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Economic complexity, structural transformation and economic growth in a regional context: Evidence for Brazil

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Abstract:

The purpose of this paper is to verify the effect of economic complexity on the growth and productive transformation of federative units (UFs) in Brazil between 2003 and 2014. We also analyze the factors that determine the economic complexity of these subnational entities. To do this we used different indices of economic complexity (linear and non-linear), as well as system generalized method of moments (GMM-SYS) estimators in dynamic panels to avoid endogeneity problems. The results showed that: i) through the descriptive analysis (both by the linear and the non-linear versions) a positive relationship between the UFs' economic complexity and economic growth was observed; ii) the econometric analysis showed that measures of economic complexity are positively related to economic growth – however, some of the coefficients did not show statistical significance and the coefficients that represent the non-linear approach showed weak correlation; iii) there is a positive relationship between the real exchange rate at the state level (R$/US$) and the UFs' productive transformation, such as between the UFs' productive transformation and the economic complexity.

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High and low productivity sectors tend to coexist in a developing country. When this country has continental characteristics, these differences in productivity levels become even more visible and the result of this tends to be greater income inequality between its regions and member states. Brazil is the main example of this: on the one hand, the Southeast region has a high per capita income, a diversified export basket and greater participation in products with higher technology; on the other hand, the North and Northeast regions have the lowest levels of income per capita and an export basket more specialized in low-tech products (IBGE, 2020; SECEX, 2020). The different degrees of diversification of the export basket influence the local complexity and identifying the factors that may be related to a greater homogeneity in the

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complexity levels within the Brazilian territory is useful to reduce the inequality of the regional productive structures and to boost the economic growth.

The economic complexity index was created to be a predictor of the future growth of an economy. The studies on economic complexity applied to the productive structure of an economy[1] came up with the seminal work of Hidalgo and Hausmann (2009). This approach has received increasing attention from the literature (Hausmann and Hidalgo, 2010, 2011; Felipe et al., 2012; Hausmann et al., 2013; Gala, 2017). As it deals with economic issues through the analysis of networks in iterative methods, it can be considered as the theory of economic complexity applied to the productive structure of a territory.[2]

The measure of economic complexity initially used by Hidalgo and Hausmann (2009) is based on a network of linear iterations between exporting economies and exported products. By having diversification and ubiquity as a parameter, more complex economies are those that, at the same time, present a more diversified and less ubiquitous (more exclusive) productive structure.

However, as diversified economies export almost all types of products, both exclusive and non-exclusive, the measure of economic complexity created by Hidalgo and Hausmann (2009) may be overestimating the complexity of non-exclusive products during the iteration process. Therefore, some studies have presented alternative measures to capture the diversification and ubiquity of an economy. Tacchella et al. (2012) modified the traditional complexity index by a non-linear iterative system, paying more attention to the exclusivity of the product than to the diversification of the economies that export it. This measure proposed by Tacchella et al. (2012) and used by Caldarelli et al. (2012) and Cristelli et al. (2015), became known as 'Fitness'.

Both the linear iteration approach created by Hidalgo and Hausmann (2009) and the non-linear approach created by Tacchella et al. (2012) start from the revealed comparative advantage (RCA) index to verify the diversification of economies and the ubiquity of products. However, RCA considers the difference in the share of a product in the export basket of different economies and not the difference in per-capita production between them. This can cause bias in economies with different population densities. Considering this, Ivanova et al. (2019, 2020) proposed the revealed effectiveness advantage (REA) index, which considers the size of the population in each territory and eliminates the bias between large and small economies.

In this context, the purpose of this paper is to verify the effect of economic complexity on the economic growth and productive transformation of subnational entities (federative units) in Brazil between 2003 and 2014. We also analyze the factors that determine the economic complexity. We assume that the complexity measures are determinants of UFs' GDP. The use of indices in two versions, as well as the use of matrices based on RCA and REA – as far as we know, not yet used in the Brazilian case – are the differentials of this paper.

The period analyzed is justified, in the first place, by the role played by the export sector in the country's growth dynamics, especially in the first years of this period. The average export growth rate was 9.2% between 2003 and 2007, above the world average of 7.2% (WDI). The

[1] The study of complex systems and agent-based models was incorporated into the economic field in the 1980s, with the works of Nelson and Winter (1982) and Arthur (1989). This literature represents the traditional approach to complexity, which is closely related to topics studied in biology. Detailed contents of these approaches can be found in Arthur (2006, 2015); Beinhocker (2006) and Mitchell (2009).

[2] Thus, this approach is almost a theorization of Latin American structuralism and contrasts some traditional concepts widely defended by the mainstream.

exported value more than doubled during these 12 years (MDIC) and the country managed to increase its share of world trade, from 0.9% in 2003 to 1.1% in 2014 (WDI).

Second, and most importantly, Brazil is a country with a large territorial extension, with productive heterogeneity between its regions. This is reflected in the UFs' export capacity. Using the export effort (EE) index, we can observe the aforementioned heterogeneity and, also, the evolution of the importance of the exporting sector over the period for each UF. For example, in 2003 the states of the Midwest region occupied the following positions in the EE index: MT (3º), MS (16º), and GO (13º). In 2014, these UFs started to occupy the first positions in this index (1º, 4º, and 8º, respectively). The data show changes in rank positions as well as the increase (reduction) in the importance of exports to the UFs (see table A1 in the appendix). This helps to understand the different dynamics of GDP per capita. As can be seen, in the period 2003-2014, the list of UFs that most increased their GDP per capita is completely different from the list of the previous period (table A2 in the appendix).

In third place, considering that a large part of the UFs export basket is composed of natural resources products, that are more subject to international cycles, it is important to include the entire period of rising commodity prices in the analysis. The increase in these prices may have driven investments in this area, with effects on the economic complexity and, consequently, the UFs economic growth capacity.

In econometric terms, we use system GMM estimators for dynamic panel data models to avoid possible problems of endogeneity. Thus, in the empirical exercise, a set of variables was included that capture different dimensions: i) physical capital and education were used as supply-side variables; ii) intermediate consumption in the manufacturing industry was used as a proxy for productive transformation; iii) the real exchange rate was used as a proxy for policies that promote greater external competitiveness; and, finally, iv) external demand and the commodity price index were used as demand-side variables. An additional differential of this paper is the fact that the real effective exchange rate was adjusted by the relative prices between tradable and non-tradable sectors of the UFs (Rodrik, 2008), while the GDP of the UFs' trading partners was used as a proxy for external demand.

Some other works have analyzed the economic complexity of Brazil in a regional context. Morais et al. (2021) show that the relationship between economic complexity and income inequality has an inverted U-shape, indicating that higher levels of complexity first worsen and then improve income distribution in Brazilian states. Verheij and De Oliveira (2020) analyzed the spatial dependence of economic complexity at the municipal level in 2010 and evaluated what implications this may have for regional industrial policies. The authors found that there are positive spillover effects of economic complexity (the spatial lag of economic complexity is found to be positive and significant in all models and specifications). Herrera et al. (2021) analyzed the evolution of the economic complexity in Brazilian states between 1997 and 2017 and found that the states with greater economic complexity are in the South and Southeast regions of the country. At the same time, in some states, the economic complexity declined or stagnated. The authors argue that trends are indicative of processes of deindustrialization and financialization and point to the need for a new development path. Operti et al. (2018) created the index known as Exogenous Fitness for the Brazilian states and correlated this index with GDP per capita. In addition, the authors compared the ranking of this index with the economic complexity index and the traditional Fitness index.

This paper is divided into five sections, in addition to this introduction. Section 1 shows the approach of economic complexity in its linear and non-linear versions and the way of measurement for Brazilian UFs; the following section presents the methodology. Section 3 presents a discussion of the results. The conclusions are presented in the last section.

1. Economic complexity and output growth

1.1. Linear approach to economic complexity

Hausmann et al. (2007) were the first to create an index that represents the future growth potential of an economy based on its productive structure. This index (EXPY) relates the specialization to the income level of economies, considering that countries that present an export structure compatible with the structure of countries with higher income are subject to present greater growth in the long run.

The literature that developed from this work (Jarreau and Poncet, 2009; Kume et al., 2012; Da Silva and Hidalgo, 2016, among others) was criticized based on the understanding that only having an export structure similar to that of rich countries does not say much about a country's future growth potential – many countries, for example, achieve high per-capita income due to their natural wealth. Thus, it is possible to say that the new index proposed by Hidalgo and Hausmann (2009) was the first to achieve the real objective of measuring the economic complexity (sophistication) of a territory based on its export structure. This index starts from the revealed comparative advantage (RCA), created by Balassa (1965), as shown in equation (1).

$$RCA_{sp} = \frac{\left(\frac{x_{sp}}{X_s}\right)}{\left(\frac{\sum_s x_{sp}}{\sum_s X_s}\right)} \qquad (1)$$

For the work presented here, x_{sp} is the export of product p in the state[3] (UF) s; X_s is the total export of the *j-th* state. The RCA measure is used to create the matrix that connects the states to the products they export (M_{sp}), and (as shown in equation (2)) the matrix will have values zero and one – one if the RCA is ≥ 1 and zero if the RCA is < 1.

$$M_{sp} = \begin{cases} 1 \; if \; RCA_{sp} \geq 1 \\ 0 \; if \; RCA_{sp} < 1 \end{cases} \qquad (2)$$

The method of Hidalgo and Hausmann (2009) considers that economic complexity depends on the diversification of economies and the ubiquity of products. In other words, more diversified and less ubiquitous economies tend to have greater economic complexity. The following equations present the measures of diversification (measured by the quantity of products that each UF exports with RCA) and the ubiquity of the products (measured by the quantity of UFs that export a certain product with RCA).

[3] Here, state is being used as a synonym for federative unit.

$k_{s,0} = \sum_{p=1}^{N} M_{sp}$ (Diversification) (3)

$k_{p,0} = \sum_{s=1}^{N} M_{sp}$ (Ubiquity) (4)

These equations already allow an analysis of the structure of each UF. However, this does not allow for more advanced comparability, which is only possible through the connection of all UFs and all products at the same time. This requires the use of the method of reflections, which consists of iteratively calculating the measures of diversification and ubiquity. Equations (5) and (6) represent the method of reflections proposed by Hidalgo and Hausmann (2009):

$k_{s,n} = \frac{1}{k_{s,0}} \sum_{p=1}^{N} M_{sp}\ k_{p,n-1}$ (5)

$k_{p,n} = \frac{1}{k_{p,0}} \sum_{s=1}^{N} M_{sp}\ k_{s,n-1}$ (6)

where $k_{s,n}$ and $k_{p,n}$ are the average diversification and average ubiquity in later iterations. Starting from UFs $(k_{s,n})$ in iterations with n starting from zero to even numbers ($k_{s,0}$; $k_{s,2}$; $k_{s,4}$; $k_{s,8}$; $k_{s,10}$) are the generalized measures of diversification and in odd iterations ($k_{s,1}$; $k_{s,3}$; $k_{s,5}$; $k_{s,7}$; $k_{s,9}$) are the generalized measures of ubiquity of the products exported by these UFs. This also occurs with products $(k_{p,n})$, but with even values ($k_{p,0}$; $k_{p,2}$; $k_{p,4}$; $k_{p,8}$; $k_{p,10}$) indicating measures of product ubiquity and odd values ($k_{p,1}$; $k_{p,3}$; $k_{p,5}$; $k_{p,7}$; $k_{p,9}$) indicating diversification of the UFs that export these products. For a better understanding, table 3 presents an example of how the method of reflections works.

Table 1 – *Reflection method: first three pairs of variables through the state-product network*

Number of iterations	State (UF)	Product category
0	$K_{s,0}$: diversification (number of products exported with RCA by state)	$K_{p,0}$: ubiquity (number of states that export product p with RCA)
1	$K_{s,1}$: average ubiquity of products exported with RCA by state	$K_{p,1}$: average diversification of states that export product *p* with RCA
2	$K_{s,2}$: average diversification of states that have an export basket similar	$K_{p,2}$: average ubiquity of products exported by states that export product p with RCA

Source: own elaboration based on Hausmann and Hidalgo (2009) and Felipe et al. (2012).

The economic complexity of a given UF is positively related to the diversification of its exports, which will be verified through the quantity of products that a UF exports with RCA. However, the economic complexity will be even greater if few other UFs have an RCA in these products and, especially, if the exports of these other UFs are highly diversified. According to Hidalgo and Hausmann (2009), these iterations must be carried out until the moment when the ranking of economies is unchanged. This would be compatible with the eigenvector associated with the largest eigenvalue in the matrix of states and products.

Studies have shown that the method of reflections, presented in equations (5) and (6), is a good measure of economic complexity and a good predictor of a country's future growth (Felipe et al., 2012), being an efficient index to explain income differentials between economies

(Inoua, 2016). Thus, the method of reflections was used here as the linear measure of economic complexity of the UFs in Brazil.

