DEYVID WILLIAM LEITE

HUMAN CAPITAL, INVESTMENT IN TECHNOLOGY, AND ECONOMIC COMPLEXITY

Dissertação apresentada à Universidade Federal de Viçosa, como parte das exigências do Programa de Pós-Graduação em Economia Aplicada, para obtenção do título de *Magister Scientiae.*

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(Orientador)

AGRADECIMENTOS

Ao meu orientador, aos outros membros da banca, à minha família e aos meus amigos que muito me apoiaram nessa etapa tão importante da minha vida.

À Coordenação de Aperfeiçoamento de Pessoal de Nível Superior – CAPES, pelo apoio financeiro e aos docentes e servidores do Departamento de Economia Rural da Universidade Federal de Viçosa.

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ABSTRACT

LEITE, Deyvid William, M.Sc., Universidade Federal de Viçosa, February, 2019. **Human capital, investment in technology, and economic complexity**. Advisor: Leonardo Chaves Borges Cardoso.

This investigation aims to explain the relationship between productive structure, exported products, human capital, and investment in technology at national level. An export sophistication index is used as a proxy for productive structure. The sophistication of exports is called economic complexity and this is used as an adequate measure of per capita income growth. Our yearly based dataset included 98 countries from 1996 to 2015. The results indicate a positive impact of the quantity and the quality of human capital on economic complexity. PISA surveys, the qualitative measure of human capital, showed that the higher percentiles of PISA scores had larger and significant effects on complexity. The influence of human capital on economic complexity decreases as education rises, yielding larger effects in countries with a low level of human capital. Investment in technology and trade openness presented positive and significant effects on economic complexity.

We concluded that investments in human capital and technology should be promoted, especially where human capital is low.

RESUMO

LEITE, Deyvid William, M.Sc., Universidade Federal de Viçosa, fevereiro de 2019. **Capital humano, investimento em tecnologia e complexidade econômica**. Orientador: Leonardo Chaves Borges Cardoso.

Esta investigação visa explicar a relação entre estrutura produtiva, produtos exportados, capital humano e investimento em tecnologia a nível nacional. Um índice de sofisticação de exportação é usado como um proxy para a estrutura produtiva. A sofisticação das exportações é chamada de complexidade econômica e isso é usado como uma medida adequada do crescimento da renda per capita. Nosso conjunto de dados com base anual incluiu 98 países de 1996 a 2015. Os resultados indicam um impacto positivo da quantidade e da qualidade do capital humano na complexidade econômica. As informações sobre o PISA, a medida qualitativa do capital humano, mostraram que os percentis mais altos de pontuação do PISA tiveram efeitos maiores e significativos na complexidade. A influência do capital humano na complexidade econômica diminui à medida que a educação aumenta, produzindo efeitos maiores em países com baixo nível de capital humano. O investimento em tecnologia e a abertura comercial apresentaram efeitos positivos e significativos na complexidade econômica. Concluímos que os investimentos em capital humano e tecnologia devem ser promovidos, especialmente onde o capital humano é baixo.

1 INTRODUCTION

This section aims to present the introductory elements of the relation between economic growth, exported products, human capital and investment in technology. The topics of this chapter proceed as follows: 1) Initial considerations, 2) The problem and its relevance.

1.1 INITIAL CONSIDERATIONS

The notion that productive structure is related to income determination is not new and the idea that exports express that relationship is not new either. Thus, we analyze the exports in order to access an economy's productive structure. Moreover, there are three different approaches that give special attention to the role of exports in per capita output. The first approach focuses on the size of the market, the second one emphasizes the technological content of exports and the third one underlines the capabilities involved in exported products. After analyzing these approaches, we relate productive structure to per capita output by using export structure.

The first approach investigates the gains that come from international trade and the benefits involved in diversifying the exported goods (KRUGMAN, 1981; DODARO, 1991; PIÑERES; FERRANTINO, 1997). According to this point of view, the gain from trade comes from either the similar factor endowments that the countries have or the more differentiated goods are.

Furthermore, Hummels and Klenow (2005) analyzed the relation between exports and economic growth, they aimed to determine from which aspect exports are related to a larger economy. The authors presented three possible reasons for the positive effect of exports on output: the quantity of each exported product; the variety of exported products; and the quality of exported products. The authors stated that the diversification of exported goods plays a vital role in a larger economy.

The second approach stated the technological structure of exports leads to different growth paths (LALL, 2000). According to this understanding, technology intensive structures are highly income elastic, they have larger spillover effects to other activities and they expand the learning capacity. In simple technology structures, the markets grow slower, there are smaller spillover effects to other activities, the learning capacity is limited and the vulnerability that comes from low wage competitors are larger. Lall (2000) showed that exporting technology intensive goods is positively related to economic growth and domestic industrial development.

The third approach takes into consideration that the differences in products stand for different combinations of capabilities (HIDALGO, 2009). Among the goods analyzed by

Hidalgo, he affirmed that producing a banana is different from producing a satellite due to the amount of knowledge that is embedded in each product. The author declared that even if the traditional factors of production (labor, land and capital) are available in a country, it does not mean that this country will be able to make a banana or a satellite.

There are two similar points of the three approaches. The first one is that exports are somehow related to economic growth. The second similar point is, in an indirect manner, that a more open economy tends to access a larger development. The main difference between the three approaches come from the distinctive ways of looking to exports. One understanding takes into account the diversity of the exported products. While another one considers the technological content in exports. And the last understanding is worried about the abilities owned by the labor force, which are indicated by the exported goods.

