The Discernment of Heterogeneous Country Industrialization Patterns through Economic Complexity

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Abstract

The analysis of inputs growth rates along the industrialisation patterns of countries shows that economic complexity plays a major role in characterising the dynamics. In particular high fitness more differentiated and complex economies face a lower barrier to start the transition through industrialisation.

1 Introduction

The industrialization of a country is a formidable process, deeply changing the population and the institutions of the country while new and old resources are tapped to achieve growth. During this transition the growth rate of the economy is much higher than the global average and much higher than the past and future growth rate of that country.

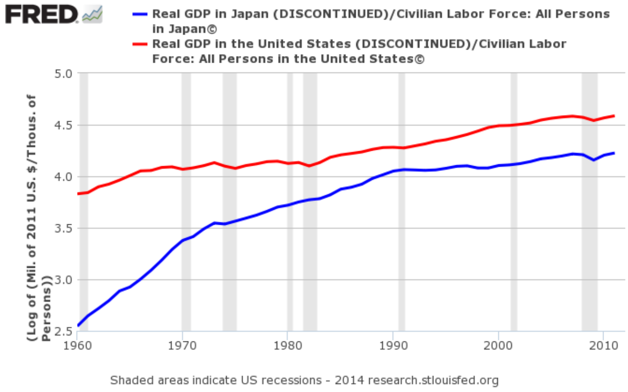
It is however a transition and, as such, limited in time. When the process of industrialization has touched all the sectors, when the population is educated and near full employment, when all the scale economies have been fullfilled, the process loses its revolutionary power and the new society now sits among the developed countries.

Two questions haunted economists since the beginning of the discipline, since Adam Smith and Max Weber. The first question is about the drivers of this sudden sprout of growth, how an entire society changes dramatically in fifty years after thousands of years of stillness. Related to this, why the process is as suddenly interrupted while the growth slows down after catching-up with the other developed countries. There are many competing answers to this part of the puzzle, the most basic being the poverty trap due to multiple equilibria that was already in Solow (1956): the phenomenon is sudden because there is a barrier, a country wealth that has to be reached to start a quick transition to a different equilibrium. Many alternative explanations are there, most notable increasing returns and demand, as in Rosenstein-Rodan (1943) and - more formally - Murphy et al. (1988), in which the barrier to overcome is a minimum internal demand to allow for returns to scale in manifacturing.

The second question is about the heterogeneity of the process among countries. England experienced its Industrial Revolution in the second half of the XVIIIth century, followed by other Western countries. In the XIXth century the United States industrialized too, and other countries followed in the XXth century. Other countries did not. What are the countries lagging behind missing to move toward prosperity? There are many alternative explanations, from cultural (Weber et al. (2002), McCloskey (2010)) to geographic (Diamond and Ordunio (1997)), even biological (Ashraf and Galor (2011)). Another explanation is political (Acemoglu et al. (2005)): to achieve growth the population has to be empowered through inclusive political institutions, leading to more inclusive economic institutions, diffused prosperity and, therefore, demand. It also leads to the population's freedom of pursuing their own interests in unexpected sectors, to increase the diversification and complexity of the economy.

Reactions to Catching-up

The process of catching up, the fast growth of developing countries toward the level of GDP per capita of the developed countries, is able to scare economists and opinionists. In 1970 many experts were forecasting that Japan's GDP per capita would overcome USA's by early '80s. Even in 1979 the influencial book "Japan as Number One" by Ezra Vogel was suggesting an overcome in the near future. This forecast was done simply interpolating the burst rate of growth that Japan was having at that time (while catching-up) for the next years. Of course, as soon as Japan mobilized all its internal resources and all the sectors industrialized, its growth rate slowed down.



