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Article

Deindustrialization, economic complexity and exchange rate overvaluation: the case of Brazil (1998-2017)

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Abstract:

We analyze the determinants of the deindustrialization of the Brazilian economy in the period between 1998 and 2017. This is a typical example of 'premature deindustrialization' in the sense that the major reason for the fall in the manufacturing share has not been the increase in per-capita income but rather real exchange rate overvaluation. In the Brazilian case, real exchange rate overvaluation results both from an appreciation of the real effective exchange rate, and an increase in the equilibrium value of the real exchange rate, the "industrial equilibrium exchange rate" of the new developmentalist literature. The elimination of the real exchange rate overvaluation requires not only the adoption of a macroeconomic policy regime in which some kind of real exchange rate targeting is adopted, but also industrial policies designed for increasing the economic complexity of the Brazilian economy and, hence, to reduce the equilibrium value of the real exchange rate.

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Economic development is a process by which the accumulation of capital and the systematic incorporation of technical progress allow for a persistent increase in labor productivity and the standard of living of the population (Bresser-Pereira et al., 2015, p. 12). The increase in labor productivity makes it possible to consistently raise real wages once the 'Lewis point' is overcome; that is, once most of the labor employed in the traditional or subsistence sectors (as a rule, agriculture) has been fully transferred to the modern or capitalist sectors (Lewis, 1954). At this moment, the unlimited supply of labor – characteristic of phase I of capitalism (Kaldor, 1980) – is exhausted, causing the continuous increase in labor demand resulting from the expansion of the level of economic activity to allow the gradual

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increase of real wages at a pace approximately equal to the growth of labor productivity. The growth of real wages, in turn, is what enables the increase in the standard of living of the population.

Capital accumulation and technical progress are the key sources of growth in labor productivity and the population's standard of living. In fact, technical progress allows, on the one hand, an increase in production efficiency, i.e. that the same goods and services are produced with smaller amounts of inputs, in particular, work; on the other hand, technical progress leads to the development of increasingly sophisticated and complex products and services, that is, products that incorporate not only a larger amount, but also more diversified, technical and scientific knowledge.[1] These more sophisticated or complex products are produced by highly skilled workers in companies operating on or near the technological frontier;[2] which is why such products have higher added value per unit of labor employed.[3] Thus, technical progress stems not only from the advancement of the state of the art technology but mainly through a process of structural change in which productive resources and workers are transferred from activities with lower added value per employee (less sophisticated or complex sectors) to activities with higher added value per employee (more sophisticated or complex sectors).

Thus, the sectoral composition or productive structure of a country conditions labor productivity and, therefore, the level of per capita income. It is not possible to account for the so-called total factor productivity without looking at the structure of employment, the structure of technological domain, and the share of sectors in the GDP (industry, agriculture, and services). This idea is one of the fundamental propositions of the Brazilian 'new-developmentalist' school.[4]

The new-developmentalist school credits the slow growth of the Brazilian economy in the last 30 years to the regression in the productive structure – that is, to its premature deindustrialization – and the behavior of two macroeconomic variables that contributed decisively to this scenario: the chronic appreciation of the exchange rate (interrupted momentarily by the cycles of exchange rate crisis and strong depreciation of the exchange rate) and the constant practice of high interest rates, even when the macroeconomic scenario was favorable, as was the case between 2005 and 2008. This process was expressed in the deindustrialization and the reprimarization of exports (Oreiro, 2016).

For new developmentalist authors, the resumption of the growth of the Brazilian economy on a sustainable basis involves a devaluation of the real exchange rate sufficient to make

[1] According to Hidalgo (2015, chapter 10), technical and scientific knowledge is embedded in people (human capital), machines and equipment (physical capital), and people's ability to connect and thus exchange information (social capital). Thus, what is produced and exported by an economy reveals the sophistication or complexity of its productive capacities.

[2] The qualification of the workforce should not only be reduced to the level of formal education of workers, as measured by the average number of years of study, but also the degree of adequacy of the workforce to the particular needs of companies. In Porter''s words, "contrary to conventional wisdom, simply having a general work force that is high school or even college educated represents no competitive advantage in modern international competition. To support competitive advantage, a factor must be highly specialized to an industry's particular needs – a scientific institute specialized in optics, a pool of venture capital to fund software companies" (Hidalgo, 2015, p. 148).

[3] Although high added value per unit of labor employed can also be seen in high-tech services and agriculture, recent empirical evidence shown by Gabriel et al. (2020, p. 63) shows that a higher share of primary sector in added value is associated with lower growth rates of GDP per capita, even after controlling for the level of technological gap. It is also shown that for developing countries, a higher share of services sector is associated with a lower growth rate of GDP growth. This means that the composition of output matters for long-run growth.

[4] See Bresser-Pereira et al. (2015) and Gala (2017).

Brazilian manufacturing companies competitive compared to their external competitors, which would induce a process of increasing productive sophistication, made possible by a significant increase in the investment rate. This is because an exchange rate at the level of the 'industrial equilibrium' – the level of the exchange rate that allows domestic companies, given the current level of technological gap, to be competitive in the international market[5] – would make the average costs charged by domestic companies equal to those of their competitors. This not only allows the increase in profit margins of companies operating in the marketable goods producing sector (thus allowing an increase in the capacity to self-finance the investment of these companies), but also induces a process of substitution of imports by domestic production.

Given the centrality of the industrial equilibrium exchange rate in new developmentalist literature, it is essential to establish how it is determined. Marconi (2012) developed a method based on the equalization of unit labor costs between domestic firms and foreign companies, which is a direct application of the structuralist model developed by Porcile and Cimoli (2007).[6] The main input for this calculation is a historical series of the industrial equilibrium exchange rate index (ICEI), which represents an effective real exchange rate calculated from the unit labor costs of the main Brazilian trading partners with regard to trade in manufactured products. The ICEI is, by definition, a competitiveness index since it is calculated from the unit costs of labor. A country's unit labor cost is a measure of productivity, calculated as the ratio between average wage and productivity (or between wage and value added, when the former is not available).

The problem with the ICEI is that it clearly underestimates the value of industrial equilibrium exchange rate for Brazil in recent years. Indeed, the calculation of the ICEI for Brazil[7] by the CND (Center for Studies of New Developmentalism) showed that since 2017, the nominal bilateral exchange rate US$/R$ is approaching the industrial equilibrium level,[8] thereby reducing the level of exchange rate overvaluation, despite the growing increase in the current account deficit as a ratio to GDP (see figure 1), which is a clear sign of real exchange rate overvaluation in economies with an abundance of natural resources.[9,10] A new

[5] An anticipation of the concept of industrial equilibrium exchange rate can be found in Diamand (1972).

[6] See equation 15, page 296 of Porcile and Cimoli (2007).

[7] See Bresser-Pereira (2020).

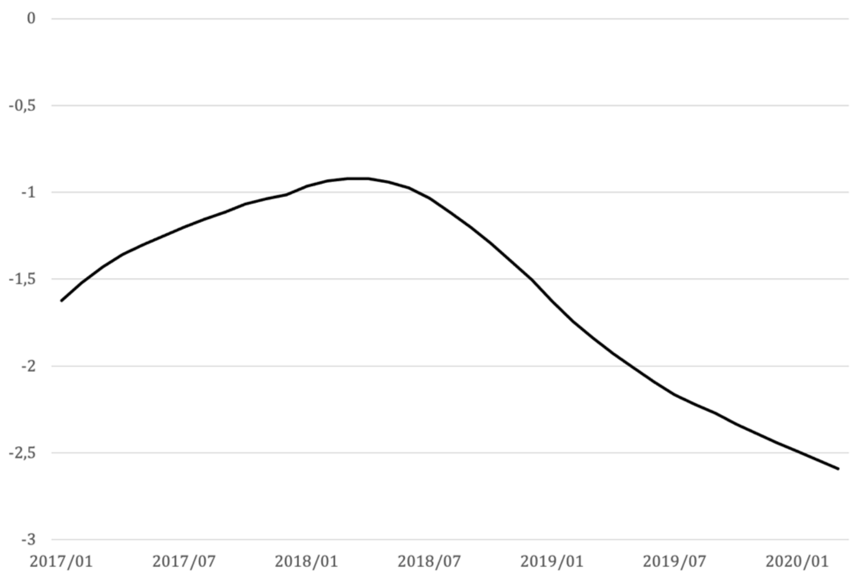
[8] See https://cnd.fgv.br/sites/cnd.fgv.br/files/Taxa%20de%20C%C3%A2mbio%20de%20Equil%C3%ADbrio%20Industrial.xls

[9] According to the new-developmentalist literature (Bresser et al., 2015) there are two concepts of equilibrium exchange rate. The first one is the industrial equilibrium exchange rate, defined as the level of real exchange rate for which domestic companies that make use of state-of-the-art technology are competitive both in domestic and international markets; the other is the current account equilibrium exchange rate, defined as the level of real exchange rate for which the current account deficit is equal to zero. In countries with abundant natural resources, the industrial equilibrium exchange rate is higher than the current account equilibrium exchange rate, since the production and export of commodities generates a kind of Ricardian income which allows the commodities sector to have a satisfactory rate of profit at a level of the exchange rate much lower than the one required by the manufacturing sector. This wedge between the industrial equilibrium exchange rate and the current account equilibrium exchange rate is precisely the Dutch disease, according to new developmentalist literature.

[10] According to the new developmentalist literature, exchange rate overvaluation can be the result of both Dutch disease and inflows of foreign capital due to the adoption of the so-called growth model with foreign savings (See Oreiro et al., 2020b), also known as *Peripherical Financialization* (Oreiro et al., 2020a). If the real exchange rate is below the industrial equilibrium exchange rate but above the current account equilibrium exchange rate, then the country must experience 'premature deindustrialization' with a surplus in the current account. The occurrence of deficits in the current account is a clear sign of exchange rate overvaluation since the real exchange rate had to be even below the current account equilibrium level, which, in countries with abundant natural resources, is lower than the industrial equilibrium exchange rate.

methodology for the calculation of industrial equilibrium exchange rate is required in order to evaluate the role of real exchange rate overvaluation in the premature deindustrialization of the Brazilian economy.

Figure 1 – *Current account balance as a ratio to GDP in Brazil, 12 month moving average* (01/2017 *to* 03/2020)



Source: IPEADATA, available at the URL www.ipeadata.gov.br.