Among these three approaches, we follow the third one, the notion that differences in capabilities lead us to the differences in products. Considering that, Hausmann et al. (2014) showed that the products that a nation makes have a particular relation to its inhabitants' knowledge and to the possibilities that an economy holds. The possibilities and knowledge are deeply connected to the existence of more enabled individuals with several kinds of instruction. The authors introduced the idea of economic complexity, which may reflect a nation's capabilities. The economic complexity index measures the levels of diversity and ubiquity of exports as well as the share in international market of each product and country.

We aim to explain the economic complexity at national level, given the importance of complexity to productive structure and to per capita income. The assumption that complexity matter to income determination leads us to an inquiry. What are the elements at a national level that explain the economic complexity? This question is the central point of our investigation.

1.2 THE PROBLEM AND ITS RELEVANCE

At the beginning of the 18th century, Portugal and England signed the Methuen Treaty. It was a military and commercial agreement between those countries. Trade relations were one of the aims of the treaty; imports of Portuguese wine and English woolen cloth were facilitated for both countries. During the remainder of 18th century and in the 19th century, Portugal and England followed distinctive economic paths, which allows us to think that differentiation between exported products played a major role in their economic activities.

Lall, Weiss and Zhang (2006) analyzed the export structure of some countries by looking at their export basket and their level of income, and inferring their levels of export sophistication. Moreover, the sophistication of exports is a result of a set of characteristics that include exporting higher-level of technology products as well as diversified products. In this context, the initial studies of economic complexity were brought about by Hidalgo (2009), Hidalgo and Hausmann (2009) and Hausmann et al. (2014), since then it has gained visibility as an income growth determinant.

Jarreau and Poncet (2012) investigated the relation between sophisticated product exports and the economic growth of 33 Chinese regions for the period of 1997-2009. The authors showed that where the exports were composed of highly sophisticated goods, income growth was larger. Nevertheless, these gains in income growth came only when exports were composed of ordinary products and undertaken by domestic firms, because sophistication in ordinary exports indicates positive technology adoption and capacity building[1].

In addition, Felipe et al. (2012) related complexity at product level to income in 124 countries for the period of 2001-2007. The authors separated products into three levels of complexity: the high one, the medium one and the low one. Their results indicated that per capita income was positively associated with the export share of more complex products. It means that the major exporters of high complexity products are the rich countries. On the other hand, the major exporters of low complexity products are the poor countries. Export shares of the high complexity products increases with income, while export share of low complexity products increases when income decreases.

Moreover, a few studies argued that there is a causal relationship between the exported products and per capita output (RODRIK, 2006; HAUSMANN; HWANG; RODRIK, 2007). In line with those investigations, Hausmann et al. (2014) find that a country's export basket, as economic complexity, is a strong and robust predictor[2] of the subsequent rate of economic growth. If an economy has a high level of complexity, but not a high level of per capita income, it means that this economy will grow faster in order to have a level of per capita income that corresponds to its level of economic complexity. For instance, nations that have high levels of economic complexity, but still low levels of per capita income are China and Thailand. According to the authors, these countries tend to present an accelerated growth in order to converge to their level of economic complexity, especially when we compare Chinese or Thai economies with the countries with a similar level of per capita income, like Peru or Iran.

On the other hand, nations with high level of per capita income, but a comparatively low level of economic complexity are Qatar, Kuwait, Oman, Venezuela and Chile. Hausmann et al.

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[1] Domestic firms normally export products that have a high share of domestic content, while foreign firms export goods that have a low share of domestic content (JARREAU; PONCET, 2012). For a further discussion on the share of domestic content in exports, see Koopman, Wang and Wei (2008).

[2] Hausmann et al. (2014) analyzed the contribution to the variance of economic growth from economic complexity and measures of governance and institutional quality; human capital; and competitiveness. Economic complexity performed better in explaining economic growth than the other three types of mentioned measures.

(2014) stated that, these countries are rich because of their geological characteristics that provide them large amounts of natural resources. These less complex economies tend to present a diminished growth, once their exports are less sophisticated and diversified than nations with a similar level of per capita income, such as Czech Republic or Hungary.

Economies mainly based on natural resources tend to present a diminishing rate of income growth over time. Furthermore, economies that supply predominantly labor-intensive products are likely to have low rates of economic growth. In the beginning, producing resource-abundant goods yields comparative advantages, however, over time it turns toward a loss of competitiveness in international market. Beyond the low income elasticity that this kind of product presents, the capacity to adapt and to recognize new opportunities are the central point to understand the difference between the dependence of an abundant resource and the growth generated by knowledge and technology (CIMOLI et al., 2005).

Cimoli et al. (2005) analyzed the structural change, the role of technology and how these are connected to economic growth in Latin America countries between 1970 and 2000. The authors affirmed that certain sectors have the abilities to increase their productivity, to expand other sectors, to be favored from high growth rates of external and internal market, and to create high productivity jobs. This view indicates that the pattern of productive specialization matters to economic development.

A few types of industries regularly increase their productivity and output at a higher rates than others, the structural change should support these specific industries in order to achieve aggregate growth. Among the manufacturing firms, which belong to technology driven or high-skill industries, one way to rise growth rates is to favor industries according to their level of entrepreneurship. The higher is the level of entrepreneurship, the greater is the capacity to innovate. Another way to boost income is related to the knowledge spillovers, since a producer may diffuse capabilities for other industries in a region and it would grow faster (PENEDER, 2003).