In the past years an approach based on methodologies from the Science of Complex Systems have been used with some success to characterize Social and Economic systems. Indeed these systems share with the traditional objects of Complex Systems analysis the emergence of an unexpected collective behavior coming from the non trivial interactions between components (Anderson, 1972). The industrialization of a country is a dynamic process in which a complex network reinforcing production capabilities and product demand emerges at the country scale. Complexity is then expected to play a crucial role in the emergence of growth patterns. It has recently been suggested (Cristelli et al., 2013, Tacchella et al., 2012) that the wellness and the potential of countries can be better characterized by considering a further dimension, the fitness(see the box for details) of that country, which takes into account the diversification and the complexity of the production system. In this paper we investigate the role played by this new measure in describing the countries' industrialization process. As it will turn out, fitness, which is a quantity tuned on the diversification and complexity of the country's products export, carries an important information with regard to the start of the industrialization process. In particular we will see how an higher Fitness is associated with a lower barrier to industrialize.

What is fitness?

Here we illustrate a new approach to measure the fitness of countries and the complexity of the exported products. This methodology has been recently introduced in Cristelli et al. (2013), Tacchella et al. (2012). The idea is the following. Each country has some *capabilities*, which represent its social, cultural and technological structure. The capabilities permit to produce and export products, so the extension of the distribution of products and their complexities are linked to each country fitness; in particular, the complexity of a product increases with the capabilities which are needed in order to produce it, and the fitness is a measure of the complexity and the diversification of the exported products. In order to make this line of reasoning more quantitative, the starting point is the global structure of the matrix M_{cp} whose entries take the value 1 if the country c exports the product p and 0 otherwise. We point out that in order to assign the values to the matrix elements we consider the Revealed Comparative Advantage: in such a way we remove any trivial correlation with export volumes. Once countries and products are suitably arranged, this matrix is *triangular*, showing that developed countries have a diversified export, while poor or less developed countries export fewer, lower complexity products. While diversification may lead to an immediate, zero-order estimate for countries' fitness as the number of products they export, the evaluation of products' complexity is more subtle, because one must, in some way, assign a low score to those products which are exported by low-fitness countries. At this point it is clear that a linear approach can not be appropriate. In order to calculate the fitness of countries and the complexity of the exported products the following set of non linear coupled equations has been proposed:

$$\tilde{F}_c^{(n)} = \sum_p M_{cp} Q_p^{(n-1)} \qquad (1) \qquad\qquad F_c^{(n)} = \frac{\tilde{F}_c^{(n)}}{< \tilde{F}_c^{(n)} >_c} \qquad (3)$$

$$\tilde{Q}_p^{(n)} = \frac{1}{\sum_c M_{cp} \frac{1}{F_c^{(n-1)}}} \qquad (2) \qquad\qquad Q_p^{(n)} = \frac{\tilde{Q}_p^{(n)}}{< \tilde{Q}_p^{(n)} >_p} \qquad (4)$$

where the normalization of the intermediate tilded variables is made as a second step and n is the iteration index. The fixed point of these maps has been studied with extensive numerical simulations and it is found to be stable and not depending on the initial conditions. We refer to Cristelli et al. (2013) for a detailed explanation of the features of this approach, which is beyond the purposes of the present paper.

The following essay will be divided in four sections in addition to this introduction. In the next section we will describe the data used in the analysis. We will then briefly sketch a simple poverty trap model, a basic rendition of Solow (1956), to fix notation. In the following section we will show some empirical shortcoming of this basic idea of poverty trap and we will show the promising role of our Fitness index to solve these shortcoming. Finally, in section 5 we will show that introducing the Fitness in the basic poverty trap narrative helps the models to describe the real world.

2 Dataset and variables

In the following we will use mostly simple national statistics, other than the Fitness measure previously described.

We use for all the national statistics data the Penn World Table 8.0. The data on phisical capital is produced with a perpetual inventory method, as described in Inklaar and Timmer (2013), while the proxy for the human capital is the average number of years of education in the population. The exogeneous growth has been computed as the residual of the total growth after removing the input growth.

Countries' fitness evaluations are based on the import-export flows as registered in the UN-NBER database, reconstructed and edited by Feenstra et al. (2005). This database includes the (discounted) imports of 72 countries and covers more than 2577 product categories for a period ranging from 1963 to 2000. Exports are reconstructed starting from these imports, which cover about the 98% of the total trade flow. There are many possible categorizations for products; we will base our study on the Sitc v2, 4-digits coding. After a data cleaning procedure, whose aim is to remove obvious errors in the database records, and to obtain a consistent collection of data, the number of countries fluctuates between 135 and 151 over the years, while the number of products remains equal to 538.

