90th percentile in every other classifications would reduce further the sample without major improvement in the distribution.

from 0.39 in 1970 to 0.10 in 2019). To put it the other way round, the role of productivity differences to explain income differences increases over the sample period across all country cases. This is observed in Figure 6 panel (c) which is obtained using Eq. (4). Productivity differences explain between 61% (in 1970) and 90% (2019) of the differences in income across FRCs countries.

But the most important implication drawn from panel (c) is that the role of productivity differences is roughly similar between CUCs and LGCs (the latter slightly to the right) and visible larger compared to the STCs. More specifically, the data suggests that over the last decades and 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%).

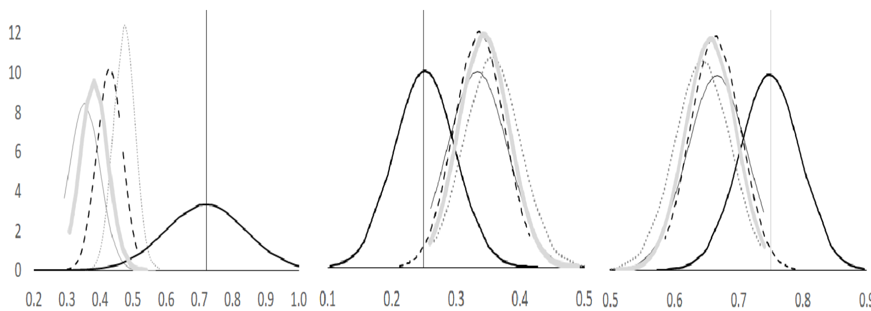


Figure 6: Dispersion of the *factors-only share* and productivity conditional on the average at the frontier. The thick grey line depicts all countries, the thick black line the FRCs, the dashed line the CUCs, the dotted line the STCs, and the thin line the LGCs. Panel (a) shows the distribution based 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 Nics, HInOECDs, LICs, Frags, and adjusting the distribution at the frontier to remain between the 10th-90th percentiles). Panel (c) shows productivity share differences.

Z-test statistics for the difference in the mean of productivity differences supports the null hypothesis that the STCs are indeed 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 left of the CUCs.[16]

Summing up, despite observable overlaps in the distribution, the data suggest that over the 1970-2019 the STCs had been significantly more affected by

[16] 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:

$$(\mu, \sigma^2, N)_{FRCs} = (0.76, 0.01, 50) \;\; and \;\; (\mu, \sigma^2, N)_{STCs} = (0.64, 0.01, 50)$$

Thus, $(0.76, 0.01, 50)_{FRCs}$-$(0.64, 0.01, 50)_{STCs}$ = -6.55 (P < $|z|$ = 2.92E-11).

a failure to accumulate productive factors, whilst the LGCs seem to have been falling behind because of their productivity weaknesses. Clearly this seems to fight intuition, after all, would it no be more obvious to expect it to have been the other way round?

In the following section, I suggests an answer to this apparent conundrum.

6.2 Diffusion or innovation, which matters the most?

Productivity decomposition has become instrumental to break down total factor productivity into *technical changes*–led by changes in technology frontier–and *changes in efficiency*–captured by the distance to the technology frontier–(Farrel 1957, Fare et al. 1994, Kummar & Russel 2002, Los & Timmer 2005).

Below, I argue that this decomposition allows for a comparison of productivity changes that are correspondingly accrued to the diffusion / adoption of technology from abroad (the *"technical changes"* component) and to local innovation (the *"changes in efficiency"* component). This seems accurate to the extent that technology trajectories are generally determined by a few of the most productive countries in the world (Coe & Helpman 1995, Keller 2002). The embodied technology that spreads to other countries through state-of-the art machines and equipment, and new knowledge, are factored in technical change. This diffusion effect is augmented by economies of scale that leads to increase (or not) production out of the increase of production factors, hence the adoption effect. When both of these elements are accounted for, what remains is the efficiency of the economy in using them to close their gaps with the frontier, hence innovation.[17]

A failure with this argument is that *"technical change"* is calculated with reference to countries wich are able to produce more output out of a given set of inputs. Countries poorly endowed with physical and human capital which however exhibit large amounts of ouput per worker–because production is based on resource extraction or because there is some kind of advantage of backwardness (Gerschenkron 1962)–are more likely to become the benchmark. As there is no convincing guidance in the literature to overcome this difficulty, results refering to the *"technical change"* should be taken with caution.