Peneder (2003) investigated the relation between industrial structure and aggregate performance for the 28 members of the Organization for Economic Co-operation and Development (OECD). The author found that the composition of economy was strongly linked to income and growth, which confirms the structural bonus hypothesis. This proposition postulates that, during the process of economic development, economies move from less productive industries towards more productive ones[3].

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[3] For an extensive discussion on the structural bonus hypothesis, see Timmer and Szirmai (2000).

Nelson and Pack (1999) studied the rapid growth of the Asian countries, such as South Korea, Singapore, Taiwan and Hong Kong, between the 1960s and 1990s, although those countries were poorly endowed in the 1950s. They argued that the increase of per capita income over that period was caused by the change in their economic structures and in the sectors of specialization. The authors presented two sorts of theories to explain the "Asian Miracle", the accumulation theories and the assimilation theories.

The theories of accumulation give special attention to the large amount of investments in physical and human capital and take these investments as sufficient explanation of the rapid growth presented in the mentioned nations. According to this approach, entrepreneurship, innovation and learning have no particular participation in the growth process and they easily come by, once the first investments have been carried out.

The theories of assimilation emphasize the role of entrepreneurship, innovation and learning in growth process, this view considers the latter ones as the central part of the new industrial organization in the Asian countries. Conversely, for this kind of approach, investments in human and physical capital are necessary, but not sufficient to drive a nation to economic growth.

Nelson and Pack (1999) stated that an exclusive importance to investments in physical and human capital is based on the assumption that technological knowledge can be accessed by having machines, equipment and blueprints, however, they refused this notion[4]. The authors affirmed that the learning capacity and the entrance into new sectors depend upon the set of new capabilities acquired by a nation; the new ways that economic activities are organized; and the product competitiveness in new markets.

Nonetheless, high rates of investments in physical and human capital are required, especially the latter due to the increase in education attainments may create a group of well-trained professionals providing an advantage in recognizing new opportunities. The identification of new opportunities and new product areas is induced by learning effectively from the advanced economies and it permits the innovation and entrepreneurship to grow (NELSON; PACK, 1999).

If an economy presents entrepreneurship, innovation and the learning capacity, the more productive sectors will progressively rise their share of output, capital and labour. In addition, the less productive sectors will decrease their participation in output, capital and labour. These outcomes are complementary to the higher level of schooling. After such changes, the level of

[4] Hobday (1995) affirmed that technology is much more tacit than explicit and the learning process should be emphasized.

national productivity increases as a result of investments in human capital and the expansion of the more productive sectors (NELSON; PACK, 1999).

Although national economies have become more integrated and global trade in goods and services have evolved a lot in the last decades, the cross-country per capita income differences did not disappear (PRITCHETT, 1997). As showed by Hidalgo and Hausmann (2009), the strength of an economy is related to the capabilities owned by its labor force. These capabilities are non-tradable between countries, which may be the reason for the uneven spread of capabilities around the world.

Barro (1991) analyzed economic growth of 98 countries in the period of 1960-1985. The author presented that the poor economies would catch up the rich ones if the ratio of human capital to output were similar between them, otherwise the differences that separate them would not decrease. Given that human capital is the collection of intangible resources, such as competencies, intellectual agility and attitude (BONTIS et al., 1999), we pay a close attention to human capital and its possible relation to economic complexity.

In this strand, Azariadis and Drazen (1990) discussed the economic development of 32 countries from 1940 to 1985. The authors suggested that a high-skilled labor force is a necessary condition, but not sufficient for a fast and sustainable economic growth. They completed stating that there is a threshold for human capital. The private and social returns to investment in education are higher for economies above that threshold and lower for the ones below that limit.

According to Mankiw, Romer and Weil (1992), human capital is one of the central factor in explaining cross-country income differences. Given that, we expect that evolutions of population's educational level will increase sophistication and diversification of goods produced and exported by spreading knowledge and new technologies faster. The increase of exports sophistication is associated with a change in productive structure, which in a second moment positively affects economic growth.

Beyond the relevance of human capital to our research, some studies have underlined the interaction between technological progress and economic growth (SOLOW, 1957; ROMER, 1990; LICHTENBERG, 1992). Moreover, Grossman and Helpman (1994) analyzed the relationship between technology and trade, they stated that gains from trading with other economies might take place where there are technological advantages and the learning process is dynamic. Furthermore, the authors suggest that investment in technology present increasing returns to scale. Considering those, technology seems to play an important role in economic growth and in productive structure.

Benhabib and Spiegel (1994) studied the role of human capital in economic growth process. The authors associated human capital with both the capacity of a country to produce new technologies and the speed of technological diffusion and catching-up. The benefits of a high level of human capital are to innovate more and to utilize other economies' innovation. The country, which has the highest human capital stock, would be the leader in technical progress and this leadership would be maintained as long as this country sustains this advantage. According to the authors, human capital attracts the other factors that determine income growth and one of these factors is technology.

This investigation aims to expand the knowledge of economic complexity at national level and verify whether there is any direct relation between complexity and both the quantity and the quality of human capital. Furthermore, if economic complexity is influenced by technology. Does a higher educational level increase economic complexity? Is there any relation between complexity and investment in technology? Do other economic variables affect economic complexity?

Despite the strong and stable correlation between complexity and income growth showed by Hidalgo (2009), Hidalgo and Hausmann (2009), Hausmann et al (2014), as far as we know, there is no indicative in them of which variables are correlated with the increase in economic complexity. This study contributes to the literature as it pursues the economic complexity determinants, once complexity may reflect an economy's productive structure thereby indicating future income growth (HAUSMANN et al., 2014).