3 A Primer in Economic Growth Theory

In our analysis we will keep a minimal economic setting to analyze growth. Since the influential Solow (1956), this minimal setting starts writing a production function,

$$Y_{i,t} = F(A_{i,t}, I^j_{i,t}), \tag{5}$$

where $Y_{i,t}$ is the production of country i at time t, $A_{i,t}$ is an efficiency measure and, for different js, $I^j_{i,t}$ are the different inputs of the production (Physical Capital, Labor, Human Capital, ...). The production function F gives the output of the economy for different levels of inputs and efficiency. The growth of output, that we will identify with GDP in the following, can therefore be the consequence of an efficiency and technological growth, i.e. a growth of A, or an input growth.

In growth models some inputs are accumulated in an endogeneous way: a part of the output is invested to build new phisical capital, a part of the working time of the laborers is spent to train new workers and accumulate human capital. Their level in equilibrium is the result of their accumulation and their depreciation. Growth due to input accumulation is therefore called endogeneous growth. On the opposite side, growth due to technology and efficiency, a growth of A, is called exogeneous growth[1].

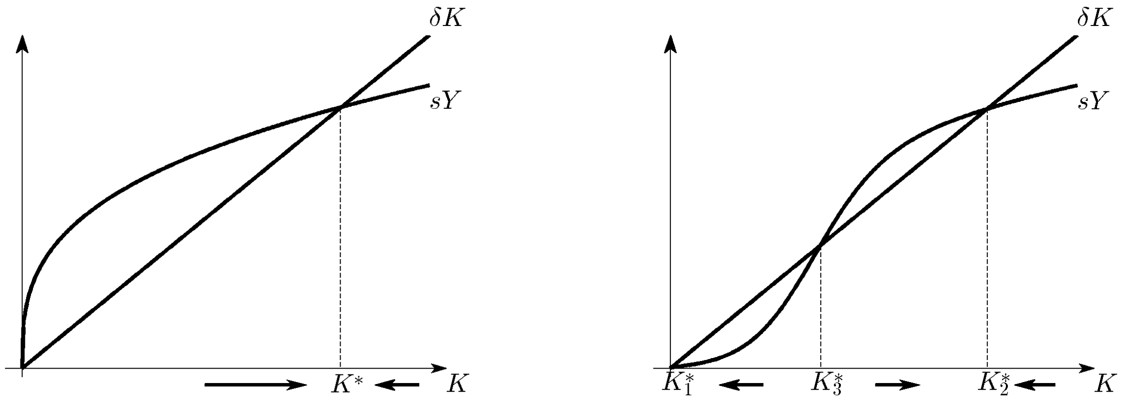
In the following we will use a minimal case. We will take a Cobb-Douglas production function with two inputs, physical capital $K_{i,t}$ and labor $L_{i,t}$:

$$Y_{i,t} = A_{i,t} K^{\alpha}_{i,t} L^{1-\alpha}_{i,t}. \tag{6}$$

If a fraction s of the output Y is invested in the production of new physical capital K and a fraction δ of K decades at each time step due to depreciation, the time evolution of physical capital is

$$K_{i,t+1} = sY_{i,t} + (1-\delta)K_{i,t}. \tag{7}$$

In figure 1a we show that this equation has only one stable equilibrium. The equilibrium is possible due to the decreasing returns on capital: the more capital a country has, the less output the country gains with an additional unit of capital. It is also worth to note that, since the equilibrium point K^* depends on A and L, K will still grow if those variables grow.



(a) a single equilibrium in K^*. The two curves δK and sY represents respectively capital depreciation and capital accumulation. The equilibrium is achieved when the two effects are equal, i.e. K^*

(b) a case with multiple equilibria. When the production function has increasing returns for some scales, multiple equilibria are possible. K^*_1 and K^*_2 are stable equilibria, while K^*_3 is unstable.