The aim of this article is to analyze the determinants of the deindustrialization of the Brazilian economy in the period 1998-2017, based in a new-developmentalist perspective. We shall argue that the Brazilian case is a typical example of 'premature deindustrialization' in the sense that the major reason for the fall in the manufacturing share is not due to the increase in the per-capita income over some threshold value – as was the case of advanced economies in the 1970's – but rather the consequence of real exchange rate overvaluation that occurred in Brazil since the beginning of the 2000s.[11] In the Brazilian case, however, real exchange rate overvaluation results both from an appreciation of the real effective exchange rate, and an increase in the equilibrium value of the real exchange rate, the so-called industrial equilibrium exchange rate of the new-developmentalist literature. The rise of the equilibrium level of the real exchange rate is due, mainly, to the huge reduction of the economic complexity, measured by the Economic Complexity Index (ECI, hereafter) of the Brazilian economy. In order to do

[11] One may argue that the premature deindustrialization of the Brazilian economy in the last 20 years was related to the Dutch disease since this phenomenon is related to the transfer of resources and labor to the primary sector, but the movement observed in Brazil was atransfer of resources and labor to the low-tech services sector. This argument ignores, however, that the real exchange rate can also be defined as the price ratio of tradeable and non-tradeable goods. This means that an appreciation of the real exchange rate signifies an increase in the prices of non-tradeable goods (for example, services) relative to tradeable goods (for example, manufactured goods), which will produce an increase in profits and wages in the non-tradeable sector and a decrease in profits and wages in the tradeable sector, thereby causing a transfer of resources and employment from manufacturing to the (low tech) services sector.

that we will present a new methodology for calculating the industrial equilibrium exchange rate, The policy implication of our results is that the elimination of the real exchange rate overvaluation in Brazil requires not only the adoption of a macroeconomic policy regime in which some kind of real exchange rate targeting is adopted; but also industrial policies designed for increasing the economic complexity of the Brazilian economy and, hence, to reduce the equilibrium value of the real exchange rate, making the required adjustment in the real exchange rate socially and politically viable.

1. Structural change and economic growth: Why deindustrialization matters

1.1. Industrialization as the engine of productivity growth

Long-term economic growth is driven by labor productivity growth. Productivity, in turn, can grow in two ways: the first way is to increase the level of labor productivity in some sectors of activity. In the case of the manufacturing sector, labor productivity increases over time due to the positive spillover effects of the technological frontier on domestic firms. These spillovers can occur through multiple channels: one channel is the purchase of machines and equipment produced abroad, which incorporate the most advanced production techniques thus enabling domestic firms to operate with the same technological standard, and therefore technical efficiency, of their counterparts abroad. Another channel is direct foreign investment, in which companies operating abroad transfer production units, and therefore technologies embedded in them, to the domestic economy. In the services sector, the advance of productivity depends on the accumulation of social capabilities, which increases the potential productivity of the services sector, thus increasing the gap with respect to the current level of labor productivity in this sector. In the traditional or subsistence sector, labor productivity tends to become stagnant due to the absence of capital in the production process.

A second way to generate increased labor productivity is through the transfer of labor from the traditional sector – where labor productivity is lower – to the industrial and services sector, where labor productivity is highest. In this case, the increase in labor productivity stems from a change in the employment and production structure of the economy[12].

These ideas are presented formally in a model developed by Rodrik (2014) and will be presented briefly in the next paragraphs. The model considers a small open economy with three sectors, namely: (a) the traditional, or subsistence sector, which does not employ capital in such a way that the productivity of labor in this sector is null or negligible; (b) the industrial or manufacturing sector in which labor productivity is positively affected by the spillovers effects from the technological frontier, thus exhibiting 'unconditional convergence'*;* which means that the further away industrial domestic firms are from the technological frontier, the higher the subsequent rate of growth in labor productivity (Rodrik, 2013a); and (c) the services sector in which the potential productivity of labor is a function of the social and institutional capabilities of the economy, which is supposed to be a geometric average between variables that reflect the accumulation of human capital and the institutional development of the economy.

It should be noted that the process of accumulation of social capabilities is gradual, but extremely slow. This is because institutional reforms in one area of the economic system

[12] Regarding the key role of manufacturing in the process of economic development see Kaldor (1967), Thirwall (2002), Szirmai (2012), Rocha (2018) and Gabriel el al. (2020).

generally require complementary and sometimes simultaneous reforms in other areas to have a noticeable effect on the efficiency and productivity of labor. For example, the adoption of an effective regulatory framework requires not only a high level of human capital, but also an accountable political system and a merit-based bureaucratic culture. Gathering all these conditions is a task that takes a lot of time and effort from the political system. Low or middle-income countries generally have low levels of social capabilities, which means that productivity of the services sector will be low in these countries. Since the growth of labor productivity in this sector is proportional to the gap between the potential productivity and the current level of this variable, productivity gains that are achieved through the transfer of labor from the traditional sector to the services sector are usually exhausted rapidly.

The manufacturing industry differs from the services sector because it benefits from technological spillovers from foreign firms, thus presenting unconditional or "absolute convergence" (Rodrik, 2013, p. 166). This allows a much faster and persistent growth of labor productivity due to transfer of labor from the traditional sector to the manufacturing sector.

The average productivity of labor in the economy is given by equation (1) below:[13]

$$y = \alpha_M y_m + \alpha_s y_s + (1 - \alpha_M - \alpha_s) \qquad (1)$$

where: y is the average labor productivity; y_m is the labor productivity in the manufacturing sector, y_s is the labor productivity of the services sector, α_M is the share of manufacturing employment on total employment; y_s is the share of the service employment on total employment.

The growth rates of labor productivity in the services sector and in the manufacturing sector are given by:

$$\hat{y}_s = \gamma[\ln y^*(\theta) - \ln y_s] \qquad (2)$$

$$\hat{y}_M = \beta\left(\ln y_M^f - \ln y_M\right) + \gamma[\ln y^*(\theta) - \ln y_s] \qquad (3)$$

$$y^*(\theta) = \frac{y^{max}}{1 + \exp[-k(\theta - \theta_0)]} \qquad (4)$$

Equation (2) shows that labor productivity growth in the services sector is proportional to the gap between potential labor productivity, which is determined by the social capabilities accumulated by the economy (θ) and the actual level of labor productivity in that sector. Equation (3) shows that productivity growth in the manufacturing sector is not only proportional to the gap between potential labor productivity and the actual productivity level of the manufacturing sector, but also proportional to the gap between labor productivity of the technological frontier y_M^f and the actual level of this variable in the domestic manufacturing sector. Finally, equation (4) shows that the relationship between social capabilities and potential labor productivity in the services sector is given by the equation of the logistic curve, which is a simple formalization of the ideas discussed above regarding the accumulation of social capabilities and its effects over potential labor productivity.

From equations (1)-(3) we get:

[13] For simplicity we will consider that labor productivity in the traditional sector is constant and equal to 1. We will also assume that labor productivity in the traditional sector is lower than labor productivity in the manufacturing sector as well as in the services sector.

$$\hat{y} = [\alpha_M \pi_m + \alpha_s \pi_s]\gamma[\ln y^*(\theta) - \ln y_s] + \alpha_M \pi_m \beta(\ln y_M^f - \ln y_M) + (\pi_m - \pi_T)d\alpha_M + (\pi_s - \pi_T)d\alpha_s \quad (5)$$

where: $\hat{y}$ is the average growth rate of labor productivity of the economy, $\pi_m = \frac{y_m}{y}$ is the ratio between labor productivity of the manufacturing sector and the average labor productivity, and $\pi_s = \frac{y_s}{y}$ is the ratio between labor productivity of the services sector and the average labor productivity.

Equation (5) shows the existence of four different channels of labor productivity growth in the economy under consideration, namely:

1. Channel (A) or type I level effect: Refers to the convergence process that accompanies the accumulation of skills and the improvement of institutions being represented by $\{[\alpha_M \pi_m + \alpha_s \pi_s]\gamma[\ln y^*(\theta) - \ln y_s]\}$.
2. Channel (B) or type II level effect: Refers to the spillover effects of the technological frontier of the foreign industrial sector to domestic manufacturing; being represented by $[\alpha_M \pi_m \beta(\ln y_M^f - \ln y_M)]$.
3. Channel (C) or type I composition effect: Refers to structural change in the sense of Lewis (1954), i.e. the reallocation of labor from the traditional sector to the industrial sector; being represented by $[(\pi_m - \pi_T)d\alpha_M]$. This effect represents the historical role of industrialization in economic development.
4. Channel (D) or type II composition effect: Refers to structural change type II, in which the reallocation of the workforce from the traditional sector to the services sector occurs; being represented by $[(\pi_s - \pi_T)d\alpha_s]$.

It should be emphasized that the power of these channels varies with the stage of economic development. In fact, in poor countries and/or middle-income countries θ is low, so channel A is weak. The B channel of technological spillovers is also weak for this group of countries, because the share of manufacturing employment in total employment is low. The C channel is strong. In fact, assuming that the relative productivity of the manufacturing industry is three times higher than that of the subsistence sector; then if 1% of the workforce is relocated from the traditional sector to the manufacturing sector per time period, then the average productivity of the economy will grow by 3% per period. Regarding channel B, if we assume that: (*i*) = $[\ln y^*(\theta) - \ln y_s] = 2.3$ (which implies that the labor productivity of the manufacturing sector at the technological frontier is ten times higher than in the domestic economy); (*ii*) 5% of the workforce is employed in the manufacturing sector; and (*iii*) the relative productivity of the manufacturing is 400%; then for a value of $\beta = 3$, we get that the average productivity of the economy will only grow by: $0.05 \cdot 4 \cdot 0.03 \cdot 2.30 = 1.4\%$ per period.[14]

In short, the best hope for fast growth in a low-income country is based on the reallocation of the workforce to manufacturing and, secondarily, on the effects of spillovers of the technological frontier to domestic manufacturing. This means that long-term growth is essentially the result of industrialization led by structural change. As stated by Rodrik (2016):

> "Our modern world is in many ways the product of industrialization. It was the industrial revolution that enabled sustained productivity growth in Europe and the United States for the first time, resulting in the division of the world economy into rich and poor nations. It was industrialization again that permitted catch-up and convergence with the west by a relatively smaller number of non-western nations – Japan starting in the last nineteenth century, South Korea, Taiwan and a few others in the 1960's. In countries that still remain mired in poverty such as those in sub-Saharan

[14] Regarding the parameter values used in the calibration of the model, see Rodrik (2014).

Africa and south Asia, many observers and policy makers believe future economic hopes rest in important part on fostering new manufacturing industries".

1.2. Deindustrialization and the limits for structural change

Even though structural change through industrialization is the most appropriate strategy to produce accelerated growth in labor productivity in low- or middle-low-income countries. This strategy has a limit; there is a ceiling (which should certainly be less than 100%) for the share of manufacturing employment in total employment. Thus, the growth of labor productivity cannot be driven ad-infinitum through the intersectoral reallocation of the workforce. Moreover, the share of manufacturing employment in total employment tends to start declining after the economy reaches a certain level of per capita income. This is a simple consequence of Engel's law. Although labor productivity growth is higher than the average productivity growth, for low levels of per capita income, the share of income spent in manufacturing goods is an increasing function of per-capita income, leading to the increase in the share of manufacturing employment. After a certain threshold level of per capita income is reached, however, the structure of domestic demand begins to be directed toward services and the share of manufacturing employment starts to decrease.