If both the quantity and the quality of human capital have positive effects on economic complexity, policies that expand both sides of human capital have an extra motivation to be promoted aiming larger income in the future. However, if only either the quantity or the quality of education has a positive effect on complexity, the efforts should be concentrated on the one that affects complexity. Investment in technology might also influence positively economic complexity, if it does, it would be encouraged in order to increase complexity and the future growth rate. On the other hand, once these two variables are either negative related or not related to complexity, policymakers should not look directly at their expansion as an attempt to raise an economy's complexity.

Our hypothesis is that human capital and investment in technology explain economic complexity, which is, in turn, related to per capita income and to future economic growth. The general objective is to identify the economic complexity determinants using a sample from 1996 to 2015[5]. Specifically, we intend to evaluate the effect of the quantity and the quality of human capital on economic complexity and relate investment in technology to economic complexity.

We confirmed our hypothesis that human capital and investment in technology explain economic complexity. The quantitative measure of human capital showed a positive and significant effect on complexity. However, when we included a qualitative measure of human capital, the quantitative measure showed no significance at all. We used data on PISA scores as the quality of education. The higher percentiles of PISA scores exhibited a larger and significant effects on economic complexity. The elasticity analyses indicated that the effect of human capital on complexity is smaller as human capital increases. On the other hand, the effect of investment in technology on complexity is larger as investments rise.

The remainder of this investigation proceeds as follows. The theoretical approach presents the conceptual framework around productive structure and the pattern of specialization, it also relates the latter ones to economic complexity, human capital and investment in technology. The methodology displays the economic complexity index and its elaboration, the method used, the estimated equation, data source and the summary statistics. Results and discussion exposes the main outcomes of the proposed equation, the robustness checks, the results for an analysis that take the quality of human capital into consideration, and the analyses of elasticities for human capital and for investment in technology with respect to complexity. Conclusion provides responses to the research problem and presents the study limitations as well as the suggestions for future studies.

[5] The availability of data restricted our period of analysis. Data on economic complexity and human capital are available for the 1960s henceforth, however data on investments in technology starts in 1996, so does the span of our research.

2 THEORETICAL APPROACH

This part of the study establishes the theory used in analysis. We adapt a model that exposes the conceptual structure around economic complexity, human capital, investment in technology and the relation between them.

Using the conceptual framework of Thirlwall (1979) and assuming an equilibrium in the balance of payments, we have:

$$P_{d(t)}X_{(t)} = P_{f(t)}M_{(t)}E_{(t)} \tag{1}$$

where X is the quantity of exports; P_d is the price of exports in home currency; M is the quantity of imports; P_f is the price of imports in foreign currency; E is the exchange rate; and t is time.

Thirlwall (1979) affirmed that for a balance of payments equilibrium in the long run, it is necessary that the growth of the value of exports equals the growth of the value of imports. Thus, in order to have the rates of growth of the values of exports and imports, we take natural logarithm and differentiate the Equation (1) with respect to time:

$$p_{d(t)} + x_{(t)} = p_{f(t)} + m_{(t)} + e_{(t)} \tag{2}$$

where the lower-case letters stand for the rate of growth of each variable.

According to standard demand theory, exports is a function of the price of the exported products, the exchange rate, the price of products competitive with exports and the world's income:

$$X_{(t)} = \left(\frac{P_{d(t)}}{E_{(t)}}\right)^{\eta} P^{\delta}{}_{f(t)} Z^{\varepsilon}{}_{(t)} \tag{3}$$

where η is the price elasticity of demand for exports, ($\eta < 0$); δ is the cross elasticity of demand for exports ($\delta > 0$); Z is the world's income; and ε is the income elasticity of demand for exports ($\varepsilon > 0$).

Following the standard demand theory, imports depend upon the price of the imported products, the exchange rate, the price of import substitutes and domestic income:

$$M_{(t)} = \left(P_{f(t)}E_{(t)}\right)^{\psi} P^{\phi}{}_{d(t)} Y^{\pi}{}_{(t)} \tag{4}$$

where ψ is the price elasticity of demand for imports ($\psi < 0$); ϕ is the cross elasticity of demand for imports ($\phi > 0$); Y is domestic income; and π is the income elasticity of demand for imports ($\pi > 0$).

After taking the natural logarithms of Equations (3) and (4), we differentiate them with respect to time:

$$x_{(t)} = \eta\left(p_{d(t)} - e_{(t)}\right) + \delta\left(p_{f(t)}\right) + \varepsilon\left(z_{(t)}\right) \tag{5}$$

$$m_{(t)} = \psi\left(p_{f(t)} + e_{(t)}\right) + \phi\left(p_{d(t)}\right) + \pi\left(y_{(t)}\right) \tag{6}$$

where the small letters represent the rate of growth of each variable.

Substituting the Equations (5) and (6) into (2) and rearranging the terms, we have:

$$y_{(t)} = \frac{p_{d(t)}(1+\eta-\phi) - e_{(t)}(1+\eta+\psi) - p_{f(t)}(1-\delta+\psi) + \varepsilon\big(z_{(t)}\big)}{\pi} \tag{7}$$

which indicates that the effect of the price of exports in local currency on domestic income growth depends on both the price elasticity of demand for exports and the cross elasticity of demand for imports; the effect of the exchange rate on domestic income growth relies on the two, the price elasticity of demand for exports and the price elasticity of demand for imports; the effect of the price of imports in foreign currency on domestic income growth depends on both the cross elasticity of demand for exports and the price elasticity of demand for imports; the world's income has a positive effect on domestic income growth, given that the income elasticity of demand for exports is positive; and the income elasticity of demand for imports has a negative effect on domestic income growth.