However already in the seminal Solow (1956) there were the idea that multiple equilibria in the capital levels are possible. If there are aggregate increasing returns at some scale of production, or non linearities in the saving rate s or the demographic rate of growth, the capital accumulation function becomes non linear. Imagining for example that a minimum threshold of capital is needed to be productive in some sectors, the production function could look like

$$Y_{i,t} = A_{i,t} \frac{K^{\alpha}_{i,t} L^{1-\alpha}_{i,t}}{1 + \mathrm{e}^{K_F - K_{i,t}}}, \tag{8}$$

and the system can present a behavior similar to figure 1b.

[1] it is also called exogeneous growth the growth of inputs that are not accumulated endogeneously in the model; e.g. demographic growth

After overcoming a barrier, in figure 1b represented by point K_3^*, the country capital would move endogeneously to K_2^*. The out-of-equilibrium dynamics from one equilibrium to another has to be characterized by fast input accumulation and, therefore, fast endogeneous economic growth.

While the overall measure of GDP growth can be deceiving and influenced by the price and discovery of natural resources and the happening of any external factor, the sudden investments in physical and human capital and the increase in labor force participation are the clear fingerprints of a structural change, a movement from an equilibrium to another.

3.1 Decomposing Economic Growth

The simple functional shape in equation 6 is useful to empirically quantify the different kinds of growth. Let us first define the labor input L as the product of the number of employees (E) and their average human capital (H). Therefore we have that the GDP per capita is equal to

$$\left(\frac{Y_{i,t}}{P_{i,t}}\right)_{i,t} = A_{i,t}\left(\frac{K_{i,t}}{P_{i,t}}\right)^{\alpha}\left(\frac{E_{i,t}}{P_{i,t}}H_{i,t}\right)^{1-\alpha}, \tag{9}$$

and therefore, defining with the lowercase letters the growth rates of the respective uppercase variables and with the hat the division by population,

$$\hat{y}_{i,t} = a_{i,t} + \alpha\hat{k}_{i,t} + (1-\alpha)\hat{e}_{i,t} + (1-\alpha)h_{i,t}. \tag{10}$$

Formula 10 divide the growth rate of GDP per capita, $\hat{y}$, in its component: the exogeneous growth rate, a, the growth rate of GDP due to per capita physical capital accumulation, $\alpha\hat{k}$, the growth rate of GDP due to an increase of the labor force share in population, $(1-\alpha)\hat{e}$, and the growth rate of GDP due to an increase of the average human capital of workers, $(1-\alpha)h$. These last three pieces form our definition of input growth, being it a phisical investment in new machinery (k), an increase in labor force partecipation(e), or additional education (h).

Since the growth rate of inputs is quantifiable, to compute the different parts of growth in equation 10 we need only to have α. Economic theory is handy in this case. If each factor of production is paid for at its marginal value, the share of national income going to capital will be α and the share going to labor $1-\alpha$. Since these shares are observable numbers, we will use those to have α. Finally, the exogeneous part can be recovered as a residual after removing the endogeneous component from the total GDP growth.

3.2 Demand versus Supply

Before looking at the data, one explanation is needed. Until now we have talked about different possible explanations for the multiple equilibria and poverty trap. In particular in the previous part of this section we have assumed a threshold in per capita phisical capital, the fingerprint of a supply side explanation. While to question the different narratives it is an important research question, it is not the question we want to answer in this analysis. Therefore any explanation, both demand and supply side, can be assumed in the following, as long as it allows for a threshold of resources needed to start industrialization. Since GDP per capita - required as a treshold by a demand side model of poverty trap with increasing returns - and the phisical capita - required as a treshold by a traditional model of poverty trap - correlates very strictly[2], we will be able to keep the same fuzzyness also in the next, more empirical, parts.

An explanation using only phisical capital for the next sections, in agreement with the previous part of this section inspired to Solow (1956), would have probably be more consistent and easy to read. We wanted however to make it clear that we are not taking any stance with regard to the causes of industrialization and that our empirical results are in agreement both with a supply side and with a demand side explanation.

In the following therefore we will use mostly GDP per capita, but the same qualitative empirical results could be produced using a phisical capital per capita measure. The choice to predilect GDP over phisical capital is also for its evocative value: the average reader is probably more used to compare different values of GDP than to compare phisical capital stocks.