1.2. Non-linear approach to the economic complexity index

In the methodology of Hidalgo and Hausmann (2009), the diversification of economies that export a given product has great weight in the final measure of economic complexity. The idea is that products that are present in diversified economies are important in the sectoral chaining process of these economies. This is completely correct from a theoretical point of view, but empirical studies (Tacchella et al., 2012) have shown that more developed economies export almost all types of products – from primary products to high-tech products, which overestimates the complexity of basic products. Tacchella et al. (2012) proposed a new approach to verify the economic complexity index. The methodology created by Tacchella et al. (2012, 2013), which received the name 'Fitness', is created from a non-linear iterative process in which the economic complexity (Fitness) is inversely proportional to the number of economies that export this product. Unlike the approach of Hidalgo and Hausmann (2009), after each iteration the variables are normalized. The Fitness index ($F_{s,n}$) of the Brazilian states and the product complexity ($Q_{p,n}$) can be calculated according to the iterative sequences represented in equations (7) and (8):

$$\tilde{F}_{s,n} = \sum_{p} M_{sp}\, Q_{p,n-1} \tag{7}$$

$$\tilde{Q}_{p,n} = \frac{1}{\sum_s M_{sp}\left(\frac{1}{F_{s,n-1}}\right)} \tag{8}$$

where $\tilde{F}_{s,n}$ represents the economic complexity (Fitness) of a given state (or UF) in period n; $\tilde{Q}_{p,n}$ is the complexity of a given product in period n; and M_{sp} is the matrix of states and products, which assumes a value of 1 if the state exports the product with a comparative advantage ($RCA \geq 1$); otherwise ($RCA < 1$), the value will be zero. In this methodology, the initial values ($\tilde{F}_{s,0}$; $\tilde{Q}_{p,0}$) are 1 for all products and for all UFs. Thus, $\tilde{F}_{s,1}$ indicates the diversification of states (UF), or how many products they export with RCA, and $\tilde{Q}_{p,1}$ represents an inverse relation of the ubiquity of the products – the value is a negative function of the number of states that export the product with RCA[4]. The values are normalized at each step of the iteration, as shown in equations (9) and (10).

$$F_{s,n} = \frac{\tilde{F}_{s,n}}{\langle \tilde{F}_{s,n} \rangle_s} \tag{9}$$

[4] When comparing the methodology of Hidalgo and Hausmann (2009) and Tacchella et al. (2013), it is possible to verify that $\tilde{F}_{s,1} = K_{s,0}$ and that $\tilde{Q}_{p,1} = \frac{1}{K_{p,0}}$.

$$Q_{p,n} = \frac{\tilde{Q}_{p,n}}{\langle \tilde{Q}_{p,n} \rangle_p} \qquad (10)$$

This procedure prevents the complexity of the product from being overestimated, as occurs in the methodology initially presented by Hidalgo and Hausmann (2009). It is worth mentioning that both methodologies use RCA to create the matrix of states and products. However, RCA represents more the specialization than the productivity that certain economies have in exporting their products. The RCA index tends to indicate that an economy has an RCA in the export of a certain product, even if the quantity exported of that product is insignificant compared to other economies. Considering that this simple observation can bias the indices proposed by Hidalgo and Hausmann (2009) and Tacchella et al. (2012, 2013) – as it may overestimate the potential of economies with low export per capita – Ivanova et al. (2019) proposed using the REA index, which considers the population proportion of the economies and eliminates the bias between large and small economies. The REA index for the states of Brazil can be presented as follows:

$$REA_{sp} = \frac{\left(\frac{x_{sp}}{N_s}\right)}{\left(\frac{\sum_s \; x_{sp}}{\sum_s \; N_s}\right)} \qquad (11)$$

where x_{sp} is the export of a given product in the state and N_s represents the population of a given state. The RCA and REA indices can be connected according to equation (12):

$$REA = \frac{g_s}{g} \, RCA_{sp} \qquad (12)$$

where $g_s = \sum_p x_{sp/N_s}$ represents the total per-capita export of each state (UF) and $g = \frac{\sum_{sp} x_{sp}}{\sum_s N_s}$ represents the country's total per-capita export. We use the population aged 15 to 69 years, instead of the total population, as a proxy for the UFs' active population.

Although these new developments have moved knowledge on the subject forward, the discussion on which of the two measures (ECI, economic complexity index, vs. Fitness) is to be preferred is not yet settled (see, among others, Albeaik et al., 2017; Sciarra et al., 2020).

1.3. Issues and challenges

Hidalgo (2021) highlights that the connection between economic complexity and economic growth has been verified in empirical approaches, with robustness tests and control variables (natural resource exports, education, export concentration, and competitiveness). In fact, Albeaik et al. (2017) show that both the ECI and the Fitness measure have a positive relationship with the growth rate. At the subnational level, the connection between economic complexity and growth has been tested in several works. For Chinese cities, the results indicated a positive relationship between the ECI and per-capita economic growth (Poncet and De Waldemar, 2013). The same positive relationship was found for Mexican states (Gómez-Zaldívar et al., 2016), for Italian provinces (Coniglio et al., 2016) and for regions in Spain (Balsalobre et al., 2019). As we already cited, some works have analyzed the economic complexity of Brazil in a regional context (Operti et al., 2018; Verheij and De Oliveira, 2020; Herrera et al., (2021)).

In our opinion, there are at least two important issues to investigate further in the relationship between economic complexity and output growth. The first involves the need to investigate in more detail which measures of complexity are more correlated with GDP growth. In this case, it is also necessary to advance in the explanations of why this occurs.

In other words, we argue that both approaches lack more robust empirical tests, especially those that take into account the econometric models and the causality between the variables. For example, in the cited literature about the Brazilian case, none of these studies empirically analyzed, through econometric estimates, the relationship between the different indices of economic complexity (ECI and Fitness) with economic growth and productive transformation. Regarding the Fitness index, little is known from an econometric point of view at the subnational level. In sum, there is a long road to the empirical investigation of both approaches.

The second challenge is about the determinants of complexity. In other words, what are the main driving forces behind economic complexity? The answer to this question has important implications. In particular, understanding the role played by each of these forces is essential to ensure an appropriate response.

As noted by Hidalgo (2015), economic complexity captures the ability of people to connect and thus exchange information (social capital), as well as the level of technical and scientific knowledge that is embedded in people (human capital) and machinery and equipment (physical capital). If we start from this definition, the identification of the main driving forces behind economic complexity becomes vague. Therefore, it is necessary to advance in understanding what are the variables and the economic policy instruments that can affect economic complexity and output growth.

Gabriel and Missio (2018) showed that an undervalued real exchange rate (RER) exhibits positive and significant effects on the economic complexity level for developing countries. For the authors, a more diversified and less ubiquitous (more exclusive) productive structure is associated with a high level of industrialization. Thus, variables that affect the share of the industry in GDP affect the ECI.

In sum, to some extent, we tried to incorporate these questions by testing empirically which aspects of "complexity" are more relevant to the economic growth of subnational entities and which variables can be identified as determinants of complexity. So, this paper attempts to fill this gap in the empirical literature on economic complexity at the subnational level for the case of Brazil and advance in identifying the economic policy instruments that can be used to increase the ECI and the economic output.

2. Methodology

The first order dynamic model presented in equation 13 demonstrates how the estimates in this paper will be specified. Basically, the intention with this equation is to verify if the ECI can be a determining factor of the economy's output level:

$$logY_{it} = \phi logY_{it-1} + \beta logECI_{it} + \gamma logX'_{it} + \mu_t + \alpha_i + e_{it} \qquad (13)$$

where t represents the time and i the UFs. Y represents the product level; ECI represents the economic complexity index in the linear and non-linear approaches, created from the data in this paper; α_i and μ_t represent the individual and time fixed effects; e_{it} represents the model's error term; and X' represents the control variables, which include the GDP of the main trading partners of each UF, the exchange rate controlled by the Balassa-Samuelson effect, and variables used as a proxy for physical capital, education, trade openness, interest rate and commodity prices.[5]

In the exercise we use the economy's output level as a dependent variable for two reasons: first, remember that the approach to economic complexity is based on the concept of diversity and ubiquity. Diversity represents the number of different products that a country/UF can produce, in which it has an RCA. It is a measure of the relative performance of the products of a certain export basket, which makes it possible to identify in which products the country/UF has a comparative advantage in relation to other countries/UFs. Ubiquity represents the number of countries/UFs that can produce the same product, in which they have an RCA. What this approach says is that high values of the ECI are associated with countries/UFs which have a pattern of industrial production that is strongly product-oriented, sophisticated, and of great technological intensity (Hartmann et al., 2017). So, the expected effects on both the income level and the growth rate go in the same direction: the higher the ECI, the higher the expected income level and the growth rate of the country/UF. The second reason is because the model uses several lags. The dynamic model did not fit well with the growth rate as a dependent variable.

Equations (14) and (15) show the specification of the model that tries to verify which variables are determinants of the ECI, as well as of the intermediate consumption of the manufacturing industry (ICMI, proxy for structural transformation) of the UFs:

$$logECI_{ik,t} = \phi logECI_{it-1} + \beta logICMI_{it} + \partial logZ'_{it} + \mu_t + \alpha_i + e_{it} \quad (14)$$

$$logICMI_{ik,t} = \phi logICMI_{it-1} + \beta logECI_{it} + \partial logZ'_{it} + \mu_t + \alpha_i + e_{it} \quad (15)$$

where Z´ represents the control variables, which includes all the variables presented in equation (13).

3. Results

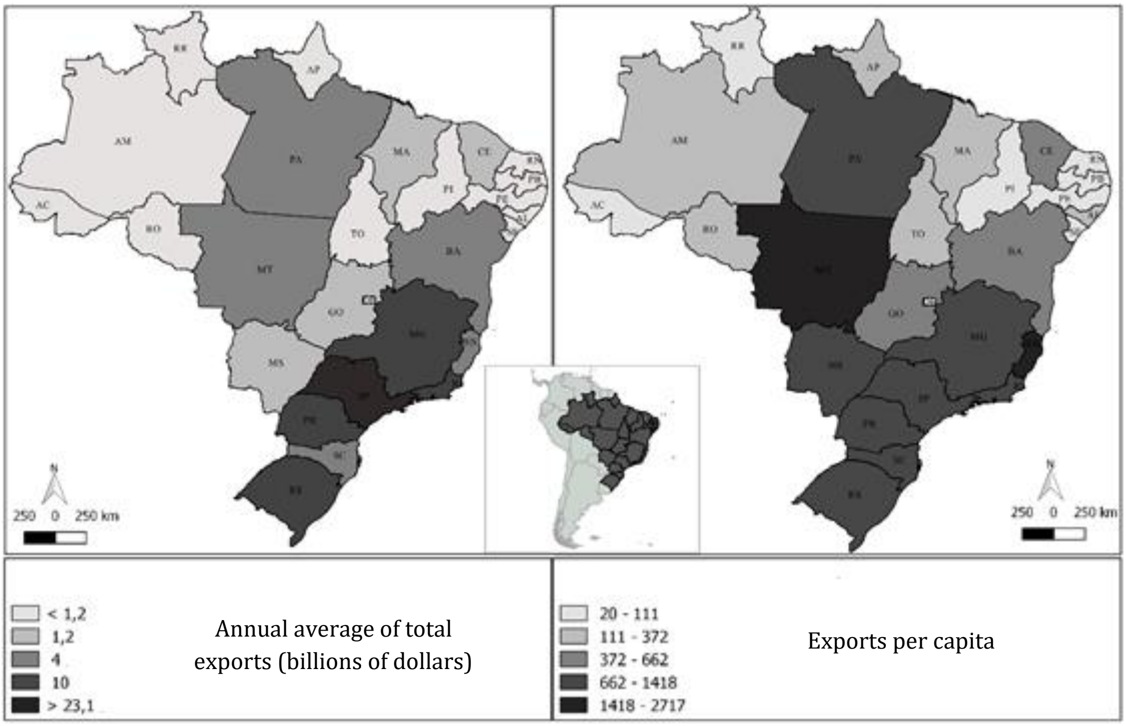
3.1. Descriptive analysis

For an analysis of economic complexity, it is initially necessary to check how the exports are distributed within the national territory.[6] It is observed that the states of Minas Gerais, Paraná, Rio de Janeiro, Rio Grande do Sul and São Paulo stand out with respect to the total exported (figure 1, map on the left), with emphasis on the latter. Almost all the states in the North region, except for Pará, and the Northeast region, except for Bahia, had a quantity exported below the average of the other states between the years 2003 and 2014.

As many states are large in territory and small in population, it is also necessary to analyze per-capita values (figure 1, map on the right), which represent a better measure of export productivity. It is observed that many states that previously had values below the average now present values above the average, as is the case of Ceará, Espírito Santo, Mato Grosso, Mato Grosso do Sul and Pará.

[5] Except for the interest rate and commodity price, all variables vary over time and between UFs.
[6] The calculation of complexity measures is based on international trade.