Following the assumption of Thirlwall (1979) that the cross elasticities of demand for exports and imports are equal to the price elasticities ($\phi = \psi\ ;\ and\ \delta = \eta$), Equation (7) turns into:

$$y_{(t)} = \frac{(1+\eta+\psi)\big(p_{d(t)} - p_{f(t)} - e_{(t)}\big) + \varepsilon\big(z_{(t)}\big)}{\pi} \tag{8}$$

applying the purchasing power parity (PPP), we may have that the growth of the price of exports in home currency is equal to the sum of the growth of the price of imports and the growth of the exchange rate$\big(p_{d(t)} - p_{f(t)} - e_{(t)} \cong 0\big)$. So, we have:

$$y_{(t)} = \frac{\varepsilon\big(z_{(t)}\big)}{\pi} \tag{9}$$

and rearranging this as:

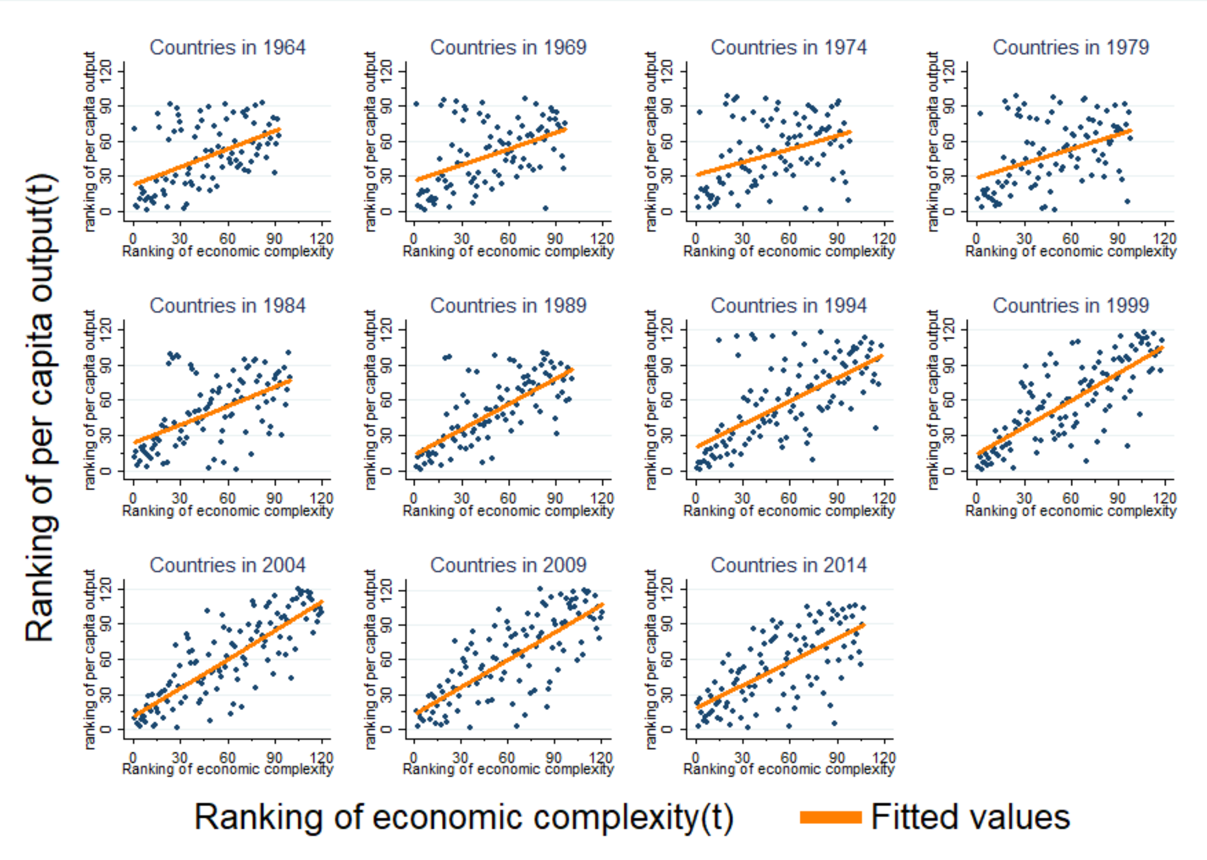
$$\frac{\varepsilon}{\pi} = \frac{y_{(t)}}{z_{(t)}} \tag{10}$$

where the ratio of the income elasticity of demand for exports to the income elasticity of demand for imports $\left(\frac{\varepsilon}{\pi}\right)$ gives the relation between the growth of domestic income and the growth of world's income.

Cimoli et al. (2010) assumed that the ratio $\left(\frac{\varepsilon}{\pi}\right)$ performs well as a measure of the pattern of specialization, which in turn is a function of a nation's economic structure and the technological gap. Furthermore, according to Gabriel (2016), the change in productive structure increases ε and decreases π, which rises the growth of domestic income.

According to Hausmann et al. (2014), there is a high positive correlation between productive structure, measured as economic complexity, and per capita output. Following the authors, we ranked countries in order of both per capita output and economic complexity index. Afterwards, we relate the rankings of the two variables in order to check the relation between them:

FIGURA 1 - Rankings of per capita output and economic complexity



Source: Elaborated by authors.