Following Kumar and Russel 2002, let the non-parametric Farrell (output based) efficiency problem for country i at time t be defined in the following way

$$E(\tilde{y}_i, \tilde{k}_i, \tilde{h}_i) = min\{\lambda | (\tilde{y}_i/\lambda, \tilde{k}_i, \tilde{h}_i) \in \bar{\tau}_{CRS}\}$$

Where $\tilde{y}, \tilde{k}, \tilde{h}$ denote the relative income and productive factors defined earlier. This equation represents the maximal amount of output that is feasible given the actual amounts of factor inputs and state of the art technology $\bar{\tau}$.

[17]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. I think my use of the concepts is more akin to accepted wisdom (see, for instance, Benhabib et al., 2014, Fagerberg et al., 2010).

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

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

$$s.t. \quad \tilde{y}_i/\lambda \leq \sum_j \theta_j \tilde{y}_j; \quad \tilde{x}_i \geq \sum_j \theta_j \tilde{x}_j; \quad \lambda, \theta \geq 0; \quad j = 1, 2, ...N$$

The value of λ obtained from the solution of this problem represents the *efficiency score* of country i and satisfies $\lambda \leq 1$. $\theta = 1$ imply that the country is part of the technological frontier. Notice that this frontier is not necessarily, and by reasons already given most probably not at all, formed by the FRCs. To avoid confusion, below I keep the distinction between *"technological frontier"* in the Farrel sense of technical efficiency and the FRCs.

The value of θ denotes the constant returns to scale level of operation of the economy for a given combination of output and inputs. Variable Returns to Scale (VRS) is allowed subject to the restriction $\sum_j \theta_j \leq 1$. The ratio between the CRS and the VRS score reflects scale efficiency (Coelli et al., 2005).

$$SE = \frac{\bar{\tau}_{CRS}}{\bar{\tau}_{VRS}}$$

Where

$$\bar{\tau}_X = (\tilde{y}_i, \tilde{x}_i) \in \mathcal{R}^3_+ |\ \tilde{y}_i \leq \sum_j \theta_j \tilde{y}_j, \tilde{x}_i \geq \sum_j \theta_j \tilde{x}_j,\ \theta_i^X$$

for X=(CRS, VRS).

Notice that, by construction, the CRS efficiency index may be obtained by multipliying scale efficiency and the VRS efficiency index,

$$\bar{\tau}_{CRS} = SE \times \bar{\tau}_{VRS}$$

As long as efficiency measures are obtained for each time period, a decomposition is possible of TFP productivity changes into technical changes, scale efficiency changes and so-called *local innovation* changes. The relevant distances needed to calculate these components rely on the linear program introduced above using Malmquist output distance functions (Malmquist 1953, Coelli et al., 2005).

Figure 7, illustrates this approach in the two dimensions space for one output (Y) and one input (X) over two time periods–hence X(0) and X(1). This seems adequate to illustrate the differences between VRS and CRS which are long-run concepts.

Under VRS the technical change component–the shift in the frontier–which therefore captures the productivity impact of technology diffusion/adoption is measured by the ratio Yf/Yd when the state of the art technology is at X(1). But by the ratio Yc/Yb when the state of the art technology is at X(0). The Malmquist index approach is based on the geometric mean of these shifts

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

Notice that under CRS the same index is

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

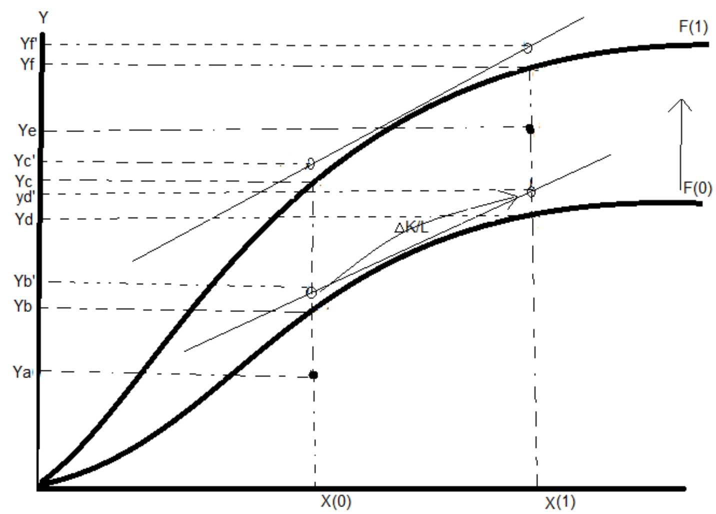


Figure 7: Productivity decomposition.