The change in the demand structure from a certain stage of economic development is one of the causes of the deindustrialization process observed in developed countries since the 1970s (Rowthorn and Ramaswany, 1999; Rodrik, 2016).[15] The evolution of the demand structure through the process of economic development generates an inverted U-shaped curve for the relation of manufacturing share in total employment and the level of per-capita income (see Rodrik, 2016).

Thus, as the share of manufacturing employment in total employment reaches this upper limit, growth slows down. Once this limit is reached, if the economy has accumulated an adequate level of social capabilities, new convergence forces will be activated, i.e. channels A and D, thus allowing the maintenance of an accelerated pace of growth in labor productivity. In this context, deindustrialization will not be a risk to the continuity of the process of economic development, because the workforce can be shifted from the manufacturing sector to highly skilled modern services. We will define this kind of deindustrialization as mature deindustrialization, since it is associated with the changes occurred in advanced economies and hence occurred at high levels of per capita income.

However, it is possible for a country to begin its deindustrialization process before it has accumulated the necessary social capabilities to activate convergence channels A and D. In this case, we will have premature deindustrialization,[16] with a reduction in the pace of growth of labor productivity and a slowdown in economic growth.

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[15] Here, it is important to differentiate between employment deindustrialization and output deindustrialization, as was done by Rodrik (2016). Developed countries have observed a considerable reduction in the share of manufacturing employment in the last 40 years; but the same was not observed with the manufacturing share of value added at constant prices. Developing economies, mainly in Latin America and Sub-Saharan Africa have observed both types of deindustrialization.

[16] According to Rodrik (2016), premature deindustrialization can be defined in two ways. The first is the idea that premature deindustrialization occurs when the share of manufacturing employment and output started to decline at a level of per capita income lower than the one observed in advanced economies. The second is to define premature deindustrialization as the structural change that has detrimental effects on economic growth.

There are policies that can act to postpone the process of deindustrialization, thus buying the time necessary for the country to accumulate the level of social training necessary to enable an accelerated pace of growth in labor productivity from the services sector.

To show this, let us define φ as the share of the added value of the manufacturing industry in domestic absorption and b as the ratio of trade surplus of the manufacturing sector to GDP. We will also assume that the numeraire of the economy is the implicit deflator of GDP and that p_m is the relative price of manufactured goods.

We can easily demonstrate that the maximum share of manufacturing employment in total employment is determined by equation (6) below:

$$\alpha_M = \frac{1}{p_m \pi_m}[\varphi(1-b)+b] \quad (6)$$

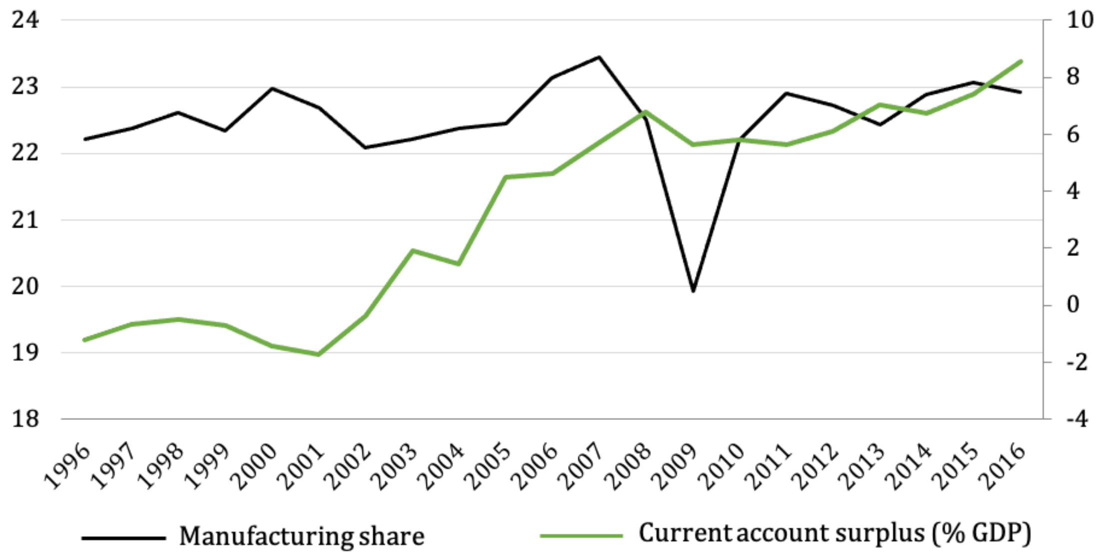
Taking the derivative of equation (6) relative to b, we get:

$$\frac{\partial \alpha_M}{\partial b} = \frac{1}{p_m \pi_m}(1-\varphi) > 0 \quad (7)$$

In equation (7) we found that an increase in the ratio of trade surplus of the manufacturing industry to GDP leads to an increase in the maximum share of industrial employment in total employment. Thus, the potential size of the manufacturing sector can be increased or decreased by reducing the deficit or increasing the trade surplus of the manufacturing industry. This means, therefore, that deindustrialization can be delayed through policies aimed at increasing the trade surplus of the manufacturing industry, thus buying the time necessary for the level of social training to reach the level necessary to activate channels A and D of productivity growth. These policies are 'neo-mercantilist policies' (Rodrik, 2013b).

One way to achieve a permanent increase of b is to keep the exchange rate at a competitive or undervalued level. As such, maintaining a permanently undervalued exchange rate is an attractive option for low-income countries wishing to achieve fast productivity gains through industrialization (Rodrik, 2008; Missio et al., 2015; Gabriel et al., 2020). This option was adopted by China and other Southeast Asian countries. But these policies are also being adopted by high-income countries. Germany managed to make a strong internal devaluation of the exchange rate in the 1995-2005 period by means of a significant reduction in the unit cost of labor compared to the level prevailing in other European countries (Flassbeck, 2017). This policy has been successful in keeping the manufacturing industry share of GDP in Germany at a relatively stable level in the period 1996-2016, as shown in figure 2.

Figure 2 – *Share of the manufacturing industry in GDP and current account surplus as a ratio to GDP in Germany* (1996-2016)



Source: World Bank.
Note: The participation of the manufacturing industry is measured on the left axis, while the balance in the current account is measured on the right.

2. Economic complexity and manufacturing: the missing link

More recently, advances in network science have brought significant contributions to the study of economic development using highly disaggregated trade data. Research on economic complexity and the relatedness between different industries have made significant methodological and empirical advances in this regard (Hidalgo et al., 2007; Neffke et al., 2011; Hausmann et al., 2014; Pinheiro et al., 2018; Balland et al., 2019; Hartmann et al., 2019). These methods capture how close or distant companies, regions, or countries are from potential new products and the technological frontier in terms of productive capabilities. They help to identify the unique structural constraints and opportunities of countries at different stages of productive diversification and the right moment to jump into complex products (Alshamsi et al., 2018; Petralia, et al., 2017; Pinheiro et al., 2018). For instance, countries at intermediate levels of productive diversification tend to have larger opportunities to jump into more distant, complex and unrelated activities (Pinheiro et al., 2018, Hartmann et al., 2019a, 2019b).

Hausmann et al. (2014) use computing, networks, and complexity techniques to create a method capable of measuring the productive sophistication, or the "economic complexity", of countries with extraordinary simplicity. Based on an analysis of a given country's exports, they can indirectly measure the technological sophistication of its production fabric. The methodology developed to build economic complexity indexes culminated in an *Atlas* (http://atlas.media.mit.edu) that gathers extensive material on countless products and countries since 1963. How does one measure an economy's "economic complexity"? Hausmann et al. (2014) devised a method that combines simplicity and comparability across countries. The two basic concepts for measuring whether a country is economically complex or sophisticated are the ubiquity and diversity of the products it exports. If a certain economy is capable of producing non-ubiquitous goods, this is indication of a sophisticated production fabric. This brings up a relative scarcity issue, particularly for natural products such as diamonds and uranium. Non-ubiquitous goods can be divided into those with high technology content, which are difficult to manufacture (such as airplanes), and those that are highly scarce in nature (niobium, for example), and which are therefore non-ubiquitous by definition.

The authors use an ingenious technique to control this issue of scarce natural resources as concerns the measurement of complexity: they compare the ubiquity of a product made in a certain country with the diversity of products that the same country can export. To illustrate: Botswana and Sierra Leone export something that is rare and therefore non-ubiquitous: uncut diamonds. On the other hand, their exports are extremely limited and undiversified. These, then, are two cases of non-ubiquity without complexity. At the opposite end lie, for example, products such as medical image processing equipment, which only Japan, Germany, and the United States can make; they are certainly non-ubiquitous products. But, in this case, the Japanese, American, and German exports are extremely diversified, indicating that these countries are highly capable of making many different things. That is, non-ubiquity coupled with diversity means "economic complexity". On the other hand, a country with a very diversified exports list that is made up of ubiquitous goods (fish, fabric, meat, ores, etc.) lacks economic complexity; it does what everyone else can also do.[17]

By calculating the probability of goods being jointly exported by several countries, Hidalgo et al. (2007) also created an interesting measure of the production know-how contained in goods, and of the local capabilities needed to produce them: the "product space". The greater the probability of two products being jointly exported, the greater the indication that they contain similar characteristics and, therefore, require similar production capabilities: they are 'sibling' or 'cousin' products. This joint exportation indicator ends up serving as a measure of the production know-how linkage between products, that is, it indicates the production links among various goods thanks to the shared requirements needed to make them. Highly connected and complex goods are therefore loaded with potential technological know-how. This makes them knowledge hubs; whereas low connectivity and less complex goods require simple production capabilities, and have low knowledge multiplication potential. In this case, manufactured goods stand out compared to commodities. For example, countries that make advanced combustion engines probably have engineers and knowledge that enable producing a range of similar and sophisticated things. Countries that only produce bananas or other fruit have limited know-how and will probably be unable to make more complex goods. It is important to emphasize that any difficulty in observing this is a result of being unable to directly measure and capture such local productive skills. International trade data shows products, not the skills that countries use to produce them.

Empirically, the *Atlas* shows that manufactured goods are generally characterized as more complex and connected whereas commodities emerge as non-complex and non-connected goods. Out of the 34 main communities of goods in the *Atlas* calculated by their network compression algorithm (Rosvall and Bergstrom, 2007), one finds that machinery, chemicals, airplanes, ships, and electronics stand out as the more complex and connected goods. On the other hand, precious stones, oil, minerals, fish and shellfish, fruit, flowers, and tropical agriculture show very low complexity and connectivity. Vegetable oils, textiles, construction

[17] See Hausmann et al. (2014) for the formal definition of economic complexity.

material and equipment, and processed food occupy an intermediate position between more and less complex and connected goods.