4 Looking at the data

What should we expect, looking at empirical data, from a poverty trap as described in section 3? Two phenomena are expected. First, if the catching up of developing countries is the result of the dynamics of inputs to a new equilibrium, we should expect high input growth among the developing countries, sharply declining for the developed ones. We should therefore expect a negative relation between the GDP growth due to input and the level of GDP for the countries that have started the transition: the growth should slow down for developing countries while the level of inputs approaches the new equilibrium and the developing countries catch up with the developed ones.

Second, both if the barrier to start the industrialization is demand driven as in Rosenstein-Rodan (1943) or if it is capital driven as in Solow (1956), we should expect that a certain level of GDP/physical capital per capita is needed to start the transition. We should therefore find a positive relation between per capita GDP growth due to input

[2]In our sample, over the period 1963-2000, the Spearman's rank correlation between GDP and physical capital is 96.2%.

and the level of per capita GDP for low levels of GDP per capita, where additional GDP per capita means additional internal demand.

Looking back at figure 1b, we expect therefore to observe a decline while the system reach K_2^* of an input growth spike that started around K_3^*.

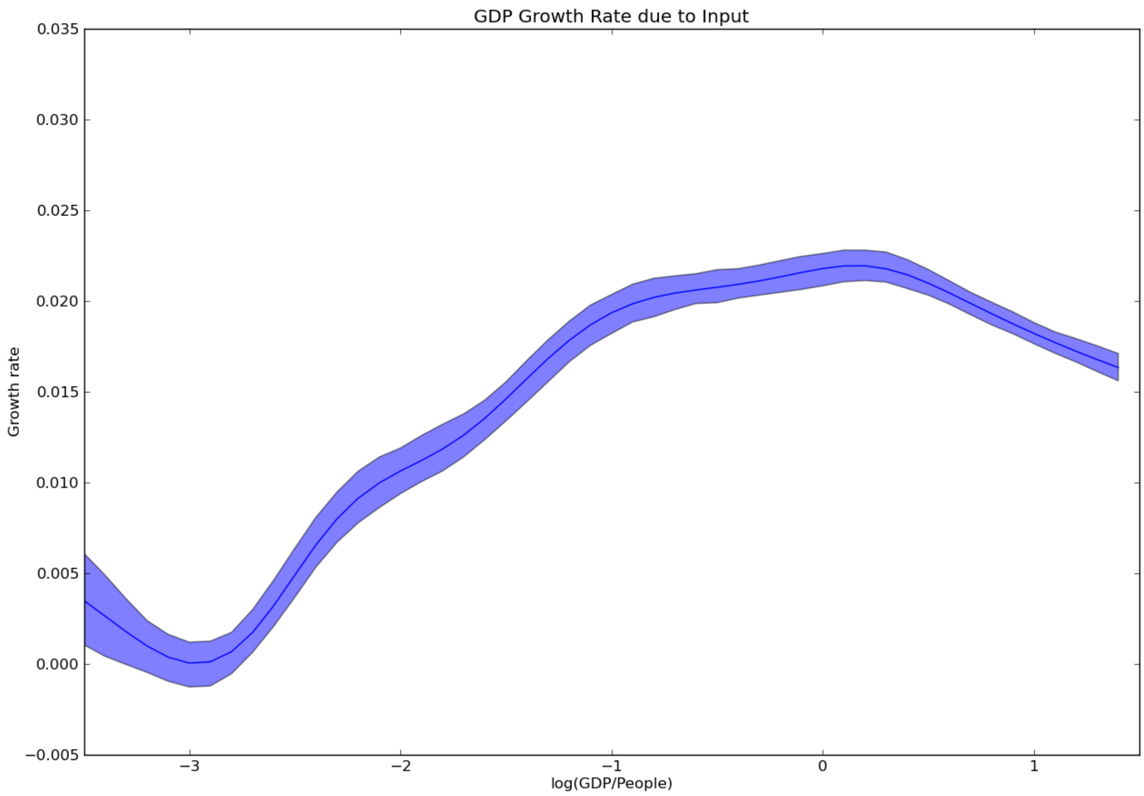


Figure 2: Endogeneous growth rate of GDP per capita versus relative GDP per capita. Shaded the 90% confidence interval. Different countries-years in the range 1963-2000 have been pooled after removing the global trend. While the low performance in increasing their input for countries with low GDP is clearly visible in the figure, the slowing done of input growth expected after catching up is modest.