Figure 1 – *Annual average of total exports (left) and exports per capita (right) between 2003 and 2014*

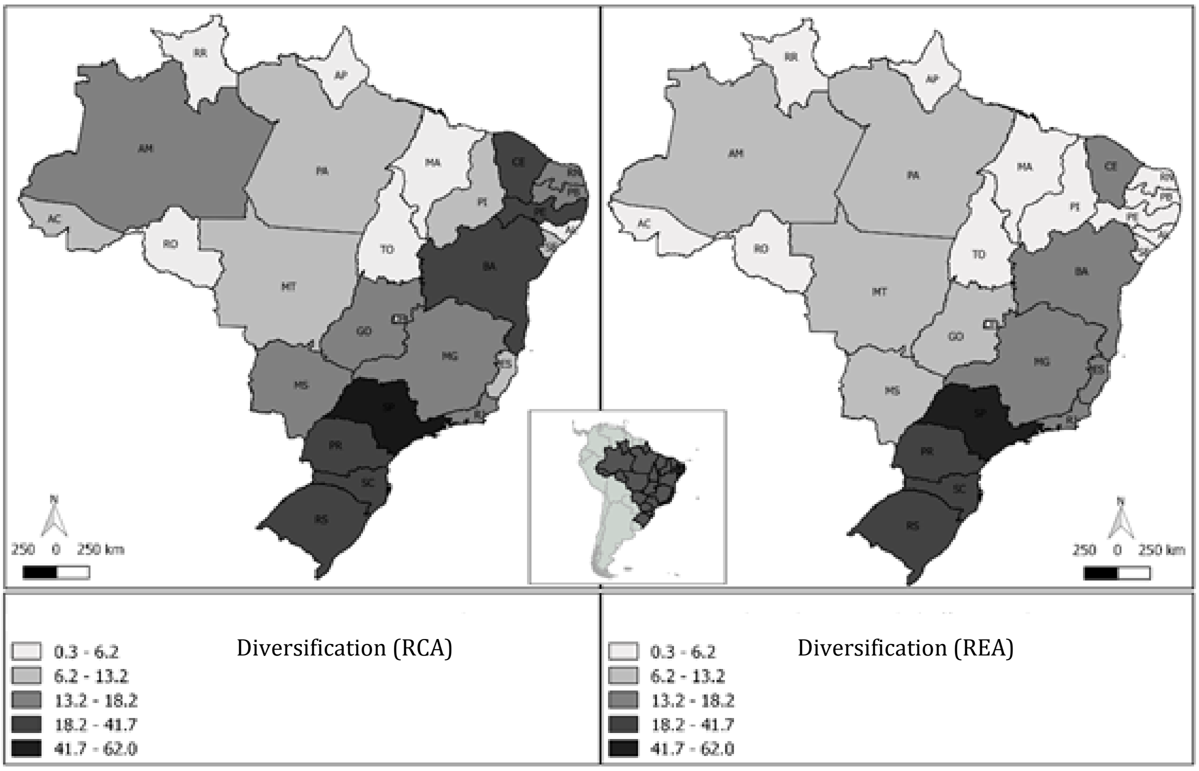


Source: elaborated by the authors, based on data from Comex Stat/Secex.
Note: Acre (AC); Alagoas (AL); Amapá (AP); Amazonas (AM); Bahia (BA); Ceará (CE); Distrito Federal (DF); Espírito Santo (ES); Goiás (GO); Maranhão (MA); Mato Grosso (MT); Mato Grosso do Sul (MS); Minas Gerais (MG); Pará (PA); Paraíba (PB); Paraná (PR); Pernambuco (PE); Piauí (PI); Roraima (RR); Rondônia (RO); Rio de Janeiro (RJ); Rio Grande do Norte (RN); Rio Grande do Sul (RS); Santa Catarina (SC); São Paulo (SP); Sergipe (SE); Tocantins (TO).

Figure 2 shows the UFs' average diversification between 2003 and 2014, through RCA (left map) and REA (right map). Diversification is verified through the quantity of products that a specific UF exports. Based on RCA, we found that the state of São Paulo exported approximately 57 product categories (out of a total of 97), with values above the average of products exported by Brazil. After that come the states of Bahia, Ceará, Paraná, Pernambuco, Rio Grande do Sul and Santa Catarina, which exported between 17.6 and 32.2 categories of products with RCA. Some states, such as Alagoas, Amapá, Maranhão, Rondônia, Roraima and Tocantins exported, on average, between 3.8 and 6.2 categories of products with RCA, being considered the states with the least diversified exports.

Through REA (figure 2, right-hand map), which controls the size of the population, we found that the state of São Paulo continued to be the most diversified. Others were less diversified, as is the case in the Distrito Federal and the states of Acre, Paraíba, Pernambuco, Piauí and Rio Grande do Norte. Good examples are the cases of Acre, Roraima and the Distrito Federal, which, in some years of the sample, did not have any category of products with REA in their export basket.

Figure 2 – *Average diversification of UFs through the revealed comparative advantage (left) and the revealed effectiveness advantage (right) between 2003 and 2014*



Source: elaborated by the authors, based on data from Comex Stat/Secex.

Despite the importance of the initial measures of diversification, the real measure of economic complexity depends on the iterations between the diversification matrix of the states and the ubiquity matrix of the products. This allows the verification of generalized measures of diversification, and the method extracts more information after each iterative process. However, a very excessive number of iterations cannot be performed, since in the linear version the measures convert to the same value after many iterations.

Through the linear approach (table 2), it is possible to verify that the state of São Paulo is first in the complexity ranking, followed by Rio Grande do Sul and Santa Catarina. These are also the states with the most diversified export structure. However, from the iteration $K_{s,8}/UF$ forward, these states begin to lose position to the states of Amazonas and Rio de Janeiro. This pattern was verified by both RCA and REA values. Like Herrera et al. (2021), the results indicated, by the traditional approach (RCA), that the states of greatest complexity are those in the South and Southeast. However, in the work of Herrera et al. (2021), the state of São Paulo assumed the first position in the ranking. In the present work, São Paulo took the lead in the ranking in the first iterations but the state of Amazonas took the lead in the complexity ranking from iteration 6.

For the specific case of the values that come from REA, the case of Alagoas stands out. Initially, this state was one of the least diversified in the country, but it gained positions during the iterations and ended up among the ten most complex states by the measure from the RCA and in second place by the measure from the REA. This was due to the method being based on a network analysis and, thus, considering not only the diversification of a specific UF but also the diversification of other UFs that export compatible products. In other words, a UF can export few products, but the measure of economic complexity tends to rise if these same products are exported by other UFs with high productive diversification. The Distrito Federal (DF) is another interesting case, since, in the analysis with RCA, it was in a considerably higher ranking when compared to the analysis through REA. This indicates that, when comparing with the size of the population, DF exports are not very productive and not very complex. As the DF is an administrative center, most of the workforce is employed in public administration and the services sector instead of export-oriented productive sectors.

Table 2 – *Ranking of economic complexity for UFs (average value 2003-2014 using the linear approach)*

	With revealed comparative advantage				**With revealed effectiveness advantage**			
Ranking	$K_{s,0}/UF$	$K_{s,2}/UF$	$K_{s,8}/UF$	$K_{s,10}/UF$	$K_{s,0}/UF$	$K_{s,2}/UF$	$K_{s,8}/UF$	$K_{s,10}/UF$
1^0	57.75/SP	32.32/SP	25.03/AM	24.71/AM	62.00/SP	37.56/SP	30.06/AM	29.54/AM
2^0	32.17/RS	28.61/RS	24.93/RJ	24.67/RJ	41.67/RS	34.20/RS	29.77/RJ	29.41/AL
3^0	29.08/SC	27.80/SC	24.91/SP	24.65/SP	34.08/SC	32.96/SC	29.75/AL	29.40/RJ
4^0	26.00/CE	27.71/AM	24.79/SC	24.60/SC	32.33/PR	31.45/AM	29.63/SP	29.31/SP
5^0	25.75/PR	26.65/RJ	24.77/RS	24.59/RS	18.25/RJ	31.35/PR	29.44/SC	29.22/SC
6^0	24.83/BA	25.49/PR	24.56/PE	24.51/SE	16.92/CE	31.05/RJ	29.41/RS	29.20/RS
7^0	24.25/PE	24.81/PE	24.55/SE	24.50/PE	16.75/MG	28.31/AL	29.27/PR	29.13/PR
8^0	17.58/RJ	24.61/CE	24.52/PR	24.47/PR	16.42/ES	24.40/CE	28.80/PB	28.93/PB
9^0	16.67/AM	24.20/BA	24.48/CE	24.46/AL	15.67/BA	24.16/BA	28.62/CE	28.83/CE
10^0	16.50/PB	22.58/PB	24.45/AL	24.46/CE	13.17/GO	23.00/MS	28.57/BA	28.80/BA
11^0	16.33/RN	22.35/RN	24.45/PB	24.45/PB	12.75/MS	22.89/MG	28.54/MS	28.78/MS
12^0	14.75/GO	22.10/SE	24.41/BA	24.42/AC	11.42/MT	22.84/ES	28.51/PE	28.77/PE
13^0	14.08/MG	21.29/AL	24.38/SC	24.42/BA	11.17/AM	22.36/GO	28.39/MT	28.71/MT
14^0	12.92/MS	21.27/AC	24.37/RN	24.41/RN	10.67/PA	22.25/PE	28.37/GO	28.69/GO
15^0	10.08/ES	20.91/DF	24.33/DF	24.39/DF	6.25/PE	22.00/PB	28.30/ES	28.64/ES
16^0	10.08/PI	19.65/PI	24.07/PI	24.26/PI	5.83/PB	21.84/MT	28.20/RO	28.61/RO
17^0	9.58/MT	19.64/GO	24.04/RR	24.25/RR	5.50/RN	20.89/SE	28.20/SE	28.60/SE
18^0	9.42/SE	18.98/MG	23.95/GO	24.20/GO	4.42/RO	19.73/RO	28.11/RN	28.57/RN
19^0	9.00/PA	18.37/MS	23.90/MS	24.19/MS	4.17/MA	18.74/PI	28.06/MG	28.50/MG
20^0	8.08/AC	18.32/RR	23.86/RO	24.17/RO	2.75/AP	18.61/RN	27.90/TO	28.45/TO
21^0	7.67/DF	17.57/ES	23.84/MT	24.16/MT	2.58/TO	18.07/PA	27.38/AP	28.17/AP
22^0	6.25/RO	17.48/MT	23.80/TO	24.15/TO	2.50/SE	17.60/TO	27.31/PA	28.11/PA
23^0	6.00/MA	17.14/RO	23.52/ES	23.96/ES	2.17/AL	15.93/AP	26.76/MA	27.81/MA
24^0	5.08/RR	16.39/TO	23.47/MG	23.94/AP	1.67/PI	15.58/MA	21.76/PI	21.79/PI
25^0	4.08/AP	15.58/PA	23.45/AP	23.91/MG	1.00/AC	11.23/AC	20.78/AC	21.26/AC
26^0	4.08/TO	15.31/AP	23.17/PA	23.79/PA	0.50/RR	7.63/RR	13.72/RR	14.09/RR
27^0	3.75/AL	12.88/MA	22.81/MA	23.61/MA	0.33/DF	4.14/DF	4.87/DF	4.87/DF

Source: elaborated by the authors, based on data from Comex Stat/Secex.
Note: Acre (AC); Alagoas (AL); Amapá (AP); Amazonas (AM); Bahia (BA); Ceará (CE); Distrito Federal (DF); Espírito Santo (ES); Goiás (GO); Maranhão (MA); Mato Grosso (MT); Mato Grosso do Sul (MS); Minas Gerais (MG); Pará (PA); Paraíba (PB); Paraná (PR); Pernambuco (PE); Piauí (PI); Roraima (RR); Rondônia (RO); Rio de Janeiro (RJ); Rio Grande do Norte (RN); Rio Grande do Sul (RS); Santa Catarina (SC); São Paulo (SP); Sergipe (SE); Tocantins (TO).

Through the non-linear approach (table 3), the rankings were more persistent during the iterations. By both the RCA and REA approaches, the five most complex states in the F_{10}

iterations were São Paulo, Rio Grande do Sul, Santa Catarina, Rio de Janeiro and Paraná, respectively. The least complex were Amapá and Tocantins. Acre, Distrito Federal and Roraima did not present an effective advantage in any product category for some years of the sample, which resulted in zero values for these states.