For our purposes, the economic complexity index (ECI) is highly useful to measure the relative distance of productive systems to the technological frontier.[18] A higher ECI means proximity to the world technological frontier, meaning that price competitiveness becomes less important than quality competitiveness where countries and companies have proprietary technologies and patents, in other words, monopolistic power. The richer the country is, the less it relies on undervalued exchange rates to bring competitiveness. The ECI index can be taken in this regard as a measure of non-price competitiveness and economic sophistication.[19] Deindustrialization at high levels of per capita income usually come hand in hand with high ECI index. Very rich countries are complex, sophisticated and go through the process described above.

3. New developmentalism, industrial equilibrium exchange rate and the dynamics of manufacturing share

One of the core propositions of the new-developmentalist Brazilian school is that the tendency toward overvaluation of the real exchange rate is one of the main obstacles to the catching-up process of middle-income countries (Bresser-Pereira, 2018, p. 57). This trend is the result of two distinct, though complementary, forces. The first one is the abundance of natural resources, the source of Dutch disease. It is known that the price of primary goods is determined by the production cost of the least efficient producer. Thus, countries with abundant natural resources are, by definition, countries in which the cost of production is lower than that countries where natural resources are scarce. The difference between the cost of inframarginal production (in countries where natural resources are abundant) and the cost of marginal production (where natural resources are scarce) is called the Ricardian rent. Since the cost of production encompasses the normal rate of return on capital applied in productive activity, activities related to the exploitation of natural resources end up obtaining an extra normal profit rate. Equalization of the profit rate between sectors therefore requires that the price of primary goods in the domestic currency be decreased to reduce its difference compared to the marginal cost of production in other sectors. The only way this can occur is through an appreciation of the nominal exchange rate, which reduces the price in national currency of primary goods, given the price in foreign currency in international markets.

The second source of appreciation of the exchange rate is foreign capital inflows. These inflows depend, however, on the liberalization of the capital account, something that may or may not be done by the governments of middle-income countries. In general, Latin American countries decided to open their capital accounts in the 1990s (see Frenkel, 2002), while East

[18] See Gabriel and Missio (2019).
[19] We are aware, however, that there are criticisms too leveled against the ECI. The main ones are that export baskets do not necessarily capture technological content of local production insofar as countries may import high-tech components and then re-export them without adding local technological content (as in "maquila countries"). An answer to this criticism is that this happens only with intermediary complexity countries such as Brazil, Mexico, or Hungary, among others. True complex countries exhibit local technological production that can be measured e.g. by numbers of patents per capita or the R&D expenditure over GDP. See the work of Schteingart (2014) as an example of how to deal with this problem by taking together the ECI index and the R&D expenditure and patents per capita in order to overcome this issue.

Asian countries either kept their capital accounts relatively closed (such as China) or made a much smaller opening than that made by Latin American countries (as was the case in South Korea and other East Asian countries).

The opening of the capital account allows surplus capital in developed countries to seek higher returns on portfolio investments in middle-income countries. Returns on financial assets are higher in middle-income countries for two reasons: (*i*) the lower liquidity due to lower organization of capital markets in middle-income countries, which is reflected in a higher risk premium for the assets of these countries relative to the assets of developed countries thus allowing greater profitability for investors; (*ii*) the significant exchange rate appreciation resulting from the inflows of foreign capital in the relatively low-liquidity financial markets of middle-income countries acts to increase the asset return differential between middle income countries and developed countries, thus refueling the incentive for speculative capital inflows into the former.

The combination of Dutch disease and the liberalization of the capital account in middle-income countries ends by generating a tendency toward overvaluation of the exchange rate that is only reversed, for brief periods, by a currency crisis—a sudden and strong devaluation of the exchange rate due to the sudden-stop of capital flows. However, after the most critical moment of the crisis, and the confidence of international markets has been restored, capital inflows start again, leading the exchange rate to appreciate, thus restarting the cycle of appreciation that will lead to the next currency crisis. This is the reason why this phenomenon is described in the new-developmentalist literature as a "cyclical trend to overvalue the exchange rate" (Bresser-Pereira, et al., 2015, p. 71).

This cyclical trend to overvalue the exchange rate is the cause of the premature deindustrialization processes in middle-income countries and, therefore, the reason for their inability to catch-up (Oreiro, 2018).

The dynamics of the manufacturing share over time are influenced by the price competitiveness as well as non-price competitiveness factors. With regards to the price competitiveness, an overvalued exchange rate, i.e. a real exchange rate below some long-run equilibrium value, may lead to a progressive reduction of the share of the manufacturing industry in GDP, since such a situation induces an increased transfer of productive activities to other countries (Cimoli and Porcile, 2014). We will call this level of the real exchange rate of the 'industrial equilibrium level'.

Bresser-Pereira and Gala (2010) and Bresser-Pereira et al. (2015) defined the industrial equilibrium exchange rate (IEER, hereafter) as the level of real exchange rate that makes firms that use state of the art technology competitive both in domestic and international markets. The problem with this concept is that, for developing countries, firms in general operate behind the technological frontier (Oreiro et al., 2020b).[20] As a matter of fact, a fundamental feature of developing economies is that they are far from the technological frontier and therefore their

[20] This concept also had problems of measurement. Marconi (2012) developed a methodology for calculating the industrial equilibrium exchange rate that implies the equalization of unit labor costs in home and foreign countries. The obvious shortcoming of using this methodology is that it requires that "average cost per unit is basically composed of the unit labor cost" (ibid, p. 661). Manufacturing activities differ a lot in terms of labor intensity in the production sector. Indeed, we can state as a stylized fact that for industries with low and middle-low technological intensity, labor costs are a very important component of the average cost per unit; but its importance is much lower in middle-high to high technological intensity manufacturing activities. Thus, depending on the technological intensity of the manufacturing industry of a given country, this method can produce a large underestimation of the industrial equilibrium rate.

firms cannot operate with state-of-the-art technology. This technological gap negatively affects the non-price competitiveness of manufacturing firms in developing economies, which produce manufactured goods that are of inferior quality and/or lower technological intensity than the manufactured goods produced in developed economies (Verspagen, 1993). As a consequence, the existence of the technological gap acts to reduce the competitiveness of developing countries industries, thus contributing to a reduction in their share of the manufacturing industry on real output.

In order to overcome this conceptual problem, we will redefine IEER as the level of real exchange rate that, for a given level of technological gap,[21] makes the share of the manufacturing industry on real output constant over time. Thus, in order to determine the IEER it is necessary to determine the factors that govern the dynamics of the manufacturing share over time. Based on previous discussion we will assume that the dynamics of the share of the manufacturing industry in real output is given by the following difference equation:[22]

$$h_t = h_{t-1} + \beta_0\theta_{t-j} + \beta_1 ICE_{t-j} + \beta_3 RPC_{t-j} - \beta_4\left(RPC_{t-j}\right)^2 \quad (8)$$

where: h_t is the share of the manufacturing industry in GDP in period t, θ_{t-j} is the real exchange rate in the $t-j$ period (j is the optimal lag period to be calculated in the econometric model). ICE_{t-j} is the index of economic complexity Hidalgo and Haussman obtained in the *Atlas of Economic Complexity*; and RPC_{t-j} is the real per capita income in period $t-j$. The lagged value of the manufacturing share is an obvious determinant of its current value due to the inertia of any structural variable. The lagged value of the real exchange rate represents the effects of price competitiveness over the manufacturing share. A time lag is required since changes in relative prices will only be capable of influencing the structure of production after some time. Economic complexity is used here as a proxy for the technological gap. The idea is that a larger technological gap implies a lower level of economic complexity, which explains the + sign in equation (8). Finally, the last term of the expression captures the effect of 'mature deindustrialization' due to effect of rising levels of per-capita income over the demand for manufacturing goods (Rowthorn and Ramaswamy, 1999; Rodrik, 2016).

Thus, the IEER level is the level of exchange rate[23] for which $h_t = h_{t-1}$. From (8) we get:

$$\theta_t^* = \frac{\beta_4(RPC_{t-h})^2 - (\beta_1 ICE_{t-h} + \beta_3 RPC_{t-h})}{\beta_0} \quad (9)$$

In equation (9) we can see that the IEER level is not constant through time, but depends on the evolution of economic complexity and per capita income. An increase in the economic complexity will reduce the level of the real exchange rate that is compatible with the stability of the manufacturing share. Since economic complexity is here a proxy for non-price competitiveness of the manufacturing industry, an increase in the level of ECI will indicate an increase in the non-price competitiveness of this sector, making it less dependent on price competitiveness for the maintenance of its share on GDP.

Real exchange rate overvaluation (*OverValue* %) in period t is thus defined as:

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[21] We will assume that the technological gap has a negative correlation with the index of economic complexity. The idea is that the higher the distance of a given country from the technological frontier, the lower its economic complexity will be since the country has lower levels of scientific and technological capabilities.

[22] For a detailed theoretical foundation of this equation and its components see Oreiro at al. (2020b) and Gabriel et al. (2019).

[23] Regarding the IEER index defined in equation (9), one of the referees commented that "hardly any literature backs and supports the use of the IEER index presented". This is true, because the main contribution of this article is precisely to develop a new concept of the industrial equilibrium exchange rate.

$$OverValue_t(\%) = \frac{\theta_t^* - \theta_t}{\theta_t^*} \quad (10)$$

4. Premature deindustrialization and overvaluation of the real exchange rate in the Brazilian economy (1995-2017)

To estimate the determinants of the manufacturing industry's share in GDP, the industrial equilibrium exchange rate, and exchange rate overvaluation in the Brazilian economy, we used yearly data for a series of variables from 1995 to 2017.[24] Data availability issues both for the manufacturing share of Brazilian economy and the ECI prevented us from starting the analysis before 1995. Table 1 describes the set of variables used and the respective data sources.

Table 1 – *Variables and data sources*

	Description	Unit	Data source
h	Share of the manufacturing industry in the Gross Domestic Product (GDP)	%	Brazilian Institute of Geography and Statistics (IBGE), available at https://www.ibge.gov.br/en/statistics/full-list-statistics.html
ICE	Economic Complexity Index[25]	Index	The Growth Lab at Harvard University, *Atlas of Economic Complexity*, available at https://dataverse.harvard.edu/dataverse/atlas
θ	Effective Real Exchange Rate – Broad Wholesale Producer Price Index, Global Supply, exports, manufactured goods, average value of the year. The annual observation was calculated by 12-month average.	Index (2010 = 100)	Institute of Applied Economic Research (IPEA), available at http://www.ipeadata.gov.br
RPC	Real per capita income (at 2010 prices), calculated by the ratio of the gross domestic product at market price to the size of the population, using the gross domestic product implicit deflator	Real Brazilian Currency	Brazilian Institute of Geography and Statistics (IBGE), available at https://www.ibge.gov.br/en/statistics/full-list-statistics.html

[24] We are aware that a number of observations greater than 30 is recommended for operating optimization methods to calculate the function parameters, given that regressions can be spurious. However, we always try to be as parsimonious as possible, in addition to always observing the residuals of regressions, and developing stability tests. However, the series of the manufacturing share had a methodological break in 1995 (Oreiro and Feijó, 2010), which means that values before 1995 are not comparable with values after 1995. This methodological break made it necessary to start the sample from 1995, making it impossible to extend the sample size, either forward or backward. Moreover, both data on the manufacturing share and the ECI are only released on an annual basis. Finally, we did not choose to create random annual numbers from observing the series trend within a specific band, with two or three periods forward and two or three periods backward to complete at least 30 observations, although over of time a linear negative trend is clearly defined.