The results in figure 2 do support the last point, since there is for sure a certain role of prosperity to kickstart investments. Data do not seem however to support the first hypothesis: if any catching up mechanism is visible from the data, it is not an awe-inspiring event. The slow down for very high level of GDP per capita, while statistically significant, is hardly economically significant. For sure it does not support the image of calm after the storm that we tried to evoke in the introductive sections.

Clearly, at this level our analysis is missing a crucial ingredient: we are not able to pinpoint the possibly different growth potentials among countries. The previous simple exercise was narrating a very simple story in which every country is following the same Growth trajectory: it was poor in equilibrium K_1^*, it passed through an homogeneous threshold K_3^* to get finally to the same end point K_2^*.

But, as it is well known, some countries have started an impressive growth process, from an industrial and a social point of view, while others simply rely on the exploitation of natural resources. For the same level of physical capital or GDP, two different countries could live a moment of intense investment and shared opportunities for the whole of the population, favoring investments both in physical and human capital, or a moment of stallness and complacence, often characterized by explotive economic institutions and high inequality. We need a quantitative measure in order to discriminate among these and others situations; from a practical point of view, a new dimension to disintangle different economies, possibly independent from the ones which are usually taken into account in mainstream economics. We believe that concepts taken from the economic complexity approach may be of help. In particular we believe that the fitness of a country, being both a quantitative measure of the number and of the quality of capabilities of a nation and a measure of diversification in advanced and complex products, is a useful indicator of the potential for growth of the country.

We will therefore replicate the exercise dividing the countries in three sets accordingly to their fitness, to see if it helps disentangling the different regimes. In figure 3 we show the results for the high fitness countries compared with the low fitness ones.

When data are split in this way, two different patterns emerge. What was confused when clubbing all the countries