Table 3 – *Ranking of economic complexity for UFs (average value 2003-2014 using the non-linear approach)*

	With revealed comparative advantage				With revealed effectiveness advantage			
Ranking	F_1/UF	F_2/UF	F_8/UF	F_{10}/UF	F_1/UF	F_2/UF	F_8/UF	F_{10}/UF
1^0	1.202/DF	4.939/SP	10.418/SP	11.243/SP	4.743/SP	5.908/SP	10.84/SP	11.361/SP
2^0	1.168/ES	2.496/RS	4.283/RS	4.553/RS	3.192/RS	3.458/RS	5.403/RS	5.600/RS
3^0	1.126/BA	1.852/SC	2.003/SC	1.931/SC	2.608/SC	2.435/SC	2.609/SC	2.536/SC
4^0	1.122/AP	1.672/BA	1.630/RJ	1.612/RJ	2.475/PR	2.233/PR	2.075/RJ	2.103/RJ
5^0	1.121/GO	1.614/PR	1.486/PR	1.407/PR	1.397/RJ	1.711/RJ	1.957/PR	1.857/PR
6^0	1.121/MT	1.495/CE	1.338/AM	1.339/AM	1.286/CE	1.550/MG	0.871/MG	0.771/MG
7^0	1.112/CE	1.433/RJ	1.262/BA	1.138/BA	1.282/MG	1.323/BA	0.835/BA	0.767/BA
8^0	1.081/MG	1.340/PE	1.040/CE	0.920/CE	1.257/ES	1.228/ES	0.661/AM	0.635/AM
9^0	1.074/PB	1.269/MG	0.839/PE	0.745/PE	1.199/BA	1.178/CE	0.649/ES	0.577/ES
10^0	1.071/PA	1.201/AM	0.778/MG	0.690/MG	1.008/GO	0.896/AM	0.555/CE	0.471/CE
11^0	1.069/MS	0.879/PB	0.356/PB	0.284/PB	0.977/MS	0.772/PA	0.116/MS	0.074/MS
12^0	1.06/MA	0.755/RN	0.260/RN	0.199/ES	0.874/MT	0.701/GO	0.112/GO	0.069/GO
13^0	1.026/SC	0.738/ES	0.255/ES	0.198/RN	0.854/AM	0.676/MS	0.088/PA	0.049/PA
14^0	1.018/RR	0.694/GO	0.180/GO	0.139/SE	0.816/PA	0.560/MT	0.076/PI	0.033/MT
15^0	1.003/RS	0.642/PA	0.178/SE	0.128/GO	0.475/PE	0.402/PB	0.060/MT	0.031/PE
16^0	0.987/TO	0.557/MS	0.111/AC	0.088/AC	0.445/PB	0.382/PE	0.050/PE	0.027/PB
17^0	0.984/SP	0.534/SE	0.108/DF	0.083/DF	0.420/RN	0.299/MA	0.046/PB	0.012/RN
18^0	0.977/AM	0.411/PI	0.108/PA	0.069/PA	0.338/RO	0.292/RN	0.022/RN	0.007/PI
19^0	0.968/SE	0.389/MT	0.102/MS	0.068/MS	0.318/MA	0.204/RO	0.014/MA	0.006/MA
20^0	0.916/AL	0.382/DF	0.084/PI	0.057/PI	0.211/AP	0.202/SE	0.009/RO	0.004/RO
21^0	0.899/PI	0.374/AC	0.052/MT	0.033/MT	0.199/TO	0.169/AL	0.006/SE	0.002/SE
22^0	0.893/PE	0.359/MA	0.036/MA	0.021/MA	0.191/SE	0.163/AP	0.004/AL	0.001/AL
23^0	0.886/PR	0.250/RO	0.024/AL	0.016/AL	0.166/AL	0.110/PI	0.003/AP	0.001/AP
24^0	0.880/AC	0.213/AP	0.023/RO	0.014/RO	0.132/PI	0.109/TO	0.002/TO	0.001/TO
25^0	0.752/RN	0.195/RR	0.020/RR	0.012/RR	0/AC	0/AC	0/AC	0/AC
26^0	0.748/RO	0.176/AL	0.018/AP	0.010/AP	0/DF	0/DF	0/DF	0/DF
27^0	0.736/RJ	0.141/TO	0.007/TO	0.003/TO	0/RR	0/RR	0/RR	0/RR

Source: elaborated by the authors, based on data from Comex Stat/Secex.
Notes: Acre (AC); Alagoas (AL); Amapá (AP); Amazonas (AM); Bahia (BA); Ceará (CE); Distrito Federal (DF); Espírito Santo (ES); Goiás (GO); Maranhão (MA); Mato Grosso (MT); Mato Grosso do Sul (MS); Minas Gerais (MG); Pará (PA); Paraíba (PB); Paraná (PR); Pernambuco (PE); Piauí (PI); Roraima (RR); Rondônia (RO); Rio de Janeiro (RJ); Rio Grande do Norte (RN); Rio Grande do Sul (RS); Santa Catarina (SC); São Paulo (SP); Sergipe (SE); Tocantins (TO). Acre, Distrito Federal, and Roraima did not present an effective advantage in any product category for some years of the sample.

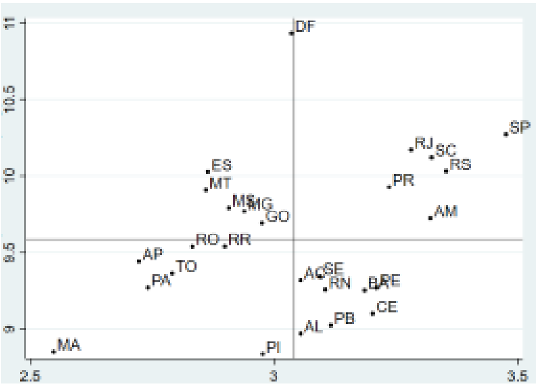
As previously discussed, the economic complexity index was created to be an indicator of the future growth potential of an economy. If two economies have compatible levels of income and one is more complex than the other, the more complex economy tends to perform better in terms of economic growth in the future. This is because this approach considers that the economic complexity index tends to capture the technical and scientific knowledge that is embedded in people (human capital), in machines and equipment (physical capital), and in the ability of people to exchange information and connect with each other (social capital). The complexity of what an economy exports and produces reveals its productive capabilities (Hidalgo, 2015).

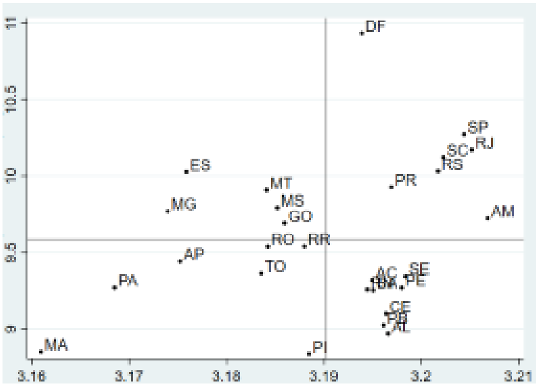
Thus, an analysis of the relationship between the economic complexity indices and GDP per capita is useful to verify which UFs have the greatest potential for future growth. The dispersion between the economic complexity indices in the linear and non-linear versions (in iterations 2 and 10) and the UFs' GDP per capita through the RCA matrix can be seen in figure 3.

Figure 3 – *Complexity measures from the RCA matrix*

Dispersion between the linear index of economic complexity in iterations 2 (left) and 10 (right) and the GDP per capita of UFs (2003-2014) through the RCA matrix

GDP per capita (log)

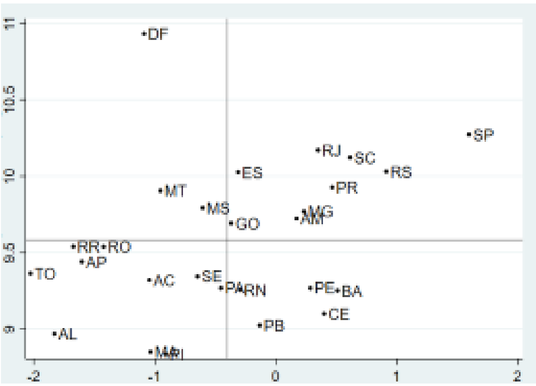


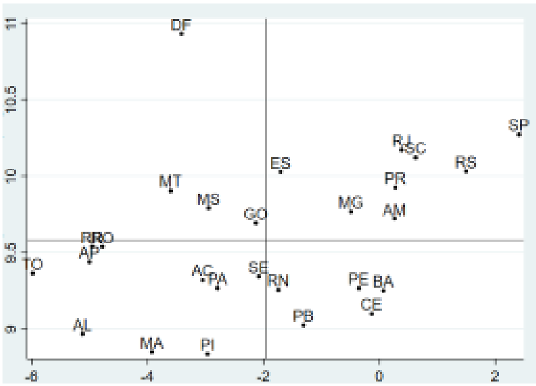


Economic complexity $K_{s,2}$ (log) Economic complexity $K_{s,10}$ (log)

Dispersion between the non-linear index of economic complexity in iterations 2 (right) and 10 (left) and the GDP per capita of UFs (2003-2014) through the RCA matrix

GDP per capita (log)





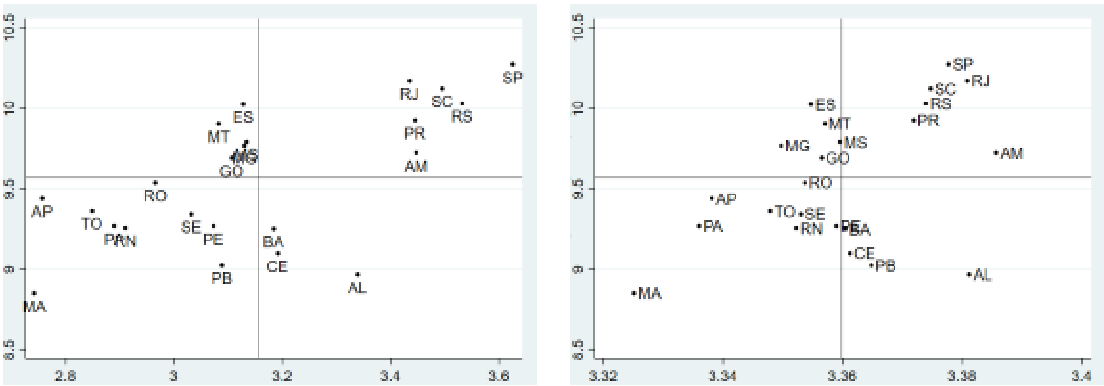
Economic complexity $F_{s,2}$ (log) Economic complexity $F_{s,10}$ (log)

The lines that cut the x and y axes represent the average value for each axis, which can be divided into quadrants: in the first quadrant (upper right) there are UFs with high values of economic complexity and high income; in the second quadrant (upper left) there are UFs with high income and low complexity. In the third quadrant (bottom left) are UFs with low income and low complexity and, finally, in the fourth quadrant (bottom right) are UFs with low income and high complexity. It is observed that there is a positive relationship between economic complexity and per-capita income. However, the interest here is not to verify the correlation, but rather to determine which UFs presented a more sophisticated (complex) export structure compared to their income level – to verify the growth potential of each one.

Figure 4 – *Complexity measures from the REA matrix*

Dispersion between the linear index of economic complexity in iterations 2 (left) and 10 (right) and the GDP per capita of UFs (2003-2014) using the REA matrix

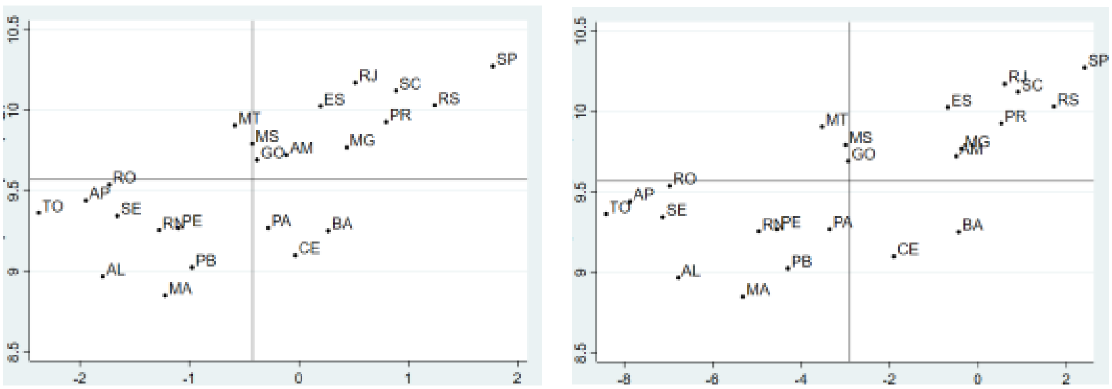
GDP per capita (log)



Economic complexity $K_{s,2}$ (log) Economic complexity $K_{s,10}$ (log)

Dispersion between the non-linear index of economic complexity in iterations 2 (right) and 10 (left) and the GDP per capita of UFs (2003-2014) using the REA matrix

GDP per capita (log)



Economic complexity $F_{s,2}$ (log) Economic complexity $F_{s,10}$ (log)

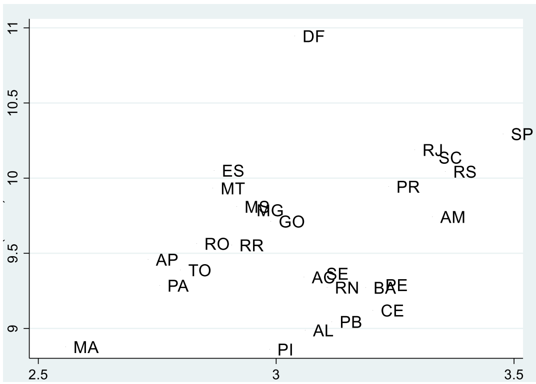
Note: Acre, Distrito Federal, and Roraima did not present an effective advantage in any product category for some years of the sample.