[25] Regarding the Economic Complexity Index, we used a HS system, also known as Harmonized Tariff Schedule (HTS) code. The HS code description and coding was created by the World Customs Organization (WCO) to categorize goods into approximately 5,000 commodity groups, which is accepted and implemented by more than 200 countries worldwide. It is more detailed and updated than the old SITC which has lower disaggregation and less updates in terms of new products. The data on the HS system, however, only starts from 1992.

With this data, we performed the following steps: we (*i*) estimated the correlation matrix between variables; (*ii*) executed stationarity tests on the series, including the tests regarding the existence of trends in the series; (*iii*) performed a principal component analysis; (*iv*) estimated the function parameters, including the diagnostic tests on the coefficients, on the residuals and checked their stability; and we (*v*) estimated the dynamics of the industrial equilibrium real exchange rate, the real exchange rate overvaluation, and the share of the manufacturing industry in the GDP. In order to estimate the role of the share manufacturing industry in the GDP, as a modelling strategy, we used: different combinations of candidate variables; various specifications, including some with dummy variables; and various optimization methods. The latter include: (*i*) ordinary least squares (OLS), conjugated with autoregressive integrated moving average (ARIMA) maximum likelihood estimation; (*ii*) robust least squares (RLS) with or without dummy variables; and (*iii*) elastic net regularization (ENR). All steps and econometric results are contained in the Appendix.

We then calculated the industrial equilibrium exchange rate defined at equation 9, θ_t^*, that is, the level of the real exchange rate for which $h_t = h_{t-1}$. For Brazil, the value of the share of the manufacturing industry in the GDP in year 2001 is approximately equal to that of year 2000, $h_{2001} \cong h_{2000}$. Therefore, we use year 2001 as base (with value 100). Using the estimated coefficients shown in table A5, we obtain six series for the industrial equilibrium exchange rate. As shown in figure 3, they are not constant because their determinants (the values of ICE_{-3}, θ_{-1}, RPC_{-2} and RPC_{-2}^2) change over time.

Figure 3 – *Industrial equilibrium real exchange rate: predicted and observed, base 100 = 2001*

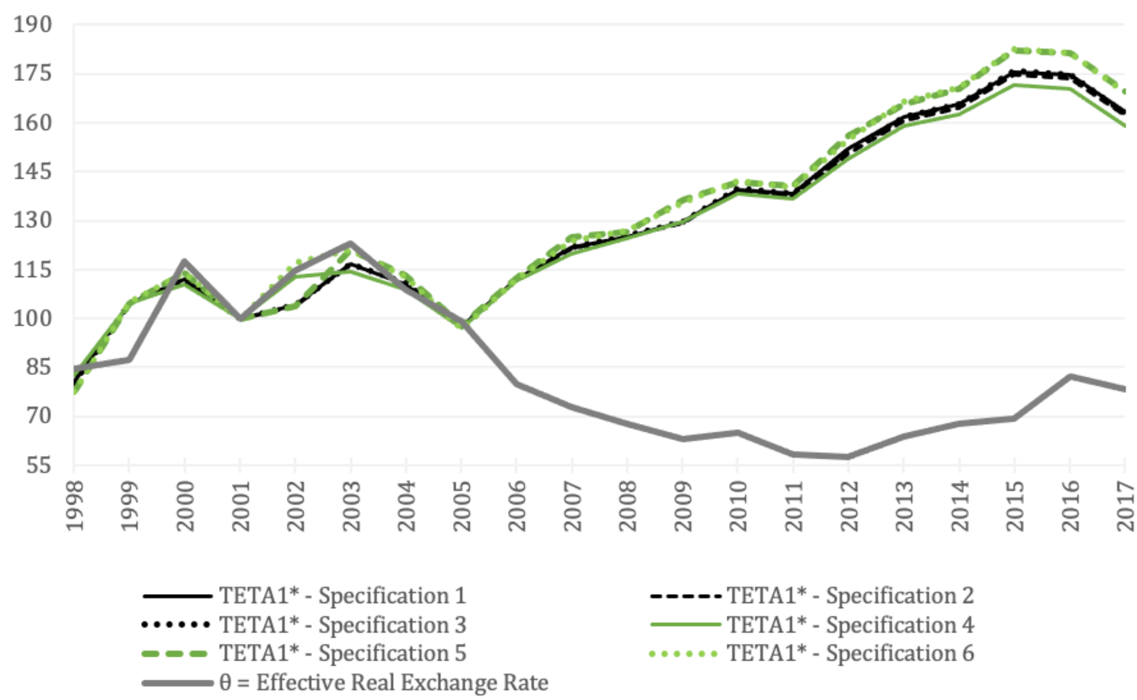
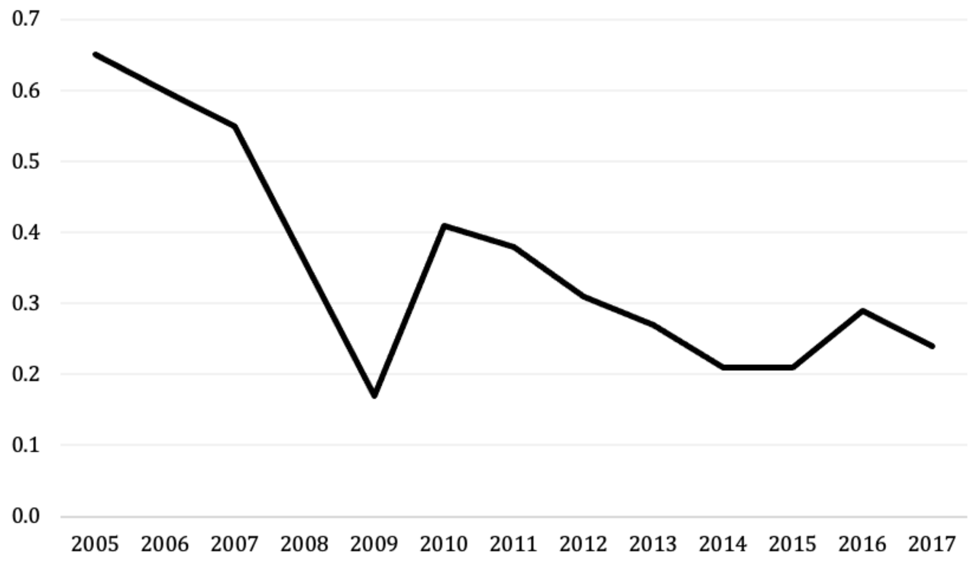


Figure 3 shows that the real exchange rate in Brazil remained more or less at a competitive level from 1998 to 2005, which is compatible with the relative stability of the manufacturing share in GDP during this period. As a matter of fact, the manufacturing share in GDP increased from 14% in 1998 to almost 18% in 2004. This small wave of reindustrialization of the Brazilian economy was probably the result of the real exchange rate undervaluation observed from 1998 to 2000, visible in figure 3. After 2005, however, the industrial equilibrium exchange rate starts to increase while the actual level of the real exchange rate decreased. Such appreciation of the real exchange rate was the result of a combination of large capital inflows to the Brazilian economy, due to the high interest rate differential generated by a very tight monetary policy, with a boom in commodity prices that increased the value of the Brazilian exports and hence increased the surplus of the trade account. What is intriguing is the behavior of the industrial equilibrium exchange rate. The question is why it increased by almost 80% until 2015.

The possible answer to this question is the behavior of the 'economic complexity index'. As equation (8) shows, the economic complexity index is a proxy for the non-price competitiveness of the manufacturing sector of an economy. Regarding the Brazilian case, figure 4 shows that economic complexity was suddenly reduced from 2005 on, indicating a huge decrease of non-price competitiveness of the Brazilian manufacturing industry.

Figure 4 – *Evolution of the Economic Complexity Index, Brazil* (*2005-2017*)



Source: The Growth Lab at Harvard University, *Atlas of Economic Complexity*, available at https://dataverse.harvard.edu/dataverse/atlas

One possible explanation for the huge reduction of the economic complexity index of the Brazilian economy after 2005 is the change in the composition of exports towards primary goods. As we can see in table 2 below, from 2008 to 2014, the share of primary goods in exports increased by 32.1% and the share of manufacturing goods decreased by 23.77%. Since primary goods have a lower economic complexity than manufacturing goods, this change in exports composition explains the decrease in the economic complexity index. This phenomenon of reprimarization of exports is a clear sign of the Dutch disease.

Table 2 – *Composition of Brazilian exports* (*2008-2014*)

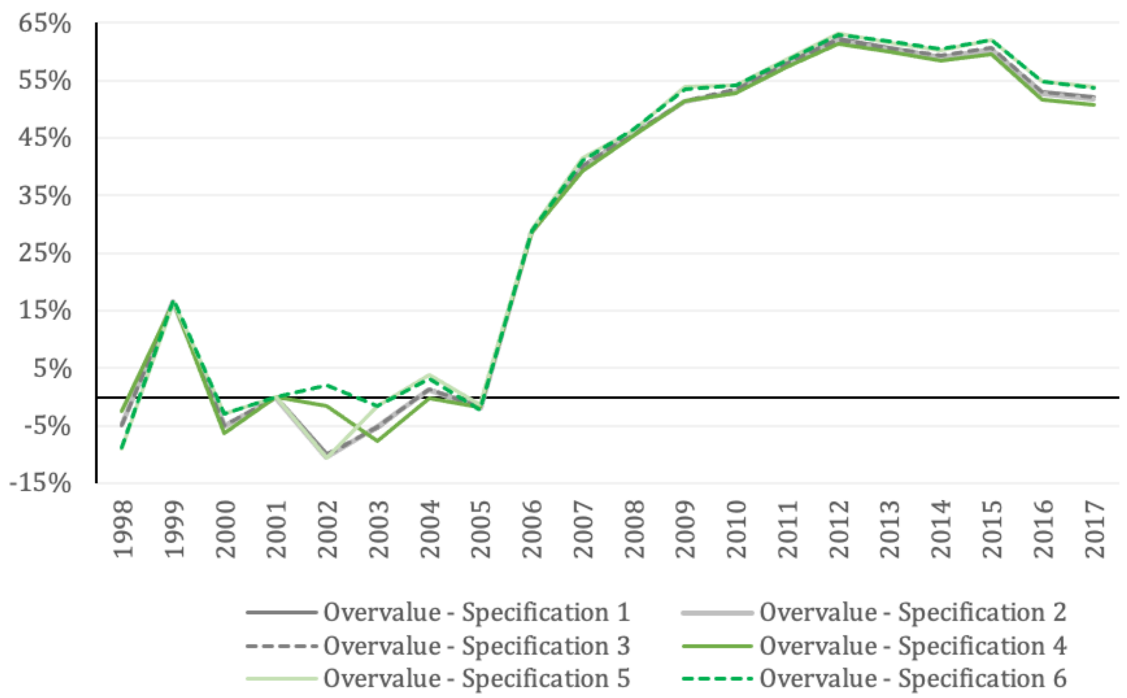
	2008	2009	2010	2011	2012	2013	2014
Primary	37.88%	41.36%	45.51%	48.83%	47.83%	47.79%	50.06%
Manufactured	48.08%	44.96%	40.23%	36.80%	38.24%	39.30%	36.65%
Semi-manufactured	14.04%	13.68%	14.26%	14.37%	13.93%	12.91%	13.28%

Source: Foundation Center for Foreign Trade Studies (FUNCEX), available at: http://www.funcexdata.com.br/

The reduction in non-price competitiveness requires an increase in price competitiveness for the manufacturing share to become stable over time. Unfortunately, this did not happen in Brazil. Indeed, after 2005 the Brazilian manufacturing industry experienced a reduction both in price and non-price competitiveness, with devastating result on its share on GDP.