Each point represents the ranking of per capita output (on the vertical axis) and the ranking of economic complexity (on the horizontal axis) for countries in the marked years at the top of each graph in Figure (1). Economic complexity and per capita output is significantly correlated with each other (*$r = 0.6248$, p-value < 0.01*). What we can draw from this figure is that the nations which have a high level of export sophistication are also the ones which have the high level of income. This relation holds for each of the chosen year between 1964 and 2014.

Beyond the strong and positive correlation between per capita output and economic complexity, authors such as Nelson and Pack (1999), Peneder (2003) and Cimoli et al. (2005) consider that productive structure causes per capita income. Moreover, Hausmann et al. (2014) affirmed that economic complexity is an adequate productive structure approximation, which may reflect the pattern of specialization. Thus, we substitute $\left(\frac{\varepsilon}{\pi}\right)$ for economic complexity in Equation (10):

$$ECI_{(t)} = \frac{y_{(t)}}{z_{(t)}} \tag{11}$$

where ECI is economic complexity. It is determined the relation between the growth of domestic income and the growth of world's income.

Nelson and Pack (1999) stated that investments in human capital is the key to increase the learning capacity that predicts a change in productive structure. Beyond the relevance of human capital, Cimoli et al. (2005) declared that the investments in technology rise the capacities to adapt and to recognize new opportunities. And, those capacities expand income growth by creating technological-knowledge-based products.

According to Nelson and Pack (1999) and Cimoli et al. (2005), the productive structure is directly related to the income determination, which in turn is associated with human capital stock and investments in technology. Thus, ruling out the growth of world's income, which is equal for all nations, we have:

$$ECI_{(t)} = HC_{(t)} + R\&D_{(t)} \tag{12}$$

where HC is human capital; and $R\&D$ is investment in technology. Hence, economic complexity is a function of the quantity and the quality of human capital, and investment in technical progress.

In this investigation and for this model, as Jones and Vollrath (2013), we assume that human capital is the result of the time spent accumulating abilities, such as the time spent by a student at school. However, we include the idea of Nelson and Phelps (1966) that human capital may speed the process of technological diffusion and transmission. The authors indicated that some jobs are highly routinized and require less education than functions that require adaptation to change. For the jobs which following and understanding new technologies is requested, educational attainment may not represent human capital well.

Furthermore, Romer (1990) introduced the notion that human capital also influences technology growth by being a factor of technical progress that may boost the innovative capacity. The author suggested that some skilled persons work for expanding technology, rather than producing final-output goods. These persons' outcome may be related to the cognitive skills that they have instead of the quantity of education.

The mentioned authors consider human capital relevant in explaining income growth. They might diverge in the size of the effect of human capital on income, but both authors agree that the effect is positive. They also take technology into account. Given that, a high-skilled worker may follow, understand and cause technical progress.

Hanushek and Kimko (2000) analyzed the relationship between labor-force quality and economic growth. The authors stated that the most important limitation left from the mentioned investigations was to take only schooling attain measures as human capital proxies. They affirmed that analyzing the quality of human capital improves the power to explain economic growth. Moreover, cognitive skills have a consistent and stable positive relation to growth rates. Therefore, in the third chapter we attempt to separate these two components of human capital, the quantity of education and the quality of education, in order to analyze the effects of both on productive structure.

According to Gould and Ruffin (1995), human capital has larger positive effects on an open economy than on a closed one. Therefore, we have to take into consideration trade openness in order to access the marginal effect of human capital onto productive structure. In addition, Chen and Feng (2000) defended that international trade leads to economic growth. Thus, we insert trade openness into our framework:

$$ECI_{(t)} = HC_{(t)} + R\&D_{(t)} + Tra_{(t)} \quad (13)$$

where Tra is trade openness.

Rodrik and Subramanian (2004) studied the growth of per capita income in India during the 1980s and 1990s. The authors analyzed various hypotheses of how the Indian economy took off. They argued that the government's attitude towards the private sector was the key to start the transition for a growth process. Consequently, we have to consider government's posture towards economy in our framework. Moreover, Hausmann, Hwang and Rodrik (2007) indicated that government policy is relevant in shaping the productive structure. Hence, we introduced government expenditure into our conceptual model:

$$ECI_{(t)} = HC_{(t)} + R\&D_{(t)} + Tra_{(t)} + Gov_{(t)} \quad (14)$$

where Gov is government expenditure.

Including variables of initial or lagged per capita output is conventional in equations that focus on income growth, although there is no wide accepted framework for economic growth determinants (LEVINE; RENELT, 1992; SALA-I-MARTIN, 1997; BARRO, 2003). Furthermore, Yanikkaya (2003) stated that the previous level of income may also be assumed as the level of capital presented in the lagged period. Thus, we introduced lagged per capita output into our conceptual model:

$$ECI_{(t)} = GDP_{(t-1)} + HC_{(t)} + R\&D_{(t)} + Tra_{(t)} + Gov_{(t)} \quad (15)$$

where $GDP_{(t-1)}$ is lagged per capita output.

3 METHODOLOGY

This part of the investigation presents some important methodological issues. The remainder of this chapter proceeds as follows: 1) Economic complexity index; 2) Empirical model; and 3) Data source.

3.1 ECONOMIC COMPLEXITY INDEX

Hausmann et al. (2014) introduced the concept of economic complexity and indicated that it is a measure of the embedded knowledge in goods that an economy produces and exports. Diversifying the set of products that an economy can make is a task that requires knowledge. Producing non-ubiquitous[6] goods also requires knowledge. The notion of economic complexity is related to: the levels of diversity and ubiquity of goods that a nation produces and exports; the share in international trade; and the other countries' exports[7]. The connectedness level between products is also taken into account. The economic complexity is measured at product level and at national level.