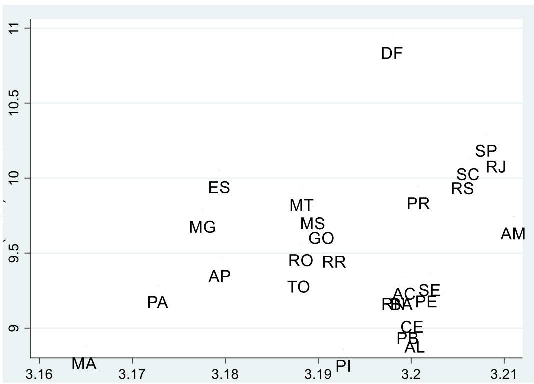
Both in the iteration $K_{s,2}$ and in the iteration $K_{s,10}$ (in the linear approach), we observed four groups by similarity: AM, SC, SP, PR, RJ and RS are in the group of UFs with high economic complexity and high income; ES, GO, MG, MS and MT are in the group with high income and low economic complexity; AP, PA, RO, RR and TO are in the low-income and low-complexity group; and AC, AL, BA, CE, PE, RN and SE are in the group with low income and medium-high complexity. Based on the complexity approach, the latter showed a very sophisticated productive structure for their income levels and greater opportunities for growth, when compared to UFs with the same income level. The Distrito Federal, Maranhão and Piauí are not included in these groups, as they showed many differences in income levels, being very high for the first and very low for the last two. A similar pattern was observed for the analysis that starts from the non-linear measures of economic complexity. Few differences were observed when considering the economic complexity measures through REA (figure 4).

Figure 5 – *Complexity measures from the RCA matrix with GDP in t+1*

Dispersion between the linear index of economic complexity in iterations 2 (left) and 10 (right) and the UFs' GDP per capita in t+1 (2003-2014) through the RCA matrix

GDP per capita in t+1 (log)

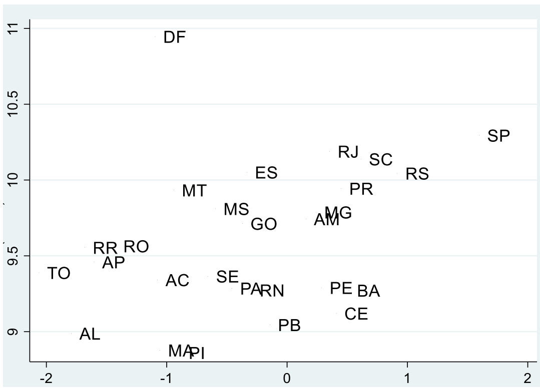


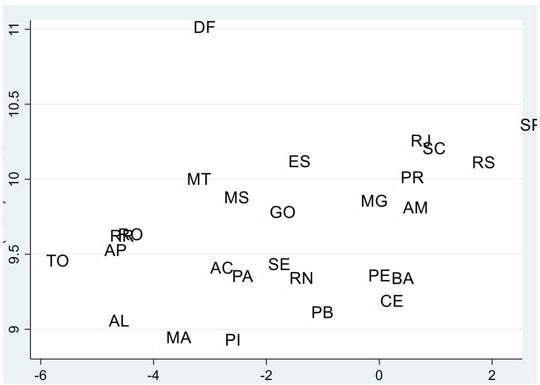


Economic complexity $K_{s,2}$ (log) Economic complexity $K_{s,10}$ (log)

Dispersion between the non-linear index of economic complexity in iterations 2 (right) and 10 (left) and the UFs' GDP per capita in t+1 (2003-2014) through the RCA matrix

GDP per capita in t+1 (log)





Economic complexity $F_{s,2}$ (log) Economic complexity $F_{s,10}$ (log)

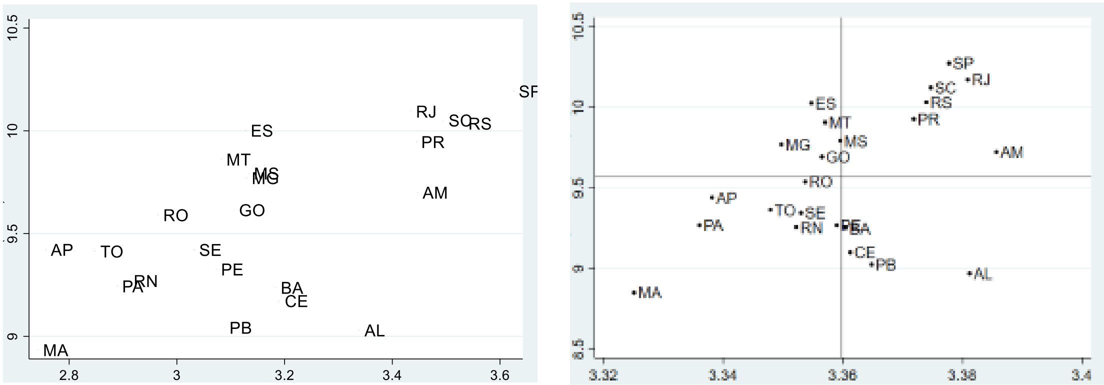
In the linear version, the main changes were that some UFs that were in the medium-high-complexity and low-income group, such as AC, SE and RN, passed to the low-complexity and low-income group. By the non-linear approach, only BA, CE and PA remained in the high-complexity and low-income group; other low-income UFs (AL; AP; MA; PB; PE; RN; RO; SE; TO) presented low levels of economic complexity.

Figures 5 and 6 show the relationship between the complexity measures and the UFs' future GDP. The exercise is the same as in figures 3 and 4 but, instead of using GDP in the same year, we use GDP in later periods. The idea behind this lies in the fact that complexity theory considers that the economic complexity index was created to be a predictor of the future growth of an economy.

Figure 6 – *Complexity measures from the REA matrix*

Dispersion between the linear index of economic complexity in iterations 2 (left) and 10 (right) and the UFs' GDP per capita in t+1 (2003-2014) using the REA matrix

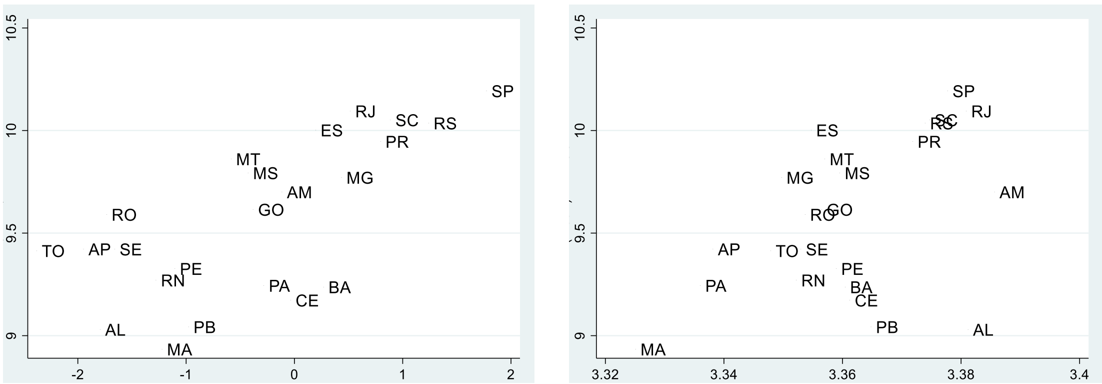
GDP per capita in t+1 (log)



Economic complexity $K_{s,2}$ (log) Economic complexity $K_{s,10}$ (log)

Dispersion between the non-linear index of economic complexity in iterations 2 (right) and 10 (left) and the UFs' GDP per capita in t+1 (2003-2014) using the REA matrix

GDP per capita in t+1 (log)



Economic complexity $F_{s,2}$ (log) Economic complexity $F_{s,10}$ (log)

Note: Acre, Distrito Federal, and Roraima did not present an effective advantage in any product category for some years of the sample.

From figures 5 and 6, we observe that there is a positive relationship of economic complexity indices (both in linear and non-linear versions, such as with RCA and REA) with GDP in the subsequent period, which reinforces the theoretical bases of the complexity approach, as well as its use for the UFs of Brazil.

3.2. Estimation results

This section is dedicated to verifying the determinants of the UFs' economic complexity, as well as the relationship of this complexity with economic growth and with the transformation of the productive structure. Intermediate consumption of the manufacturing industry (ICMI) is used as a proxy for the transformation of the productive structure, since it represents the activity level of the high-productivity industrial sector. As explanatory variables, we used: i) the GDP of the main commercial partners of each UF; ii) the exchange rate controlled by the Balassa-Samuelson effect; iii) a proxy for physical capital; iv) a proxy for education; v) trade openness; vi) interest rate; vii) commodity prices.[7] In some cases, dependent variables in some estimates, such as economic complexity index and ICMI, are used as explanatory in others.

All estimates in this section were performed by two-step system GMM estimators. Thus, the possibly endogenous variables are transformed by differencing and lag, to be used as an instrument for their level values. We did this to avoid problems of endogeneity, since the economic complexity indices can be endogenous and, in turn, a consequence rather than a cause of the economic performance of a region. An estimation without considering the possible endogeneity of economic complexity measures, for example, may raise doubts as to whether the causal relationship goes from economic complexity to GDP growth or from GDP growth to economic complexity.

Starting with the relationship between economic complexity and economic growth (tables 4 and 5), we found that some of the economic complexity measures had a positive and significant relationship with the UFs' GDP in the approach that starts from the RCA matrix (table 4). In the REA approach (table 5), a positive relationship with statistical significance was observed only in the F_{10} iteration.

[7] Except for interest rates and commodity prices, all variables vary over time and between UFs. We would like to acknowledge the anonymous reviewer's suggestion to add the degree of urbanization as a control to the difference between UFs of urban or rural character. We will pay attention to this in future work.

Table 4 – *UFs' GDP determinants: economic complexity indices based on the RCA matrix*

Variable	UFs' GDP	UFs' GDP	UFs' GDP	UFs' GDP	UFs' GDP	UFs' GDP	UFs' GDP	UFs' GDP
UFs' GDP (t–1)	0.872***	0.758***	0.778***	0.762***	0.802***	0.804***	0.833***	0.790***
	(0.179)	(0.183)	(0.153)	(0.144)	(0.163)	(0.167)	(0.157)	(0.176)
UFs' GDP (t–2)	0.116	0.252	0.237	0.256*	0.180	0.179	0.162	0.196
	(0.167)	(0.186)	(0.157)	(0.147)	(0.159)	(0.159)	(0.157)	(0.163)
Complexity ($K_{s,2}$)	0.0874							
	(0.0633)							
Complexity ($K_{s,6}$)		0.249**						
		(0.121)						
Complexity ($K_{s,8}$)			0.270*					
			(0.135)					
Complexity ($K_{s,10}$)				0.295*				
				(0.148)				
Complexity (F_2)					0.0333*			
					(0.0182)			
Complexity (F_6)						0.0138		
						(0.0111)		
Complexity (F_8)							0.00797	
							(0.00767)	
Complexity (F_{10})								0.00713
								(0.00871)
Exchange rate BS	−0.0386	0.272	0.334	0.389*	0.0136	0.0911	0.0434	0.119
	(0.294)	(0.239)	(0.234)	(0.225)	(0.289)	(0.266)	(0.206)	(0.297)
Trade openness	0.00139	−0.00617	−0.00685	−0.00734	−0.00358	−0.00115	−0.00411	−4.73e−05
	(0.00977)	(0.00967)	(0.00894)	(0.00842)	(0.00936)	(0.00692)	(0.00540)	(0.00718)
Trading partners' GDP	0.00202	−0.0223	−0.0293	−0.0334	0.00266	0.00474	−0.00847	0.00145
	(0.0308)	(0.0252)	(0.0240)	(0.0242)	(0.0323)	(0.0309)	(0.0158)	(0.0342)
Capital expenditure	−0.000112	−0.00182	−0.00197*	−0.00214	−0.00112	−0.000990	−0.00169	−0.000851
	(0.00220)	(0.00113)	(0.00112)	(0.00127)	(0.00123)	(0.00127)	(0.00115)	(0.00124)
Education	−0.0192	−0.0121	−0.00509	−0.000647	−0.00707	−0.00937	−0.0131	−0.00992
	(0.0189)	(0.0197)	(0.0169)	(0.0170)	(0.0209)	(0.0171)	(0.0149)	(0.0180)
Commodity prices	0.0967**	0.117***	0.118***	0.122***	0.105***	0.118***	0.120***	0.123***
	(0.0419)	(0.0348)	(0.0330)	(0.0325)	(0.0350)	(0.0341)	(0.0347)	(0.0364)
Interest rate	0.0204*	0.0190**	0.0173**	0.0175**	0.0186**	0.0199**	0.0212**	0.0220**
	(0.0111)	(0.00877)	(0.00760)	(0.00761)	(0.00759)	(0.00885)	(0.00897)	(0.00953)
Constant	−0.369	−1.262	−1.379*	−1.531*	−0.110	−0.353	−0.182	−0.422
	(0.982)	(0.755)	(0.739)	(0.764)	(0.841)	(0.736)	(0.481)	(0.844)
Observations	270	270	270	270	270	270	270	270
Num. Id	27	27	27	27	27	27	27	27
AR (2)	0.212	0.097	0.074	0.057	0.167	0.175	0.164	0.146
Hansen test	0.169	0.306	0.420	0.409	0.326	0.276	0.252	0.180
Lag of instruments	2	2	2	2	2	2	2	2

Source: Prepared by the authors.
Notes: Standard errors in parentheses; *** p < 0.01, ** p < 0.05, * p < 0. The correction for standard errors proposed by Windmeijer (2005) was used.