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 state of the art technology is at X(1), and by the ratio $Yb'/Yb \times Yc'/Yc$ when the state of the art technology is at X(0). The geometric mean of these shifts is

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

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

Notice that if the economy is at the same distance to $\Delta tech|VRS$ and $\Delta tech|CRS$, production in the countries at the frontier occurs under a CRS technology, therefore, the economy's scale efficiency is equal to unity. Otherwise, when the economy is at a higher distance to $\Delta tech|VRS$ than to $\Delta tech|CRS$– e.g., the frontier exhibits increasing returns (IRS)– scale efficiency is reducing. And, when the economy is at a shorter distance to $\Delta tech|VRS$ than to $\Delta tech|CRS$ scale efficiency is increasing.

Lastly, the distance of the economy to the VRS-based frontier is measured by the ratio $\frac{Yf/Ye}{Ya/Yb}$. Notice that this captures the ability of the economy to short the distance to the frontier after accounting for technical changes (or shifts in the frontier) and economies of scale (in)efficiencies, which is why I argue that it amounts to a measure of *local innovative efficiency*, thus

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

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 & Timmer 2013, below I provide also a conventional parametric estimate of TFP changes based on the following representation.

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

where $\tilde{A}, \tilde{y}, \tilde{q}$ are defined in Eq. (3), and the relevant capital share is assumed to be country and time invariant ($\alpha = 1/3$).[18]

Table 2 shows decade-averages of the parametric and non-parametric measures of productivity and its relevant decompositions. These estimates are obtained for the sample of 110 countries with complete information over 1970-2019 (left panel), and the sample of 59 countries after exclusion of special country cases (Nics, HInOECDs, LICs, Frags) and the adjustment of the frontier to remain between the 10th-90th percentiles (right panel).
Notice that the non-parametric estimates of TFP ($\overline{\Delta tfp}$) are generally similar, not equal, to the conventional estimates ($\overline{\Delta ctfp}$). There is a notable difference in the overall mean for the CUCs. And, through the decades, there are also notable differences over 2000-2010 mostly for other than the FRCs. However, the Pearson´s correlation coefficient between both productivity estimates–not shown– is quite high in all cases (generally over 0.9). Particularly after subtraction of the special country cases.[19] Given the methodological differences of this approach with the parametric technique, these similarities support to the Malmquist based TFP estimates. Below, I shall focus on the latter.

There are five issues worth highlighting from the results presented in Table 2

1. TFP was generally decreasing over all decades. With a focus on the overall mean, the only exception is FRCs in the right panel (0.03%). However, whether one focus on the left or the right panel, productivity decrease appears to have been more severe for the STCs and LGCs than for the CUCs (mean of -0.54% on the left and -0.46% on the right). Over the decades, the most severe reduction in countries other than the CUCs ocurred in early decades (through the 1970s and 1990s).

[18] PWT V.10 report statistics for *ctfp* using USA as the benchmark and country specific factor shares. As noted throughout I prefer to rely on the average accross FRCs as the benchmark. On the other hand, as noted earlier, Gollin 2002, and Pritchett 2000b suggest to be cautios on the reliability of official statistics related to factor shares.

[19] The exception is the CUCs when the whole sample (21 countries) is used (correlation is 0.83).