In figure 5 we show the predicted values of real exchange rate overvaluation, defined as $OverValue_t(\%) = [(\theta_t^* - \theta_t)/\theta_t^*]$, according to the six specifications.

Figure 5 – *Predicted real exchange rate overvaluation between 1998 and 2017*

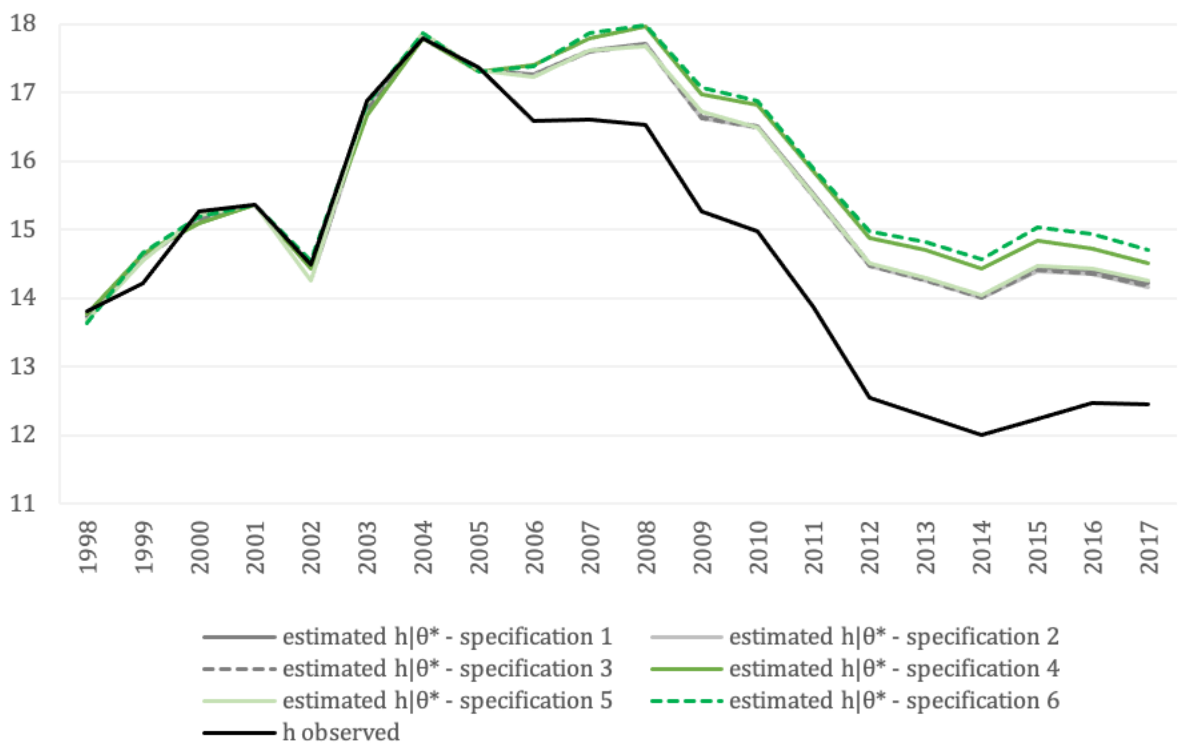


The six estimates show similar results regarding the time path of the overvaluation of the real exchange rate. We can divide the series results into two periods: from 1998 to 2005, and from 2006 to 2017. The first period is characterized by a slight undervaluation of the real exchange rate, except for the years 1999 (average 16.63%) and 2004 (average 1.84%), when overvaluation occurred. In the other years of the first period, there was a small undervaluation of the real exchange rate, by between -6.79% in 2002 and -1.76% in 2005. The second period, from 2006 to 2017, is marked by a chronic overvalued real exchange rate. Between 2006 and 2012, overvaluation reached its maximum average value of 62.25% in 2012. Between 2013 and 2015, the average exchange rate overvaluation remained at 60.33%. Finally, in the last two years of the series, there was a small fall in the overvaluation of the real exchange rate, with an average for the 2016-2017 period of 52.83%. It must be noticed that the chronic overvaluation of the industrial equilibrium exchange rate occurs as a consequence of a huge fall in the economic complexity index, from 0.65 in 2005 to 0.24 in 2017, that is a fall of -63.08% in this period.

It is obvious that an exchange rate overvaluation of almost 60% cannot be solved only by means of depreciation of the nominal exchange rate, since it will produce a huge inflation acceleration and a politically unacceptable reduction of real wages. A combination of depreciation of the nominal and real exchange rates with policies designed to increase economic complexity is required in order to eliminate the overvaluation of the real exchange rate.

Finally, we run a counterfactual exercise in which we analyze what the possible dynamics of the share of the manufacturing industry in GDP could be if the real exchange rate were kept at its industrial equilibrium value during the entire period. The results are reproduced in figure 6.

Figure 6 – *Predicted share of the manufacturing industry in the GDP if the industrial equilibrium exchange rate had been observed between 1998 and 2017*



We can easily see that after 2005 there is an increasing difference between the actual value of the manufacturing share in GDP and the values that would be observed if the real exchange rate were kept at the industrial equilibrium level. For 2017, the estimated value for the manufacturing share calculated at the industrial equilibrium level of the real exchange rate is 14.34% (average of all model specifications), a value 1.89 percentage points (p.p.) higher than the actual value, of 12.44%, for that year. Thus, observing the average of the six specifications, the overvaluation of the real exchange rate is responsible for a reduction by 13.19% of the Brazilian manufacturing share in 2017.

The results shown in figure 6 also demonstrate that even if the real exchange rate were kept at the industrial equilibrium level, the manufacturing share in GDP would fall after 2005; in other words, a competitive real exchange rate would not have been enough to prevent the deindustrialization of the Brazilian economy. The fall of non-price competitiveness of the manufacturing industry after 2005 was probably the main cause of Brazilian deindustrialization in the last 15 years. Indeed, the manufacturing share calculated at the industrial equilibrium level of the real exchange rate falls from 17.32% in 2005 to 14.34% in 2017, a reduction of -2.99 p.p. which is 1.58 times higher than the one caused by the real exchange rate overvaluation.

The results presented in figure 6 also allowed us to conclude that 61.06% of the total reduction of the manufacturing share in GDP observed since 2005 (4.88 p.p.) can be explained by the reduction in non-price competitiveness, and 38.94% by exchange rate overvaluation. These results are summarized in table 3.

Table 3 – *Evolution and decomposition of the deindustrialization of the Brazilian economy*

	2005	**2017**	**2005-2017**
Actual share of the manufacturing industry	17.32%	12.44%	-4.88 p.p.
Estimated share of the manufacturing industry at the industrial equilibrium exchange rate	17.32%	14.34%	-2.98 p.p.
% change of the manufacturing share due to a reduction of non-price competitiveness	-	-	61.06%
% change of the manufacturing industry due to exchange rate overvaluation	-	-	38.94%

6. Final remarks

Throughout the paper, we developed a new method for calculating the industrial equilibrium exchange rate, a central element of new-developmentalist literature, which allowed us to estimate the impact of both changes in price and non-price competitiveness on the dynamics of the manufacturing share of GDP. In order to do this, we redefined the concept of industrial equilibrium exchange rate as the level of real exchange rate that is compatible with a constant share of the manufacturing share in GDP.

Using Brazilian data for the period of 1998 to 2017 we estimated an econometric model for explaining the evolution of the manufacturing share as a function of a list of variables such as the economic complexity index, the real effective exchange rate, and per-capita income. The estimated coefficients were then used for calculating the industrial equilibrium real exchange rate. The estimation results showed that after 2005, a huge and growing overvaluation of the real exchange rate happened in Brazil, resulting both from the appreciation of the actual level of the real exchange rate and a depreciation of the industrial equilibrium level of this variable. The depreciation of the industrial equilibrium exchange rate was the consequence of a reduction in the non-price competitiveness of the Brazilian manufacturing industry as expressed by the economic complexity index.

Finally, we showed that although the real exchange rate had an important role in the deindustrialization process of the Brazilian economy, it can only explain a little less than 40% of the reduction of the manufacturing share in Brazil from 2005 to 2017. As such, almost 60% of the deindustrialization process is explained by the reduction in the economic complexity of Brazil.

Concerning policy implications, the maintenance of the exchange rate at its industrial equilibrium level is not sufficient to allow the development and expansion of firms in middle-income countries like Brazil. It is also necessary to implement industrial, science and technology, and foreign trade policies that aim: (*i*) to gradually reduce the technological gap that separates domestic firms from their competitors in developed countries, and hence to increase the economic complexity; and (*ii*) to ensure minimum conditions of survival and expansion for domestic firms until they reach the technological frontier**.** In this context, import tariffs can be used for a limited and defined period of time, as a necessary instrument to ensure isonomic conditions for domestic companies in a context in which they have a significant technological lag with respect to their competitors abroad.

This means that the elimination of real exchange rate overvaluation in Brazil requires not only the adoption of a macroeconomic policy regime in which some kind of real exchange rate targeting is adopted (Frenkel, 2014); but also policies designed to increase the economic complexity of the Brazilian economy and, hence, to reduce the equilibrium value of real exchange rate, making the required adjustment in the real exchange rate socially and politically viable.

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Appendix

A1. Multivariate and univariate analysis

In order to define the possible set of explanatory variables in the statistical model, as a first step, we used multivariate analysis based on the correlation analysis between variables.[26] Table A1 shows the results of the correlation tests and p-values for the share of the manufacturing industry in GDP without lags, h_0, with explanatory variables candidates: $h_t, \theta_t, \text{ICE}_t, \text{RPC}_t,$ and RPC_t^2, with $t = 0, -1, -2, \text{and} - 3$, in levels, first differences, growth rates, and with lags.