Table 5 – *Determinants of UFs' GDP: economic complexity indices based on the REA matrix*

Variable	UFs' GDP	UFs' GDP	UFs' GDP	UFs' GDP	UFs' GDP	UFs' GDP	UFs' GDP	UFs' GDP
UFs' GDP (t–1)	0.896***	0.891***	0.867***	0.886***	1.156***	1.072***	1.048***	1.027***
	(0.308)	(0.281)	(0.296)	(0.313)	(0.181)	(0.202)	(0.214)	(0.216)
UFs' GDP (t–2)	0.240	0.234	0.270	0.253	−0.0607	−0.0134	0.00349	0.0325
	(0.322)	(0.292)	(0.301)	(0.315)	(0.182)	(0.199)	(0.218)	(0.216)
Complexity ($K_{s,2}$)	0.0273							
	(0.152)							
Complexity ($K_{s,6}$)		−0.00449						
		(0.317)						
Complexity ($K_{s,8}$)			0.155					
			(0.321)					
Complexity ($K_{s,10}$)				0.236				
				(0.310)				
Complexity (F_2)					0.0314			
					(0.0313)			
Complexity (F_6)						0.0180		
						(0.0181)		
Complexity (F_8)							0.0163	
							(0.0136)	
Complexity (F_{10})								0.0173*
								(0.00972)
Exchange rate BS	0.672	0.693	0.783	0.689	0.217	0.269	0.280	0.553
	(0.844)	(0.895)	(0.846)	(0.873)	(0.588)	(0.777)	(0.834)	(0.740)
Trade openness	−0.0205	−0.0200	−0.0182	−0.0185	−0.0295*	−0.0266	−0.0280	−0.0400*
	(0.0155)	(0.0145)	(0.0144)	(0.0136)	(0.0164)	(0.0196)	(0.0201)	(0.0216)
Trading partners' GDP	−0.0803*	−0.0760	−0.0745	−0.0677	0.00760	0.0271	0.0352	0.0700
	(0.0455)	(0.0566)	(0.0536)	(0.0541)	(0.0737)	(0.0844)	(0.0875)	(0.0876)
Capital expenditure	−0.133**	−0.120**	−0.135***	−0.137***	−0.116**	−0.0813*	−0.0749	−0.0826*
	(0.0571)	(0.0446)	(0.0361)	(0.0303)	(0.0464)	(0.0447)	(0.0460)	(0.0427)
Education	0.00258	0.00185	0.00626	0.0100	−0.0289	−0.0264	−0.0291	−0.110
	(0.0414)	(0.0534)	(0.0525)	(0.0503)	(0.0288)	(0.0361)	(0.0393)	(0.103)
Commodity prices	0.327**	0.321***	0.340***	0.334***	0.300**	0.261*	0.258*	0.306**
	(0.140)	(0.110)	(0.0911)	(0.0894)	(0.116)	(0.129)	(0.131)	(0.124)
Interest rate	0.0200	0.0201	0.0198	0.0229	0.0410**	0.0355**	0.0350**	0.0223
	(0.0158)	(0.0240)	(0.0244)	(0.0249)	(0.0179)	(0.0160)	(0.0168)	(0.0175)
Constant	−0.319	−0.360	−1.089	−1.348	−0.859	−1.269	−1.422	−2.419
	(1.547)	(1.759)	(1.583)	(1.522)	(1.344)	(1.782)	(1.949)	(2.100)
Observations	230	230	230	230	230	230	230	230
Num. Id	23	23	23	23	23	23	23	23
AR (2)	0.185	0.141	0.083	0.091	0.365	0.238	0.222	0.277
Hansen test	0.857	0.701	0.677	0.726	0.675	0.556	0.543	0.709
Lag of instruments	2	2	2	2	2	2	2	2

Source: Prepared by the authors.
Notes: Standard errors in parentheses; *** p < 0.01, ** p < 0.05, * p < 0.1. The correction for standard errors proposed by Windmeijer (2005) was used.

In short, tables 4 and 5 showed that some economic complexity measures are directly related to the UFs' growth. However, this relation is not a robust and unambiguous result since most measures of complexity are not significant.

The lack of significance in the estimates for the non-linear version may be related to some factors, such as:8 i) the normalization of variables after each iteration, since the differential of this approach (being non-linear) can make it difficult to correlate with other variables in temporal analysis – by presenting more variations from one year to another, this can damage the analysis of correlations with other variables in a sequential period; ii) the coefficient of the non-linear index is very small and this may be causing problems of weak correlation with other variables, mainly with GDP; iii) as opposed to the linear approach, where the complexity values tend to move towards a common value after several iterations, in the non-linear approach the complexity values presents great differentiation between places with greater and lesser complexity in the course of iterations. Thus, it is understandable that the non-linear approach starts to highlight the relationship between complexity and economic growth after some iterations. This, in part, can explain why only the F_{10} iteration was significant in the nonlinear approach (table 5).

Of course, we do not discard the hypothesis that the lack of significance of these measures may be precisely associated with the fact that it is more refined than the RCA measures. In this case, it is possible that the estimate in table 5 captures the real relationship between the variables analyzed. Similar reasoning can be made regarding the significance of some measures in the approach that starts from the RCA matrix.

Based on the results achieved, we raised some questions. Is it possible to measure the competitiveness of subnational entities by looking at the complexity of their export basket? Is the economic complexity approach a good predictor of UFs' growth potential? Are the measures of complexity we know suitable only for entities that compete on an unequal playing field? Could the multifaceted concept of complexity economics be a puzzle for empirical investigation in economics?

As we mentioned earlier (subsection 1.3), there is a research agenda that still needs to move towards identifying which measures of complexity are correlated with GDP growth, if any. It is also necessary to advance in the explanations of which measure is more adequate to capture the concept of economic complexity. Unfortunately, further discussion of this issue is beyond the scope of this paper.

In addition to these results, we found that the UFs' GDP was strongly influenced by the commodity price index. The rise in the commodity price index benefited Brazil and the countries of Latin America as a whole, which are, for the most part, potential exporters of these products. This had a positive effect on disposable income and the level of capacity utilization in several regions (and UFs) in Brazil.

This positive scenario occurred not only due to the advance of the primary sector but also of some industrial sectors that were benefited by the greater demand for final goods and capital goods. Brazil was influenced both by the income effect resulting from China's economic growth and by the income effect of other Latin American countries. When considering that most countries in Latin America have benefited in terms of income from the rise in commodity

[8] Of course, we must remember the well-known fact that in econometrics the results can be sensitive to the model specification, the methodology used, period of time, etc. So, we draw attention to the limitations of the tests performed here and the need for new exercises, including the application of the methodology to other countries/regions.

prices, it is possible to divide the income effect into primary and secondary. Exports of non-industrial products were impacted by the primary income effect, due to the greater Chinese demand for Brazil's agricultural and mineral products. Exports of Brazil's industrial products, in turn, were influenced by the secondary income effect, which was due to the higher income of other countries in Latin America. The main example of the secondary income effect was the significant increase in exports of the automobile industry (automobiles, tractors, parts, and others) from Brazil to Argentina, which was approximately 1 billion (US$) in 2003 and 9 billion (US$) in 2013 (UN Comtrade, 2020).

Thus, in the period in which the estimates were made (2003-2014), there was a favorable scenario (in terms of income and expectations regarding future demand) for investment in certain sectors of the industry that benefited from the secondary income effect. The question that deserves to be discussed, however, is whether incentive policies have taken place to maximize this gain from secondary income. This could have a significant effect on diversification and, in turn, on the economic complexity and structural transformation of certain regions. Despite the expansion of both sectors being influenced by Chinese economic cycles, a greater incentive to the manufacturing industry could generate a know-how effect and increase competitiveness, targeting other markets, such as the USA and Europe.

In this context, the results of tables 6 to 9 verified the relationship between the economic complexity and the transformation of the productive structure of the UFs, as well as its possible determinants.

The first results (tables 6 and 7) showed that economic complexity is positively influenced by structural transformation (ICMI) and exchange rate lag. We use exchange rate lag because we believe that the export structure takes time to assimilate exchange rate variations. The effect of the exchange rate on economic complexity in the contemporary period (same year) proved to be negative. A possible explanation for this result is based on the hypothesis that the increase in the cost of imported inputs reduces the diversification of exports in the short term (same year), but in later periods companies tend to benefit from greater price competitiveness at the international level and start to produce in sectors that before were unfeasible.9

Considering the analysis by effective advantage (table 7), it was seen that the exchange rate has a direct and positive effect on linear measures of economic complexity. This occurs because the effective advantage responds more quickly to variations in relative prices. In other words, the most depreciated exchange rate tends to insert strategic and more technological sectors in the international market. This is captured directly in effective terms (table 7) but takes a period when the analysis is done in comparative terms (table 6). Thus, we emphasize that the complexity indices must also be based on a matrix of effective advantages and not only comparative advantages, as is traditionally done. On the positive effects of the exchange rate, economic complexity and exports on output growth, see, among others, Caglayan and Demir (2019), Marconi et al. (2021) and Oreiro et al. (2020). For a literature review on the effects of the real exchange rate (RER) on international trade, economic development, and growth, see Demir and Razmi (2021). Gabriel and Missio (2018) showed that an undervalued RER exhibits positive and significant effects on the economic complexity level for developing countries.

[9] Another explanation for this result can be found in the role of expectations. The undervalued exchange rate could be capturing a deterioration in expectations (same years), with effects on incremental investments and, therefore, on the diversification of the productive structure. When we use this variable in lag (exchange rate), this effect disappears, because past expectations are already incorporated in the current values of the variables.

Table 6 – *Determinants of economic complexity: values from the RCA matrix*

Variable	$K_{s,2}$	$K_{s,6}$	$K_{s,8}$	$K_{s,10}$	F_2	F_6	F_8	F_{10}
Exchange rate BS	–0.455	–0.703***	–0.683***	–0.669***	–0.184	–1.462	–1.887	–2.541
	(0.511)	(0.141)	(0.0786)	(0.0497)	(0.859)	(2.046)	(2.716)	(3.552)
Exchange rate BS (t–1)	0.509	0.553**	0.472***	0.414***	1.152	2.386	2.493	2.443
	(0.650)	(0.201)	(0.132)	(0.101)	(1.542)	(2.871)	(3.605)	(4.316)
Trading partners' GDP	–0.0519	–0.0235	–0.0173	–0.0122	–0.0174	–0.164	–0.233	–0.272
	(0.0610)	(0.0201)	(0.0117)	(0.00817)	(0.0575)	(0.157)	(0.211)	(0.255)
Education	–0.0249	–0.0270	–0.0244	–0.0251*	0.110	0.252	0.270	0.276
	(0.0666)	(0.0309)	(0.0178)	(0.0124)	(0.0733)	(0.161)	(0.217)	(0.278)
Trade openness	–0.0134	–0.00633	–0.00450	–0.00321	0.00819	0.0431	0.0514	0.0537
	(0.0189)	(0.00712)	(0.00447)	(0.00291)	(0.0169)	(0.0449)	(0.0642)	(0.0819)
Capital expenditure	0.000522	–0.00152**	–0.00130***	–0.00108**	0.00773*	0.0417***	0.0560***	0.0694***
	(0.00205)	(0.000580)	(0.000437)	(0.000413)	(0.00437)	(0.0112)	(0.0140)	(0.0163)
Commodity prices	0.0120	0.0351	0.0343**	0.0325***	0.0519	–0.153	–0.282	–0.443
	(0.0810)	(0.0237)	(0.0151)	(0.0103)	(0.206)	(0.426)	(0.546)	(0.667)
ICMI	0.0318	0.0102**	0.00537**	0.00212	0.0677	0.156	0.194	0.217
	(0.0228)	(0.00458)	(0.00253)	(0.00156)	(0.0644)	(0.105)	(0.121)	(0.134)
$K_{s,2}$ (t–1)	0.683***							
	(0.171)							
$K_{s,6}$ (t–1)		0.441***						
		(0.0797)						
$K_{s,8}$ (t–1)			0.337***					
			(0.0534)					
$K_{s,10}$ (t–1)				0.279***				
				(0.0374)				
F_2 (t–1)					0.864***			
					(0.109)			
F_6 (t–1)						0.817***		
						(0.110)		
F_8 (t–1)							0.801***	
							(0.112)	
F_{10} (t–1)								0.798***
								(0.113)
Constant	1.784	2.419***	2.746***	2.922***	–2.700	–1.002	0.700	2.707
	(1.636)	(0.751)	(0.535)	(0.405)	(2.516)	(4.764)	(5.808)	(6.766)
Observations	297	297	297	297	297	297	297	297
Num. Id	27	27	27	27	27	27	27	27
AR (2)	0.814	0.320	0.156	0.054	0.147	0.533	0.824	0.937
Hansen test	0.224	0.153	0.142	0.139	0.745	0.647	0.520	0.435
Lag of instruments	2	2	2	2	2	2	2	2

Source: Prepared by the authors.
Notes: Standard errors in parentheses; *** p < 0.01, ** p < 0.05, * p < 0.1. The correction for standard errors proposed by Windmeijer (2005) was used.