	Whole sample (110 countries)					Adjusted Sample (59 countries)				
	$\overline{\Delta tech}^{*}$	$\overline{\Delta ineff}$	$\overline{\Delta seff}$	$\overline{\Delta tfp}$	$\overline{\Delta ctfp}$	$\overline{\Delta tech}^{*}$	$\overline{\Delta inff}$	$\overline{\Delta seff}$	$\overline{\Delta tfp}$	$\overline{\Delta ctfp}$
FRCs	24 countries					20 countries				
1970	-8.48	6.10	2.16	-0.83	-0.38	2.11	-0.12	-2.05	-0.14	-0.04
1980	-8.66	10.91	-1.65	-0.38	-0.16	-4.73	0.69	4.00	-0.24	-0.11
1990	-1.17	1.96	-0.23	0.53	0.37	0.66	-0.03	-0.09	0.53	0.41
2000	-0.42	-0.68	0.71	-0.39	0.01	0.31	0.50	0.24	0.05	0.13
2010	-4.08	2.67	1.51	-0.08	-0.01	1.02	-1.20	0.17	-0.04	-0.17
Mean	**-4.56**	**4.19**	**0.50**	**-0.23**	**-0.03**	**-0.12**	**-0.23**	**0.46**	**0.03**	**0.04**
CUCs	21 countries					11 countries				
1970	-6.89	8.41	-0.19	0.69	1.33	-0.88	0.44	1.18	0.62	1.04
1980	-3.73	3.20	-0.54	-1.25	-0.54	-0.37	-0.69	-0.46	-1.54	-0.97
1990	-0.67	-0.26	-0.14	-1.07	-0.16	-3.43	1.55	0.26	-1.71	-0.70
2000	-0.66	0.20	-0.33	-0.82	0.85	-1.75	1.09	0.51	-0.16	1.13
2010	-3.42	2.94	0.39	-0.23	0.35	0.85	-0.49	0.15	0.50	0.79
Mean	**-3.07**	**2.90**	**-0.16**	**-0.54**	**0.37**	**-1.11**	**0.38**	**0.33**	**-0.46**	**0.26**
STCs	25 countries					12 countries				
1970	-7.36	5.51	0.28	-2.02	-1.81	-0.77	0.04	-0.68	-1.52	-1.77
1980	-4.61	2.27	-0.50	-2.98	-3.00	-0.48	0.10	-0.60	-1.04	-0.88
1990	-0.57	-0.79	0.34	-1.06	-1.10	-4.20	1.28	0.82	-2.20	-2.31
2000	-0.46	0.16	0.00	-0.26	1.10	-1.71	1.00	0.70	-0.04	0.97
2010	-2.76	2.29	-0.12	-0.64	-0.38	0.71	-0.42	0.16	0.44	1.00
Mean	**-3.15**	**1.89**	**0.00**	**-1.39**	**-1.04**	**-1.29**	**0.40**	**0.08**	**-0.87**	**-0.60**
LGCs	40 countries					16 countries				
1970	-6.96	5.47	0.46	-1.53	-1.82	0.14	-1.31	-0.04	-1.20	-1.53
1980	-3.50	1.64	-0.72	-2.66	-2.64	-1.49	-0.95	-0.20	-2.64	-2.32
1990	-1.27	-1.88	0.44	-2.71	-3.03	-4.12	2.89	-0.56	-2.01	-1.99
2000	-0.25	0.29	-0.19	-0.15	0.55	-1.59	0.02	0.79	-0.85	-0.30
2010	-1.56	2.04	-0.18	0.27	-0.58	0.65	-0.52	0.47	0.59	-0.22
Mean	**-2.71**	**1.51**	**-0.04**	**-1.36**	**-1.50**	**-1.28**	**0.03**	**0.09**	**-1.22**	**-1.27**

Table 2: Decade-averages of cross country TFP changes and their components (for the FRCs (1970s): $\overline{\Delta tfp} = (1 - 0.0848) \times (1 + 0.061) \times (1 + 0216) = (0.992 - 1)$). $\overline{\Delta ctfp}$ is obtained using conventional growth accounting. All variables are measured in relative terms, hence $\tilde{y}, \tilde{k}, \tilde{h}$. Results obtained from the software DEAP (Coelli et all., 2005).
* *Technical change* wrt VRS technology: $\Delta tech|VRS$

2. The data suggests that the main trigger of the CUC's performance was innovation (overall mean of 2.90% on the left panel and 0.38% on the right panel). Compared to the STCs and LGCs this component was generally increasing at higher rates or decreasing at slower rates over all decades, with some exceptions in the right panel.

3. Technical change ($\Delta tech|VRS$) was generally decreasing for all groups. According to Eq. (5), this implies increasing scale efficiencies that extent to all economies. In fact, notice that the mean value of scale efficiency is positive for all groups but the CUCs and LGCs in the left panel. In fact, scale efficiency appears to have a major role within the STCs and LGCs than the CUCs in the left panel. But a major role for the CUCs in the panel on the right, when the reduced sample is considered instead.