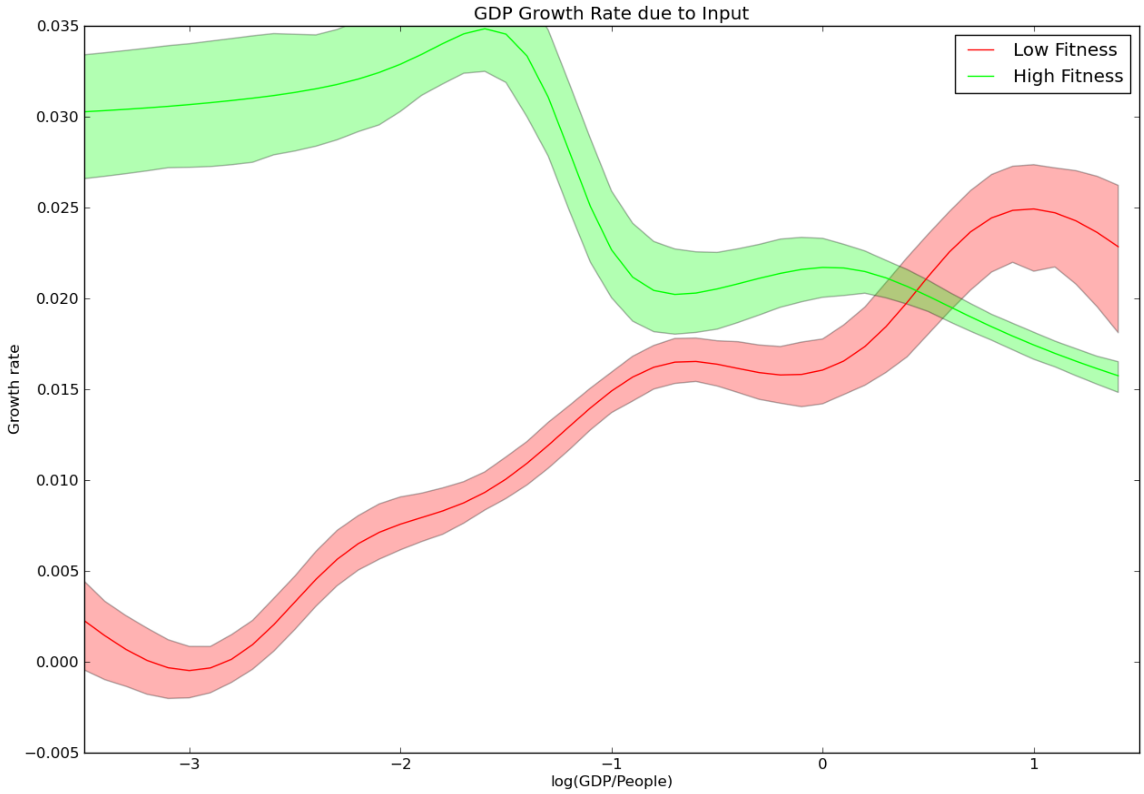


Figure 3: Endogeneous growth rate of GDP per capita versus GDP per capita for the lowest tertile of the fitness distribution and for the top tertile. Shaded the 90% confidence interval. Different countries-years in the range 1963-2000 have been pooled after removing the global trend. Dividing the countries in sets accordingly to their fitness highlights very different behaviors and reconcile the theory with the empirical observation.

together is now visible and in agreement with the predictions from section 3. The high fitness economies, the ones able to differentiate their production in advanced products, present a clear downward slope of the growth of GDP per capita due to input growth with respect to the level of GDP per capita. The countries with lower fitness instead have issues to start the transition. They experience an higher barrier and they need a very high level of GDP per capita to experience the mobilization of resources expected by economic theory.

The complexity based measure of country fitness seems to lower the barrier to start the transition, and we will see it in more detail in the next session.

5 The Cliff toward Economic Growth

In the previous section we observed different behaviors for countries with different fitness. A possible explanation that the fitness allows for industrialization, lowering the barrier to push forward the investments in inputs, has been hinted; it requires however additional investigation. What we observed for the two categories of top and lowest fitness should be generalized to a continuous process. We try this in the next exercise, in figure 4

This plot completely supports our argument: country fitness, the complexity and diverisification of the economy, acts as a catalyst, reducing the needed GDP per capita to start the transition. Figure 2 does not show a catching up behavior because for each level of GDP per capita the plot represents the projection of different fitness levels and, therefore, different states of the transition.

High fitness countries are able to start the transition, the sprout of investments and efforts causing high input growth, even when starting from a very low level of GDP per capita. On the opposite, low fitness countries, characterized by exports concentrated in few sectors, requires very high level of GDP per capita to start the transition and attract investments.

It is trivial to integrate this result in a demand side explanation: there is a complementarity between fitness, a proxy for export competitiveness, and GDP per capita, a proxy for internal demand, in kindling the process of industrialization of a country.

Even a supply side explanation is however consistent with this empirical results: if the new accessible sectors allows new - intrinsicly different - inputs to be used and accumulated, the scale of production can increase without an increase in the factor productivity, consistently with an input lead growth. Going back to the basic growth model