Table 7 – *Determinants of economic complexity: values from the REA matrix*

Variable	$K_{s,2}$	$K_{s,6}$	$K_{s,8}$	$K_{s,10}$	F_2	F_6	F_8	F_{10}
Exchange rate BS	−0.814	0.0362	0.260*	0.369***	−2.024	−7.591	−8.746	−11.40
	(0.614)	(0.226)	(0.141)	(0.0797)	(1.600)	(4.610)	(7.958)	(9.782)
Exchange rate BS (t−1)	−0.135	−0.286*	−0.332***	−0.342***	0.409	1.214	1.448	2.259
	(0.494)	(0.159)	(0.0947)	(0.0475)	(1.258)	(2.219)	(2.809)	(3.511)
Trading partners' GDP	−0.0463	−0.00983	−0.0119	−0.00859	−0.0668	−0.200	−0.523	−0.629
	(0.0704)	(0.0374)	(0.0218)	(0.0127)	(0.341)	(0.749)	(1.147)	(1.361)
Education	0.0342	−0.0131	−0.00455	−0.00253	0.115	0.243	0.247	0.241
	(0.0909)	(0.0384)	(0.0243)	(0.0151)	(0.140)	(0.390)	(0.485)	(0.623)
Trade openness	0.0281	0.00171	0.000430	2.36e−05	0.0967	0.197*	0.266*	0.329*
	(0.0286)	(0.00946)	(0.00659)	(0.00448)	(0.0578)	(0.101)	(0.129)	(0.164)
Capital expenditure	−0.0568**	−0.0173**	−0.0107*	−0.00531	−0.0898	−0.300	−0.519	−0.652*
	(0.0262)	(0.00785)	(0.00525)	(0.00377)	(0.0981)	(0.213)	(0.313)	(0.350)
Commodity prices	−0.187*	−0.0400	−0.0262	−0.0210	−0.435	−1.110	−1.194	−1.429
	(0.0918)	(0.0389)	(0.0240)	(0.0141)	(0.339)	(0.834)	(1.296)	(1.549)
ICMI	0.0984**	0.0234	0.0154	0.00933	0.232	0.488*	0.783**	0.977**
	(0.0395)	(0.0151)	(0.00956)	(0.00585)	(0.177)	(0.251)	(0.364)	(0.412)
$K_{s,2}$ (t−1)	0.297							
	(0.263)							
$K_{s,6}$ (t−1)		0.319*						
		(0.176)						
$K_{s,8}$ (t−1)			0.137					
			(0.140)					
$K_{s,10}$ (t−1)				0.00459				
				(0.0875)				
F_2 (t−1)					0.677***			
					(0.193)			
F_6 (t−1)						0.698***		
						(0.123)		
F_8 (t−1)							0.644***	
							(0.125)	
F_{10} (t−1)								0.620***
								(0.127)
Constant	5.409**	3.200***	3.455***	3.609***	4.274	17.81	27.61	34.01
	(2.393)	(0.835)	(0.551)	(0.302)	(8.101)	(15.33)	(18.89)	(22.19)
Observations	253	253	253	253	253	253	253	253
Num. Id	23	23	23	23	23	23	23	23
AR (2)	0.767	0.087	0.002	0.000	0.698	0.650	0.651	0.662
Hansen test	0.637	0.283	0.264	0.242	0.881	0.771	0.793	0.767
Lag of instruments	2	2	2	2	2	2	2	2

Source: Prepared by the authors.
Notes: Standard errors in parentheses; *** p < 0.01, ** p < 0.05, * p < 0.1. The correction for standard errors proposed by Windmeijer (2005) was used.

When considering the factors that are related to structural transformation (ICMI, tables 8 and 9), we saw that the ICMI responds positively to the shocks of devaluation in the real exchange rate. This is in line with the hypothesis raised in the previous paragraph, that devaluations in the exchange rate insert export sectors in the international market and this increases the diversification of the economy. The results also showed that increases in economic complexity (through the linear approach and starting from the RCA) had positive effects on the transformation of the productive structure (ICMI). Lag was not used for the exchange rate, as it is being related to an intermediate good. We consider intermediate consumption in the manufacturing industry as a proxy for industrial transformation. If we were to consider a final good, it would be interesting to include the exchange rate lag, since there is a time from the use of inputs to final production.

Table 8 – *Determinants of intermediate consumption in the manufacturing industry: economic complexity values from the RCA matrix*

Variable	ICMI	ICMI	ICMI	ICMI	ICMI	ICMI	ICMI	ICMI
ICMI (t–1)	0.938***	0.958***	0.971***	0.981***	0.945***	0.947***	0.950***	0.952***
	(0.0404)	(0.0287)	(0.0232)	(0.0195)	(0.0524)	(0.0425)	(0.0402)	(0.0385)
Exchange rate BS	1.482***	1.488***	1.556***	1.579***	1.324***	1.406***	1.416***	1.424***
	(0.485)	(0.489)	(0.467)	(0.484)	(0.465)	(0.495)	(0.503)	(0.509)
Trading partners' GDP	0.108	0.0874	0.0655	0.0511	0.0890	0.0923	0.0903	0.0888
	(0.100)	(0.0766)	(0.0555)	(0.0465)	(0.0734)	(0.0719)	(0.0717)	(0.0714)
Education	0.0275	0.0434	0.0423	0.0420	0.0214	0.0221	0.0227	0.0232
	(0.0619)	(0.0573)	(0.0472)	(0.0404)	(0.0432)	(0.0458)	(0.0452)	(0.0449)
Trade openness	0.0375	0.0300*	0.0236*	0.0190*	0.0233	0.0245	0.0242	0.0240
	(0.0234)	(0.0172)	(0.0136)	(0.0110)	(0.0173)	(0.0173)	(0.0171)	(0.0169)
Capital expenditure	0.00448	0.00271	0.00128	0.000209	0.000463	−2.48e−05	−0.000256	−0.000412
	(0.00994)	(0.00820)	(0.00699)	(0.00554)	(0.00506)	(0.00504)	(0.00490)	(0.00481)
Commodity prices	0.0700	0.0414	0.0427	0.0409	0.0747	0.0828	0.0821	0.0816
	(0.0759)	(0.0751)	(0.0596)	(0.0562)	(0.0692)	(0.0720)	(0.0724)	(0.0726)
$K_{s,2}$ (t–1)	0.133							
	(0.102)							
$K_{s,6}$ (t–1)		0.346**						
		(0.154)						
$K_{s,8}$ (t–1)			0.458***					
			(0.163)					
$K_{s,10}$ (t–1)				0.530***				
				(0.166)				
F_2 (t–1)					0.0439			
					(0.0567)			
F_6 (t–1)						0.0210		
						(0.0213)		
F_8 (t–1)							0.0164	
							(0.0163)	
F_{10} (t–1)								0.0135
								(0.0133)
Constant	−4.918**	−5.251**	−5.319***	−5.318***	−3.780**	−4.018**	−4.012**	−4.008**
	(2.291)	(1.898)	(1.774)	(1.663)	(1.699)	(1.776)	(1.807)	(1.825)
Observations	297	297	297	297	297	297	297	297
Num. Id	27	27	27	27	27	27	27	27
AR (2)	0.149	0.156	0.151	0.146	0.124	0.134	0.135	0.135
Hansen test	0.202	0.242	0.248	0.255	0.175	0.185	0.188	0.191
Lag of instruments	2	2	2	2	2	2	2	2

Source: Prepared by the authors.

Notes: Standard errors in parentheses; *** p < 0.01, ** p < 0.05, * p < 0.1. The correction for standard errors proposed by Windmeijer (2005) was used.

Table 9 – *Determinants of intermediate consumption in the manufacturing industry: economic complexity from the REA matrix*

Variable	ICMI	ICMI	ICMI	ICMI	ICMI	ICMI	ICMI	ICMI
ICMI (t–1)	0.997***	1.029***	1.027***	1.037***	0.960***	1.004***	1.012***	1.018***
	(0.0518)	(0.0470)	(0.0432)	(0.0431)	(0.0778)	(0.0526)	(0.0506)	(0.0495)
Exchange rate BS	1.454***	1.552***	1.550***	1.492***	1.408***	1.422***	1.412***	1.402***
	(0.487)	(0.489)	(0.473)	(0.458)	(0.475)	(0.464)	(0.470)	(0.474)
Trading partners' GDP	–0.00880	–0.0168	–0.0176	–0.0256	–0.00315	–0.0103	–0.0122	–0.0136
	(0.0402)	(0.0386)	(0.0378)	(0.0398)	(0.0395)	(0.0361)	(0.0361)	(0.0362)
Education	0.0213	0.0360	0.0364	0.0291	0.0159	0.0245	0.0246	0.0246
	(0.0479)	(0.0430)	(0.0424)	(0.0393)	(0.0348)	(0.0493)	(0.0492)	(0.0491)
Trade openness	0.00443	–0.00142	–0.000284	–0.00414	0.0128	0.00410	0.00288	0.00199
	(0.0144)	(0.0196)	(0.0181)	(0.0161)	(0.0125)	(0.0102)	(0.0105)	(0.0107)
Capital expenditure	0.00945	–0.0233	–0.0219	–0.0321	0.0439	0.00452	–0.00246	–0.00756
	(0.0526)	(0.0500)	(0.0470)	(0.0476)	(0.0608)	(0.0454)	(0.0452)	(0.0454)
Commodity prices	0.0676	0.0878	0.0862	0.0919	0.0566	0.0609	0.0617	0.0622
	(0.0752)	(0.0775)	(0.0757)	(0.0733)	(0.0671)	(0.0635)	(0.0654)	(0.0669)
$K_{s,2}$ (t–1)	0.0250							
	(0.0585)							
$K_{s,6}$ (t–1)		0.00264						
		(0.140)						
$K_{s,8}$ (t–1)			0.0574					
			(0.212)					
$K_{s,10}$ (t–1)				0.202				
				(0.283)				
F_2 (t–1)					0.0141			
					(0.0425)			
F_6 (t–1)						0.000213		
						(0.0147)		
F_8 (t–1)							–0.00104	
							(0.0112)	
F_{10} (t–1)								–0.00160
								(0.00904)
Constant	–2.534*	–2.202	–2.369	–2.467*	–2.803*	–2.319*	–2.202*	–2.112*
	(1.441)	(1.471)	(1.447)	(1.369)	(1.446)	(1.227)	(1.224)	(1.220)
Observations	253	253	253	253	253	253	253	253
Num. Id	23	23	23	23	23	23	23	23
AR (2)	0.339	0.336	0.338	0.352	0.374	0.332	0.324	0.320
Hansen test	0.324	0.298	0.309	0.371	0.425	0.330	0.329	0.329
Lag of instruments	2	2	2	2	2	2	2	2

Source: Prepared by the authors.
Notes: Standard errors in parentheses; *** p < 0.01, ** p < 0.05, * p < 0.1. The correction for standard errors proposed by Windmeijer (2005) was used.

In general, the results of this section indicated that: i) the ECI is to some extent related to the UFs' growth potential; ii) The greater price competitiveness (real exchange rate devaluations) has direct positive effects on the ECI when it is calculated in effective terms (Table 7), but this effect takes a year when the analysis is done in comparative terms; iii) there is a positive relationship both between the real exchange rate at the state level (R$/US$) and the UFs' productive transformation, as well as between the UFs' productive transformation and economic complexity.