Table A1 – *Correlations between the share of the manufacturing industry in the GDP and possible explanatory variables to be included in the statistical model*

Correlation	h_0	p-value	Correlation	h_0	p-value	Correlation	h_0	p-value
h_{-1}	0.89	0.00	$\Delta\theta_{-2}$	-0.17	0.48	$\%\text{RPC}_{-1}$	0.28	0.25
h_{-2}	0.73	0.00	$\Delta\theta_{-3}$	-0.18	0.46	$\%\text{RPC}_{-2}$	-0.05	0.82
h_{-3}	0.59	0.00	ICE_0	0.64	0.00	$\%\text{RPC}_{-3}$	-0.05	0.82
$\%h_{-1}$	0.41	0.08	ICE_{-1}	0.62	0.00	ΔRPC_0	0.37	0.12
$\%h_{-2}$	0.38	0.11	ICE_{-2}	0.64	0.00	ΔRPC_{-1}	0.27	0.26
$\%h_{-3}$	0.49	0.03	ICE_{-3}	0.69	0.00	ΔRPC_{-2}	-0.07	0.78
Δh_{-1}	0.40	0.09	$\%\text{ICE}_0$	0.03	0.91	ΔRPC_{-3}	-0.07	0.75
Δh_{-2}	0.36	0.13	$\%\text{ICE}_{-1}$	-0.04	0.85	RPC_0^2	-0.60	0.00
Δh_{-3}	0.47	0.04	$\%\text{ICE}_{-2}$	-0.04	0.87	RPC_{-1}^2	-0.71	0.00
θ_0	0.23	0.33	$\%\text{ICE}_{-3}$	0.10	0.67	RPC_{-2}^2	-0.73	0.00
θ_{-1}	0.50	0.03	ΔICE_0	0.01	0.97	RPC_{-3}^2	-0.51	0.02
θ_{-2}	0.71	0.00	ΔICE_{-1}	-0.04	0.85	$\%RPC_0^2$	-0.03	0.90
θ_{-3}	0.80	0.00	ΔICE_{-2}	-0.09	0.71	$\%RPC_{-1}^2$	-0.22	0.36
$\%\theta_0$	-0.52	0.02	ΔICE_{-3}	0.07	0.76	$\%RPC_{-2}^2$	-0.18	0.46
$\%\theta_{-1}$	-0.41	0.08	RPC_0	-0.66	0.00	$\%RPC_{-3}^2$	-0.35	0.14
$\%\theta_{-2}$	-0.23	0.35	RPC_{-1}	-0.77	0.00	ΔRPC_0^2	0.29	0.22
$\%\theta_{-3}$	-0.20	0.42	RPC_{-2}	-0.83	0.00	ΔRPC_{-1}^2	0.00	0.99
$\Delta\theta_0$	-0.48	0.04	RPC_{-3}	-0.78	0.00	ΔRPC_{-2}^2	-0.21	0.38
$\Delta\theta_{-1}$	-0.37	0.12	$\%\text{RPC}_0$	0.38	0.11	ΔRPC_{-3}^2	-0.43	0.07

The results indicate that the variables real effective exchange rate, index of economic complexity, per capita income, and squared per capita income, with and without time lags (except the real effective exchange rate without time lags), as well the lagged share of the manufacturing industry in the GDP, in general have a strong and significant correlation with the share of the manufacturing industry in the GDP without lags, at a significance level between 1% and 10%.

The second step of the analysis is the investigation of the variable-generating stochastic process, that is, whether the variable follows a non-stationary or a stationary process. For this purpose, we used five stationarity tests: (*i*) the Augmented Dickey Fuller (ADF), as modified by Said and Dickey (1984); (*ii*) the PP test (Phillips and Perron, 1988); (*iii*) the KPSS test

[26] According to the Cauchy-Schwarz corollary, we adopted numerical criteria to differentiate the degree of correlation and linear dependence between variables. Pearson's numerical correlations greater than 0.3, in absolute values, as long as they are statistically significant according to the p-value, have been considered an indication of possible explanatory variables.

(Kwiatkowski et al., 1992); (*iv*) the test by Ng and Perron (2001); and (*v*) unit root tests with breakpoints, P_{break}, proposed by Perron (1989).[27] In order to decide whether or not to introduce a linear trend in the unit root tests, we calculated three non-parametric trend tests: the Wald-Wolfowitz (1940), Cox-Stuart (1955), and that by Mann (1945) and Kendall (1955). The summary results are presented in the tables A2 and A3.

Table A2 – *Results of the Wald-Wolfowitz, Cox-Stuart, and Mann-Kendall trend tests*

	Wald-Wolfowitz		***Cox-Stuart***		**Mann-Kendall**	
	statistic	*p*-value	Statistic	*p*-value	statistic	*p*-value
h_0	-3.54	0.00	1	0.00	-0.58	0.00
h_{-1}	-3.47	0.00	1	0.00	-0.56	0.04
h_{-2}	-2.76	0.00	2	0.04	-0.52	0.00
h_{-3}	-2,29	0.02	3	0.05	-0.49	0.00
θ_0	-3.47	0.00	1	0.00	-0.43	0.00
θ_{-1}	-3.21	0.00	2	0.05	-0.44	0.00
θ_{-2}	-3.68	0.00	1	0.02	-0.45	0.00
θ_{-3}	-3.22	0.00	0	0.00	-0.77	0.00
ICE_0	-4.14	0.00	0	0.00	-0.71	0.00
ICE_{-1}	-3.22	0.00	0	0.00	-0.72	0.00
ICE_{-2}	-2.91	0.00	0	0.00	-0.76	0.00
ICE_{-3}	-3.21	0.00	0	0.00	-0.76	0.00
RPC_0	-4.13	0.00	10	0.00	0.74	0.00
RPC_{-1}	-4.13	0.00	10	0.00	0.76	0.00
RPC_{-2}	-4.13	0.00	10	0.00	0.82	0.00
RPC_{-3}	-4.13	0.00	10	0.00	0.86	0.00
RPC_0^2	-4.13	0.00	10	0.00	0.74	0.00
RPC_{-1}^2	-4.13	0.00	10	0.00	0.74	0.00
RPC_{-2}^2	-3.88	0.00	9	0.00	0.75	0.00
RPC_{-3}^2	-3.62	0.00	8	0.00	0.84	0.00

Under the null hypothesis that there is no trend in the time series, the results of all tests suggest that all time-series have a trend, with levels of significance between 1 and 5%. For this reason we performed stationarity tests with intercept and a trend. The results of the ADF, PP, Ng-P, and P_{break} tests suggest that all series in levels, lagged or not, are stationary, as the null hypothesis of unit root is rejected. In the KPSS test, the values of the LM statistic compared to the critical value also suggest that all series at levels, both with or without lags, have a stationary tendency around an average, that is, the null hypothesis is not rejected. We concluded that all the series can be considered as stationary or with a stationary tendency around an average, i.e. they are integrated of order zero, I(0). Additionally, the P_{break} test presented in table A3 suggests that there is a structural break in the intercept and/or trend, for some series in specific years between 2002 and 2010. This suggests that the functions can optionally be estimated and tested including dummy variables for specific years (see section A2).

[27] See Zivot-Andrews (1992), Banerjee et al. (1992), Vogelsang and Perron (1998), and Perron (2006).

Table A3 – *ADF, PP, KPSS, Ng-Perron, and P_{break} stationarity tests*

	Equation	ADF			PP			KPSS			Ng-Perron					P_{break}				$I(d)$
		Lag	*t*	*p*	*Lag*	*t-adj*	*p*	*B*	*LM*	*p*	*B*	*MZα*	*MZt*	*MSB*	*MPT*	*p*	*Lag*	*t*	*p*	*Break*	
h_0	I,T	3	-6.64	0.00	4	-5.57	0.00	5	0.12	0.12	3	-24.12	-3.91	0.13	3.97	0.01	5	-22.5	<0.01	2002	I(0)
h_{-1}	I,T	0	-5.86	0.00	0	-5.01	0.00	2	0.09	0.26	6	-53.87	-16.41	0.03	0.16	0.00	1	-12.3	<0.01	2003	I(0)
h_{-2}	I,T	1	-3.61	0.04	3	-4.16	0.02	2	0.10	0.23	4	-20.31	-3.2	0.15	4.98	0.04	1	-13.37	<0.01	2003	I(0)
h_{-3}	I,T	2	-4.40	0.01	4	-3.26	0.10	2	0.09	0.27	3	-49.65	-4.98	0.10	1.85	0.00	4	-5.83	<0.01	2004	I(0)
θ_0	I,T	3	-3.89	0.03	3	-9.83	0.00	3	0.09	0.28	3	-85.87	-9.63	0.05	0.49	0.00	3	-5.79	<0.01	2004	I(0)
θ_{-1}	I,T	3	-3.49	0.06	3	-7.90	0.00	3	0.10	0.21	2	-14.25	-2.65	0.19	6.48	0.09	3	-4.84	<0.01	2004	I(0)
θ_{-2}	I,T	3	-3.88	0.04	3	-6.81	0.00	3	0.10	0.20	3	-90.17	-6.70	0.07	1.06	0.00	3	-4.56	0.04	2005	I(0)
θ_{-3}	I,T	3	-3.32	0.08	3	-6.81	0.00	3	0.09	0.29	3	-90.17	-6.70	0.07	1.06	0.00	3	-4.56	0.04	2005	I(0)
ICE_0	I,T	2	-3.92	0.03	2	-3.92	0.03	3	0.07	0.45	3	-16.40	-2.85	0.17	5.65	0.00	1	-5.72	<0.01	2009	I(0)
ICE_{-1}	I,T	2	-3.92	0.03	3	-3.82	0.04	3	0.06	0.54	3	-28,13	-4,15	0.02	3,23	0.00	2	-5.83	<0.01	2010	I(0)
ICE_{-2}	I,T	0	-3.92	0.03	3	-3.89	0.03	3	0.10	0.22	1	-17.75	-2.98	0.17	5.13	0.00	3	-5.61	0.02	2009	I(0)
ICE_{-3}	I,T	0	-3.88	0.03	3	-3.74	0.04	3	0.05	0.67	4	-23.94	-34.09	0.02	4.16	0.01	3	-6.47	0.02	2010	I(0)
RPC_0	I,T	0	-5.43	0.00	1	-4.79	0.00	1	0.22	0.00	3	-18.13	-2.72	0.17	5.71	0.07	0	-7.13	<0.01	2010	I(0)
RPC_{-1}	I,T	0	-5.43	0.00	1	-4.59	0.00	1	0.09	0.25	3	-17.88	-1.71	0.25	4.27	0.07	1	-6.69	<0.01	2004	I(0)
RPC_{-2}	I,T	0	-5.40	0.00	1	-5.35	0.00	1	0.09	0.29	7	-39.13	-4.38	0.11	2.57	0.00	1	-7.59	<0.01	2008	I(0)
RPC_{-3}	I,T	0	-5.06	0.00	0	-4.81	0.00	1	0.07	0.56	4	-34.13	-4.29	0.12	2.89	0.01	1	-7.01	<0.01	2009	I(0)
RPC_0^2	I,T	3	-3.46	0.09	2	-3.79	0.04	2	0.10	0.24	2	-16.01	-2.67	0.18	6.61	0.08	2	-5.83	<0.01	2008	I(0)
RPC_{-1}^2	I,T	0	-3.26	0.09	2	-3.90	0.04	2	0.10	0.24	3	-14.21	-2.64	0.18	6.58	0.10	2	-5.99	<0.01	2008	I(0)
RPC_{-2}^2	I,T	0	-3.41	0.07	2	-3.93	0.04	2	0.10	0.24	3	-25.38	-2.66	0.18	6.63	0.08	2	-5.35	<0.01	2009	I(0)
RPC_{-3}^2	I,T	0	-5.06	0.00	2	-3.99	0.04	2	0.09	0.30	3	-14.26	-2.67	0.18	6.61	0.10	2	-5.48	<0.01	2009	I(0)