At product level, the goods are considered according to their levels of ubiquity and connectedness to the others goods. A product that is exported by a large amount of countries may be easier to be produced, while a good that is exported by few may be harder to be made. On the other hand, there are products that need more knowledge to be manufactured. Thus, the capabilities required to produce these goods may be used at producing other goods, so certain products present more connections than others.

In this context, if a good is not ubiquitous, but low connected to other goods, it indicates that this product does not request much knowledge, for example, mineral products. If a ubiquitous good is high connected to others goods, it suggests that this product requires much knowledge, but this kind of knowledge is somehow explicit, for instance, paper products. The less ubiquitous and more connected is a product, the higher is its complexity, for example, optical instruments.

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[6] We talked about technology intensive products in the first chapter. However, aiming methodological issues, we henceforth talk about the ubiquity. A ubiquitous good seems to be found everywhere, while a non-ubiquitous good seems to be found in very few places. The level of ubiquity in exports helps explaining economic complexity more than talking about technology intensity or other measures of technological content in exports, once the level of ubiquity is more objective than the level of technology.

[7] The economic complexity index is based on data on exports and not on data on domestic consumption. The authors of the index explained that if a country is able to export a good it has mastered the necessary capabilities to produce this good. They also stated that data on exports are more available and comparable than other national-specific economic measure.

Goods are separated into groups. There are 21 groups of products and it is reasonable to assume that, inside a group, products may share some required knowledge to be produced. The groups are animal and vegetables bi-products; animal hides; animal products; arts and antiques; chemical products; foodstuffs; footwear and headwear; instruments; machinery; metals; mineral products; miscellaneous; paper goods; plastics and rubbers; precious metals; stone and glass; textiles; transportation; vegetable products; weapons; and wood products.

At national level, the authors assume that a country is complex the more knowledge workers use at producing goods. The reason why economies differ significantly refers to the amount of knowledge embedded in their products. Two abilities are used to analyze complexity at this level. The first ability is to produce and export non-ubiquitous goods, which means goods that few countries can produce. The x-ray equipment is an example of a non-ubiquitous product, because few countries can produce and export it. We can highlight the diamond exports, which production and export are also restricted to a small number of countries. Nonetheless, we know that there is a noticeable difference between x-ray equipment exporters and diamond exporters. This difference leads us to the second ability of economic complexity.

The second ability refers to the production and export of a wide variety of goods, which is represented by an almost unlimited diversity of products that an economy can supply. Among the non-ubiquitous product exporters, it is used the second ability to verify the reason for the scarcity. The first reason can be a geological characteristic, such as the production of diamonds or copper. The second possible reason would be a comparative advantage that comes from a high productive economy, which is in a select country group where high complex products are exported, such as x-ray equipment.

In this context, an economy is considered complex when it has both the ability to produce non-ubiquitous goods and the ability to produce diversified goods. If a country exports the two types of products, non-ubiquitous and diversified ones, it means that this country exports sophisticated goods and is a high complex economy. Exporting either only non-ubiquitous products or only diversified products does not lead to a higher level of economic complexity, which is linked to higher output.

The interplay between nations and products lead us to calculate each country's diversity level and the ubiquity level of each exported good in a single measure. This measure is the economic complexity index and it takes into account the revealed comparative advantages that a nation has in exporting a product.

Balassa (1965) affirmed that revealed comparative advantage (RCA) exists when the ratio of product p in a country's export share to the world's export share of the same product is higher than the unity (RCA≥1). For example, in 2016, with exports of $30.1 billion, coffee represented

0,20% of world trade. Of this total, Brazil exported $5.08 billion, and since Brazil's total exports in 2016 was $191 billion, coffee accounted for 2,65% of Brazil's exports. Since $RCA_{Brazil,coffee} = 13{,}25$ (2,65% divided by 0,20%), we can say that coffee is a product in which Brazil has revealed comparative advantage.

RCA is a measure of the relevance of a good in a nation's export basket that controls for the size of the nation's economy as well as the size of the market of each product. Formally, we can express this notion as:

$$RCA_{cp} = \frac{X_{cp}}{\sum_c X_{cp}} \Big/ \frac{\sum_p X_{cp}}{\sum_{c,p} X_{cp}} \tag{16}$$

where RCA_{cp} is the revealed comparative advantage of a country *c* in exporting product *p*; X_{cp} is exports of product *p* by country *c*; $\sum_c X_{cp}$ is total exports of country *c*; $\sum_p X_{cp}$ is world total exports of product *p*; and $\sum_{c,p} X_{cp}$ is world total exports of all products.

Using data on exports, Hausmann et al. (2014) define a matrix M_{cp}, which is *1* if country *c* produces good *p* with revealed comparative advantage, and *0* otherwise:

$$Diversity = k_{c,0} = \sum_p M_{cp} \tag{17}$$

$$Ubiquity = k_{p,0} = \sum_c M_{cp} \tag{18}$$

where $k_{c,0}$ and $k_{p,0}$ are the sum of the connections "country-product". The Equation (16) expresses the number of products that a country produces with a relative advantage, while the Equation (17) indicates the number of countries that produce each good with advantage.