As the ECI and the ICMI cannot be controlled through public policies, the real exchange rate is the endogenous variable that can be, at least in part, influenced by macroeconomic policies for strategic purposes. At the same time, caution is needed when considering the exchange rate as an option to boost the economic complexity of a country or region, for the effectiveness of a more competitive exchange rate in inserting strategic sectors in the international market will also depend on expectations regarding the future economic scenario.

4. Conclusion

Data analysis using the RCA showed that São Paulo is the most diversified state in Brazil, followed by Bahia, Ceará, Paraná, Pernambuco, Rio Grande do Sul and Santa Catarina. When considering REA, which controls by the size of the population, we observed that the state of São Paulo proved to be even more diversified and started in first in the economic complexity ranking, followed by Rio Grande do Sul and Santa Catarina. However, after several iterations, these states began to lose positions to the states of Amazonas and Rio de Janeiro. The case of Alagoas was interesting, since it was gaining positions during the iterations. This is because the method considers not only the productive structure of a specific UF but also how it is related to the productive structure of other UFs.

The diagrams between economic complexity and GDP per capita showed that: AM, SC, SP, PR, RJ and RS are in the group of UFs with high economic complexity and high income; ES, GO, MG, MS and MT are in the group with high income and low complexity; AP, PA, RO, RR and TO are in the group with low income and low complexity; and AC, AL, BA, CE, PE, RN and SE are in the group with medium-high complexity and low income. It can be considered that the latter group has a very sophisticated production structure for their income levels and, therefore, greater expectations for future growth.

In short, the results of descriptive analysis showed that there is a positive relationship between the UFs' economic complexity and economic growth. Furthermore, the findings regarding the diversification of UFs seem adequate, based on our knowledge of the country's productive structure. Some results indicate the existence of a weak positive correlation (especially in the non-linear approach). Based on these inconclusive findings, we raised some doubts and questions about how adequate the complexity theory is to explain the growth for entities that compete on an equal playing field, like the UFs in Brazil. Of course, new tests and exercises may illuminate these questions in the future.

Another interesting econometric result, in line with expectations, showed that an exchange rate devaluation tends to positively influence the productive transformation (ICMI) and increase the economic complexity in a later period. At the same time, we saw that ECI and productive transformation are positively related. Then, as the variations in ECI and productive transformation (ICMI) depend on other factors and cannot be controlled through public policies, we consider that the exchange rate is the variable that, by indirect effects, could be used as a public policy option to boost productive transformation, regional economic complexity and, in turn, economic growth. However, we highlight limitations and scenarios that must be considered when relating exchange rates to growth and economic complexity.

On the one hand, the effectiveness of this policy will also depend on expectations regarding the future scenario. Although devaluations in the exchange rate increase external demand and allow the insertion of strategic sectors in the international market, this will only occur if companies are willing to increase investment in these sectors – animal spirits, in the Keynesian approach. Otherwise, the effect of an exchange rate devaluation may be reflected only by cost channel and may negatively affect economic complexity and economic growth.

On the other hand, we emphasize that the analysis of this paper – as well as the economic complexity indices – is based on the foreign market. As devalued exchange rates also tend to cause increases in the prices of imported products and, in turn, a reduction in the purchasing power of wages, this could – by reducing household consumption – negatively affect aggregate demand and the diversification of the industry that serves the domestic market. However, in the latter case, the effect of higher wages on aggregate demand will also depend on the existence of a strong industry in consumer goods sectors. Otherwise, the effect on growth could be negative, as the lack of domestic supply tends to cause an increase in demand for imported goods and, in turn, to further restrict the country's growth. These issues, among others, are topics to be discussed in future works.

Appendix

Table A1 – *Export effort index*

UF	2003	Rank	2014	Rank	Dif (2014-2003)	Rank
MT	23.65	3	34.28	1	10.63	1
PA	25.53	2	26.89	2	1.36	7
ES	31.58	1	21.46	3	−10.12	26
MS	6.58	16	15.52	4	8.94	2
MG	14.89	7	13.33	5	−1.56	14
RS	19.39	4	12.25	6	−7.15	23
PR	18.73	5	10.96	7	−7.76	24
GO	6.96	13	9.93	8	2.97	6
BA	14.00	9	9.70	9	−4.31	19
SC	16.65	6	8.68	10	−7.96	25
MA	10.96	11	8.55	11	−2.41	16
TO	1.99	22	7.71	12	5.72	4
AP	1.66	23	7.46	13	5.80	3
RO	2.99	20	7.37	14	4.38	5
RJ	6.81	14	6.97	15	0.15	9
SP	11.22	10	6.44	16	−4.78	21
AL	8.26	12	3.61	17	−4.65	20
CE	6.72	15	2.74	18	−3.98	18
AM	14.51	8	2.51	19	−12.01	27
PI	2.00	21	1.59	20	−0.41	12
PE	3.06	19	1.43	21	−1.63	15
RN	6.03	17	1.09	22	−4.94	22
PB	3.30	18	0.79	23	−2.50	17
SE	0.95	24	0.49	24	−0.47	13
RR	0.43	26	0.46	25	0.04	10
DF	0.07	27	0.39	26	0.32	8
AC	0.46	25	0.13	27	−0.33	11

Source: SECEX/MDIC. Contas Regionais/IBGE. Elaborated by the authors.

Table A2 – *Variation in per capita GDP*

UF	1992-2002 (%)	Rank	2003-2014 (%)	Rank
PI	9.4	21	100.7	1
ES	10.0	20	90.1	2
PA	6.0	24	84.1	3
TO	22.2	16	78.1	4
PE	−0.5	27	76.4	5
AC	34.8	9	76.3	6
MT	58.7	3	71.7	7
AP	77.3	2	71.6	8
CE	30.4	12	71.6	9
MA	20.4	17	68.5	10
RR	52.6	4	65.6	11
SC	7.0	23	63.5	12
MG	1.9	25	62.5	13
RN	49.9	5	62.1	14
GO	38.0	6	62.1	15
RO	26.8	14	61.8	16
MS	35.9	8	61.0	17
PB	31.0	11	57.5	18
DF	16.9	18	50.9	19
BA	28.9	13	50.2	20
AM	121.1	1	48.5	21
RJ	9.2	22	46.3	22
AL	23.1	15	43.4	23
SE	37.2	7	41.3	24
SP	15.7	19	39.6	25
PR	32.0	10	38.3	26
RS	1.7	26	34.0	27

Dynamic panel data model

Estimation by the generalized method of moments (GMM), initially developed by Holtz-Eakin, Newey, and Rosen (1988) and, later, by Arellano and Bond (1991), Arellano and Bover (1995), and Blundell and Bond (1998), has been widely used in the empirical literature for cases in which the variables are not strictly exogenous. According to Cameron and Trivedi (2005, p. 743), it is much easier to obtain instruments for panel data than for cross-sectional data, since regressors in other periods can be used as instruments for endogenous regressors of the contemporary period.

For Roodman (2009), the estimators of dynamic panels are indicated for situations in which the variables are not strictly exogenous – that is: they are correlated with their past values and possibly with the present errors; the dependent variable shows a temporal trend, depending on its values in previous periods; there are many individuals on the panel; and there is heteroscedasticity and autocorrelation within individuals but not between them. In the specification tests, the data in this paper presented several of the characteristics mentioned by

Roodman (2009), which led to the use of dynamic panels[10] to eliminate the bias in the estimates. Roodman (2009) also emphasizes the importance of second-order autocorrelation analysis, through the AR(2) test of Arellano-Bond, and the validity of the instruments, through the Hansen test. The null hypothesis of the AR(2) test indicates the absence of second-order autocorrelation and the null hypothesis of the Hansen test indicates that the instruments are exogenous. Furthermore, the author also emphasizes that the number of instruments cannot be greater than the number of individuals on the panel.

Database

In the present paper, the following data series were used:

- State exports by product according to the SH2 classification, which comprises 97 products, collected from the ComexStat/SECEX system.
- GDP of the main export destinations for each UF, used as a proxy for external demand. This variable was collected in the Penn World Table (PWT) database. We decided to use the GDP of 5 to 10 trade partners from each UF.
- Selic rate, discounted from inflation expectations, as a proxy for the ex-ante real interest rate – Central Bank of Brazil (*Banco Central do Brasil* – BACEN).
- Gross fixed capital formation, as a proxy for investment – IPEA.[11]
- Commodity price index – International Monetary Fund (IMF Data).
- GDP per capita of the UFs – IPEA.
- Population aged 15 to 69 years, used as a proxy for the UFs' active population – IBGE
- Education, whose proxy is the net enrollment rate in high school – IBGE. As no data was found for the year 2010, an average of the years 2009-2011 was used.

Intermediate consumption of the manufacturing industry (ICMI) – Brazilian Institute of Geography and Statistics (IBGE).

The other three variables will be explained in more detail, as they underwent some transformations after data collection.

- Degree of trade openness for each UF = [(exports + imports) / GDP].
- Potential output and capacity utilization. The methodology created by Hamilton (2018) was used to build a smoothed series two years earlier. Hamilton's approach can be put as follows:

$$log\, Y_{t+2} = \beta_0 + \beta_1\, logY_t + \beta_2\, logY_{t-1} + \epsilon_{t+2} \qquad (16)$$

This method aims to remove the cyclical component of the UFs' GDP series and leave only the trend, which is used as a proxy for the UFs' potential output. The degree of capacity utilization, on the other hand, is the gap between observed GDP and potential GDP $\left(\frac{GDP}{Potential\ GDP}\right)$.

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[10] Two-stage dynamic panel was estimated. (Cameron and Trivedi, 2005) consider that the two-stage estimation is more efficient and tends to have lower standard errors than the one-stage estimation.
[11] Institute of Applied Economic Research (Instituto de Pesquisa Econômica Aplicada, IPEA).

- Real exchange rate – to create the exchange rate weighted by the Balassa-Samuelson effect for each UF, the real effective exchange rate[12] (IPEA) was used, together with the price data for a set of food products considered essential (basic food basket in the country's capitals), as a proxy for the population's purchasing power (DIEESE).

This approach follows the methodology proposed by Rodrik (2008), which aims to adjust the exchange rate by purchasing power parity and by the relative price levels between tradable and non-tradable sectors. This is used as a proxy for the individual real exchange rate of each UF. The procedure indicated by Rodrik (2008) can be summarized in three parts: the first is given by the ratio between the exchange rate and the purchasing power parity conversion factor[13], according to the following equation:

$$log\ RER_{it} = log(ER_t/PPP_{it}) \qquad (17)$$

where RER is the proxy for the real exchange rate of each UF and ER[14] is the country's real exchange rate, collected at IPEA.[15] As a proxy for purchasing power parity (PPP), we used the ratio between the prices of a consumer basket[16] in the state capitals[17] and the average price of a consumer basket in the country. The Balassa-Samuelson effect is based on the idea that places with higher income, mainly in tradable sectors, tend to have higher prices for non-tradable goods. Considering this, it is important to adjust the effects of these income variations on the exchange rate. For this, a panel with fixed time effects[18] was used, as shown in Equation (18):

$$log\widehat{RER}_{it} = \alpha + \beta\ logGDPpc_{it} + f_t + \varepsilon_{it} \qquad (18)$$

where $GDPpc$ is the GDP per capita of each UF, f_t is the fixed effect and ε_{it} the error term. The panel with fixed-year effects captured a $\hat{\beta}$ of –0.092 (with standard errors of 0.018 and z-statistic of – 4.94), indicating that variations in UFs' income tend to cause an appreciation in the RER. Thus, to arrive at the real effective exchange rate adjusted by the Balassa-Samuelson effect (RER_BS) for UFs, equation (19) is used:

$$logRER\_BS_{it} = logRER_{it} - log\widehat{RER_{it}} \qquad (19)$$

where $log\widehat{RER_{it}}$ is the value estimated by Equation 18.

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[12] Built by the weighted arithmetic average of the country's bilateral real exchange rates with 23 selected trading partners.

[13] The PPP conversion proxy proposed in this paper can be presented as follows: $PPP = \left(\frac{p_{ij}}{p_{ik}}\right)$, where p is the price of the basket i, $j = 1,.., n$ for each UF, k is the country.

[14] ER varies only over time, but not between UFs.

[15] The real effective national exchange rate was practically adjusted by the purchasing power of each UF. RER values below ER indicate that the value of the currency of a given UF is lower (more appreciated) than the country's effective exchange rate if domestic purchasing power is considered.

[16] We use the products of a basic basket as items of the consumption basket.

[17] State databases are restricted. Thus, some simplifications were necessary, as well as using data from the capital of each state as a proxy.

[18] The verification of this hypothesis could be done through cross-section estimates for each year of the sample, as did Subramanian et al. (2007). However, we follow Rodrik (2008) and estimate a fixed effects model for all years.

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