Notes: the symbols are: I = intercept; T = trend; p = p-value; t = Student statistic; t-adj = adjusted Student statistic; B = bandwidth; *Lag* = Lag length; *LM* = LM statistic. For the ADF, PP tests, we used the lag length based on Schwarz criteria and critical values described in MacKinnon (1996) with one side p-values. For the KPSS test, we used bandwidth type Newey-West, with spectral estimation of the Bartlett-Kernel and the critical values described in Kwiatkowski et al. (1992, table 1). For the Ng-Perron test, we used bandwidth type Newey-West, with spectral estimation of the Bartlett-Kernel and critical values described in Ng and Perron (2001, Table 1). For the P_{break} test, we used the break type “innovation outlier”, and the breakpoint selection type “Dickey-Fuller min-t” break specification in the intercept and trend, with lag length type “Schwarz criteria”, and the critical values described in Vogelsang (1994), with one side p-value.

Regarding the third step, in order to reduce the number of explanatory variables, we applied the principal component variance analysis method. This method shows the main variables that explain most of the original variability (variance) using a relatively small number of *k* components, among the total set of *p* components, to describe the behavior of the dependent variable. The summary results of principal components ordered by eigenvalues, with the individual and accumulated proportions of variance explained for the share of the manufacturing industry in the GDP without time lags, are presented in table A4. Among all the candidate explanatory variables, 11 have eigenvalues above 1 (a conventional threshold for inclusion).

Table A4– *Principal components of the share of the manufacturing industry in the GDP*

Importance	Variable	Eingenvalues	Difference	Individual proportion	Accumulated proportion
1	h_{-1}	30.67	18.98	38.34%	38.34%
2	ICE_{-3}	11.70	2.02	14.62%	52.96%
3	θ_{-1}	9.67	4.13	12.09%	65.06%
4	RPC^2_{-2}	5.54	0.08	6.93%	71.99%
5	RPC_{-2}	5.46	1.36	6.82%	78.81%
6	h_{-2}	4.10	1.15	4.99%	83.80%
7	h_{-3}	2.95	0.23	3.69%	86.49%
8	ICE_{-2}	2.73	0.78	3.54%	90.03%
9	θ_{-2}	1.95	0.59	3.44%	93.47%
10	RPC_{-1}	1.36	0.22	1.70%	95.17%
11	RPC^2_{-1}	1.14	0.25	1.42%	96.59%
12	ICE_{-1}	0.89	0.16	1.11%	97.70%
13	ICE_0	0.73	0.21	0.91%	98.61%
14	θ_{-3}	0.52	0.23	0.65%	99.26%
15	θ_0	0.29	0.13	0.37%	99.63%
16	RPC^2_0	0.16	0.09	0.20%	99.83%
17	RPC_0	0.08	0.02	0.10%	99.93%
18	RPC_{-3}	0.06	0.06	0.07%	100%
19	RPC^2_{-3}	0.00	0.00	0.00%	100%

Notes: __Principal components, __Do not discard or disposable frontier, and __Disposable.

As shown in table A4, of the total variance of the share of the manufacturing industry in the GDP without time lags, we find that (*i*) 38.34% is explained by the share of the manufacturing industry in the GDP, lagged by one period; (*ii*) 14.62% is explained by the economic complexity index, lagged by three periods; (*iii*) 12.09% is explained by the effective real exchange rate, lagged by one period; (*iv*) 6.93% by the squared per capita income, lagged in two periods; and (*v*) 6.82% by per capita income, lagged in two periods. Adding up the proportions of the variance explained by each main component, we can conclude that five components explain 78.81% of the sample variance of the share of the manufacturing industry in the GDP without time lag. Other components, namely, the share of the manufacturing industry in the GDP, lagged by two and three periods; the economic complexity index, lagged by two periods; the effective real exchange rate, lagged by two periods and; per capita income and squared per capita income, lagged by one period, all explain a small proportion of the variance of the share of the manufacturing industry in the GDP, between 4.99% to 1.42% per component. Finally, some variables explain an insignificant proportion of the variance of the share of the manufacturing industry in the GDP, and are not part of the set of main components.

And can be ignored. These variables are: (*i*) the economic complexity index, without lags and lagged by one period; (*ii*) the effective real exchange rate, without lags and lagged by three periods; and (*iii*) per capita income and squared per capita income, without lags and lagged by three periods.

A2. Estimation of the equation for the share of the manufacturing industry in the GDP

In order to estimate the role of the share manufacturing industry in the GDP, as a modelling strategy, we used: different combinations of candidate variables; various specifications, including some with dummy variables; and various optimization methods. The latter include: (*i*) ordinary least squares (OLS), conjugated with autoregressive integrated moving average (ARIMA) maximum likelihood estimation; (*ii*) robust least squares (RLS)[28] with or without dummy variables; and (*iii*) elastic net regularization (ENR).[29] Table A5 summarizes the main econometric results.

Table A5 – *Estimations of the share manufacturing industry in the GDP, 1998-2017. Dependent variable: share manufacturing industry in the GDP*

	Optimization method								
	1 - OLS			2 – ENR			3 – RLS		
	c	**s.e.**	***p***	**c**	**s.e.**	***p***	**c**	**s.e.**	***p***
h_{-1}	1.017	0.128	0.00	1.015	0.08	0.00	1.003	0.08	0.00
ICE_{-3}	2.547	1.315	0.07	2.084	0.847	0.00	2.193	1.17	0.00
θ_{-1}	2.07E-2	6.1E-3	0.00	2.06E-2	3.61E-3	0.00	2.04E-2	5.62E-3	0.08
RPC_{-2}	9.09E-4	4.8E-4	0.07	8.54E-4	3.44E-4	0.04	8,14E-04	1.68E-08	0.08
RPC^2_{-2}	-3.75E-8	1.97E-8	0.07	-3.8E-8	1.4E-08	0.01	-4,02E-08	4.01E-4	0.08
R^2		0.72			0,62			0.70	
Adjusted R^2		0.68			0.56			0.67	
s.e. reg		0.63			-			0.66	
Durbin-Watson		2.03			-			2.09	
	Optimization method								
	4 – RLS			**5 – RLS**			**6 – RLS**		
	c	**s.e.**	***p***	**c**	**s.e.**	***p***	**c**	**s.e.**	***p***
h_{-1}	1.008	0.042	0.00	1.015	0.082	0.00	1.018	0.114	0.00
ICE_{-3}	1.642	0.758	0.00	3.054	1.222	0.00	2.365	0.689	0.00
θ_{-1}	2.55E-2	5.1E-3	0.05	1.98E-2	5.6E-3	0.03	2.48E-2	5.94E-3	0.00
RPC_{-2}	9.98E-04	1.32E-8	0.03	7.37E-04	1.68E-8	0.02	6.45E-04	1.69E-8	0.03
RPC^2_{-2}	-4.95E-08	3.15E-4	0.02	-2.80E-08	3.99E-4	0.02	-3.33E-08	4.14E-4	0.03
d02	-1.091	0.097	0.00	-	-	-	-1.839	-	0.00
d09	-	-	-	-0.935	0.234	0.00	-0.759	0.286	0.02
R^2		0.64			0.64			0.65	
Adjusted R^2		0.62			0.61			0.62	
s.e. reg		0.52			0.65			0.51	
Durbin Watson		1.92			2.07			1.93	

Notes: c = coefficient, s.e. = standard error and p = p-value. In the method ENR: alpha is 0.5, lambda at minimum error is 5.78e+06, cross-validation method is K-Fold, and selection measure is the mean squared error. RLS with MM-estimation (Yohai 1987), HAC standard errors with estimated covariance by Bartlett kernel, we applied Newey-West fixed.

[28] Robust least squares refer to a variety of regression methods designed to be robust, or less sensitive to outliers. We presented specifications with dummies for the years 2002 and/or 2009, since specifications including dummies in 2003, 2004, 2008, and 2010 were not statistically significant.
[29] See Zou-Hastie (2005).

All specifications show results with the expected signs for the coefficients of h_{-1}, ICE_{-3}, θ_{-1}, RPC_{-2}, and RPC_{-2}^2. The estimated coefficients of the dummy variables for the years 2002 and 2009 are negative. All coefficients are statistically significant, and the values of the coefficients are very close one to the other in the three optimization methods. In all specifications the Durbin-Watson statistics are around 2, indicating that there are no serious serial residual correlation problems. The adjusted R^2 is between 0.56 to 0.68, depending on the specification. The next step was to develop the Jarque-Bera (1987) test for each series of residuals generated, for each of the proposed specifications. The results, which are found in table 6A, suggest that residuals are normally distributed.

Table A6 – *Jarque-Bera test results on residuals*

Specifications	**1**	**2**	**3**	**4**	**5**	**6**
Mean	-2.05E-3	-4.01E-3	-2.95E-3	-2.37E-3	-3.16E-3	-3.03E-3
Median	-1.38E-2	-2.01E-2	-2.76E-3	-1.28E-2	-1.11E-4	-1.27E-2
Maximum	1.16	1.21	0.90	1.19	0.88	1.04
Minimum	-1.53	-1.65	-0.82	-1.41	-0.83	-1.11
Std. Dev.	0.59	0.43	0.44	0.56	0.41	0.40
Skelness	-0.41	-0.19	0.28	0.16	0.36	-0.09
Kurtosis	4.08	3.01	2.78	3.21	3.22	3.51
Jarque-Bera	1.54	1.69	0.54	1.98	0.48	0.63
Probability	0.46	0.65	0.76	0.37	0.78	0.43

Lastly, we apply the CUSUM and CUSUM-SQ stability tests on the residuals. The tests indicate parameter instability if the cumulative sum or square cumulative sum of residuals goes outside the interval between two critical values: in our estimates, the results indicate stability in each specification at the 5% significance level.