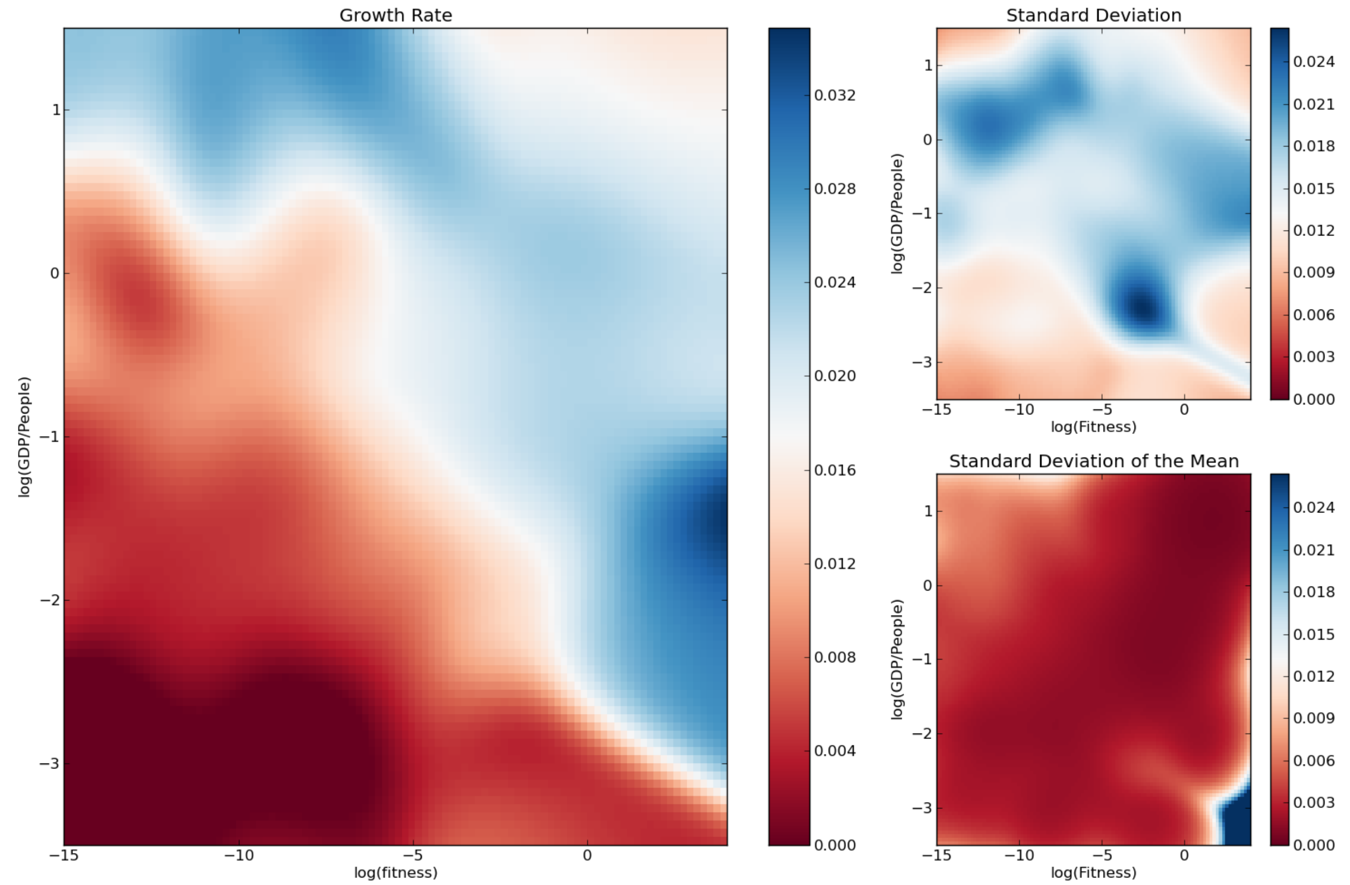


Figure 4: The color map represents the part Per Capita GDP Growth due to inputs, for different values of Fitness and GDP per Capita. Different countries-years in the range 1963-2000 have been pooled after removing the global trend. Both the role of the fitness of the country in lowering the threshold to enter in the high endogeneous GDP growth regime (the blue band in the center) and the slowing down of the process for developed countries (the top-right corner) are evident.

sketched in section 3, the empirical observation is consistent with a model connecting the fitness of the country to the position of K_3^* in figure 1b or, equivalently, to the value of K_F in equation 8: in this hypothetical model high fitness countries have high K_F and therefore K_3^* is very near to K_1^*; low fitness countries have low K_F so that K_3^* is near to K_2^*. Therefore they do not start the endogeneous transition until they have already high level of capital.

6 Conclusions

We shown in the paper that simple toy models of countries' growth (in particular models assuming that all countries are homogeneous objects characterized only by one state variable, being it the per capita GDP or per capita physical capital) are not able to catch the different patterns of industrialization and, therefore, to predict the starting point of industrialization, the moment in which they will come out of the poverty trap.

We also shown that the measure of Fitness is able to properly disentangle these different patterns, highlighting countries that are ready to take off and to industrialize and countries that, even with similar standard of living, are far from the threshold.

While the field will require additional study, in particular the modelization of some insights that here are just sketched, we think that already the empirical results give a deeper comprehension of the poverty trap, both for the academic economists and for policy makers.

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