4. Scale efficiency of the FRCs is the highest in both panels (mean value of 0.50% on the left and 0.46% on the right) with technical change decreasing in both panels. It has been mentioned that these results in particular need to be taken with caution. Notice, however, that technical change indeed increases for FRCs over 1980s-2010s which seems consistent with the fact that technology trajectories that are new to the world are generally determined by a few of countries in this group. Apparently, the extreme country cases (those under the 10th and over the 90th percentiles) imply a larger change in the performance of countries at the frontier which might explain the large negative values observed for the technical change component in the left panel.

5. Scale efficiency of the CUCs is the largest after the FRCs in the panel on the right (0.33%). But it is the lowest in the left panel (-0.16%). The results for this component are rather mixed in comparison with other groups over the decades in both panels. But it seems apparent, particularly on the right panel, that the CUCs exhibit a better performance than the STCs and LGCs in both technical change and scale efficiency.

The generalized decline in productivity across all country groups and over time, presented in the table, suggests a productivity ranking that is consistent with the country classifications introduced in this research. In this ranking the best performance is shown by FRCs countries. It was based on the combination of a high degree of innovation with technical changes and scale efficiency. Particularly, when extreme country cases in this group are factored out (right panel).

Nevertheless, to the extent that the FRCs are used here as a benchmark, the true "winners" in the ranking are the CUCs. Although they also rank high in the three above mentioned components, there is a different explanation. Unlike the FRCs, the innovation component appears to have been more important whether one focus on the most heterogeneous sample of countries in the left panel or the most stable middle income economies in the right panel.

In contrast with the CUCs and FRCs, the STCs show severe productivity declines over the 1970s and 1990s, and slow recovery thereafter. Although the countries in this group also show a high degree of innovation, it is generally behind the CUC's. But it seems apparent that they failed mostly in the ability to improve scale efficiency. This is particularly relevant in the case of middle income countries (right panel), where the overall mean of innovation efficiency of the STCs is the highest, even slightly larger than the CUC's, but scale efficiency is quite low.

The same reasoning, but much more dramatic, extents to the LGCs, which show the largest productivity declines over the first four decades and some (slow) recovery in the last decade. Innovation efficiency lags in general behind other groups. The remarkable fact in the left panel, however, is that scale efficiency although falling is better, on average, than in the CUCs (-0.04%) and in the right panel it is even slightly better than the STC's (0.09%). Actually, over the 2010s the LGCs appears to perform better than any other group in productivity, and this is based overall on its scale efficiency. This might explain the distribution of the LGCs to the right of other groups but the FRCs in the analysis of Figure 6 panel (c).

Summing up, the productivity outcomes presented here are largely consistent with the four-types of countries classification and, in my view, provide suggestive evidence to the ongoing debate on the impacts of local innovation efficiency and the diffusion / adoption of foreign technology to catching up.

7 Concluding Remarks

The four-types of countries classification introduced in this paper may prove a valuable research avenue to study the reasons why some countries are more able to catching-up than others.

The general observation is that over long periods of time some countries have been successfully catching up, whereas many other remain stagnant or keep lagging behind the reference countries at the frontier in terms of income and productivity. This, in my opinion, gives a new perspective to the research in development economics. Clearly, catching-up is a dynamic phenomenon which depends both on relative levels of income and adjusted growth rates because the countries at the frontier are a moving rather than a static target.

This places catching-up in historical perspective, e.g., by taking into account past performance to derive a country catching-up perspectives. The result is non-trivial. I have shown in this research 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 to as much as 194 years if the frontier keeps growing at the historical pace. In turn, STCs countries are to between 69 and more than two thousand years (India 2242 years) and LGCs to between 483 and far beyond off the frontier. This is in striking contrast with predictions made at the beggining of the new millenia suggesting that convergence would be fulfilled by the end of the 21st century.

While differences in levels of income and productivity seem to be closely correlated, the productivity decomposition in this paper strongly suggests that the ability to catching-up has been a result of local innovation efficiency. While it does not neglect the importance of technology diffusion from abroadsuccesful adoption, this outcome provides support to recent research on the complex feedback effects between technology diffusion/adoption and innovation (Nelson & Pack 1999, Malerba & Lee 2020, Perilla 2019, 2020).

A worthwhile avenue for future research under this framework would be to investigate differences in the approach to innovation, the institutional design of the innovation policy that explain long run growth outcomes, and the sustainability implications of getting all countries in the four-types framework to reach the income standards of the frontier.

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