Hausmann et al. (2014) used a technique called "method of reflections" due to this method produces the same set of variables for the two analyzed points, countries and products. The method of reflections iteratively calculates the average value of preceding-level properties of a node's neighbors. It is defined as:

$$k_{c,N} = \frac{1}{k_{c,0}} \sum_p M_{cp} k_{p,N-1}\,, \tag{19}$$

$$k_{p,N} = \frac{1}{k_{p,0}} \sum_c M_{cp} k_{c,N-1}\,, \tag{20}$$

where $N \geq 1$ and the initial conditions are given by the Equations (16) and (17). In order to access economic complexity, it is required to consider both the average ubiquity of products that a country exports and the average diversity of countries that export each good. Inserting Equation (19) into Equation (18):

$$k_{c,N} = \frac{1}{k_{c,0}} \sum_p M_{cp} \frac{1}{k_{p,0}} \sum_{c'} M_{c'p}\, k_{c',N-2}\,, \tag{21}$$

and rearranging this as:

$$k_{c,N} = \sum_{c'} \widetilde{M}_{cc'} k_{c',N-2} \tag{22}$$

where

$$\widetilde{M}_{cc'} = \sum_p \frac{M_{cp} M_{c'p}}{k_{c,0} k_{p,0}} \tag{23}$$

where the eigenvector of $\widetilde{M}_{cc'}$ associated with the largest eigenvalue is a vector of ones and it is not informative. Thus, the authors use the eigenvector associated with the second largest eigenvalue, this eigenvector captures the largest amount of variance in the system and is used as a measure of economic complexity. The economic complexity index (ECI) is defined as:

$$ECI = \frac{\vec{K} - <\vec{K}>}{stdev\,(\vec{K})} \tag{24}$$

where $\vec{K}$ is the eigenvector of $\widetilde{M}_{cc'}$ associated with the second largest eigenvalue, < > means the average and *stdev* stands for the standard deviation. The ECI is a normalized index, which is the reason for the use of the average and the standard deviation of the eigenvector.

The value of the ECI is a time-varying measure, which has *0* average, 1 as standard deviation and lies between $-\infty$ and ∞. The difference in the values of the ECI between nations is smaller than between cities, because the latter ones have more distinct economic aspects than the former ones. Cities may specialize in exporting some goods while the other necessary goods are bought domestically from other cities. For example, in 2015 for the 679 cities in Brazil that the ECI is available, the highest level of complexity presented an ECI of 30.603, while the median level was -0.0344 and the lowest level was -6.245. In that analysis, the distance from the median ECI to the highest ECI is more than 4 times larger than to the lowest ECI[8].

Differently of the cities, a nation that specializes in exporting few product has more difficulties to access the necessary inputs due to trading with other nations yields problems that does not exist within a country, such as different currencies or languages. These difficulties

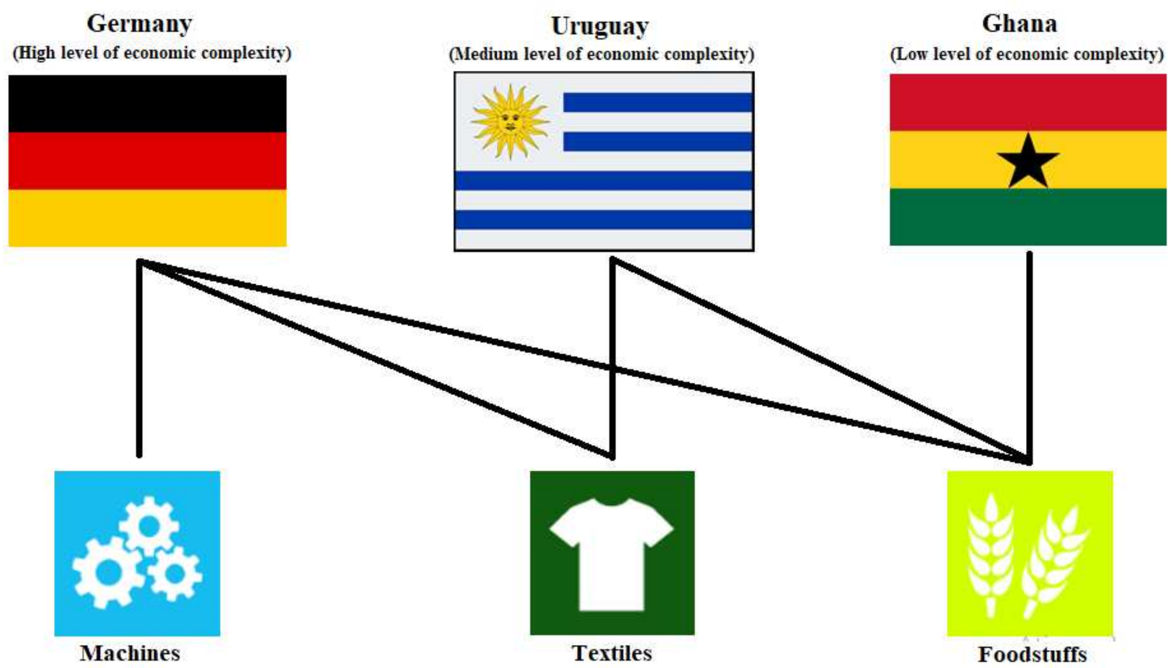
[8] The distance from the highest ECI to the second highest is larger than the distance from the second highest to the lowest ECI. In economic complexity terms, the first municipality in the ranking of ECI in Brazil is much farther from the others. The ECI for some Brazilian municipalities is presented in the Appendix D.

lead countries to attempt to produce their own inputs. Thus, nations are closer, in economic complexity terms, to each other than cities and we can see it in the ECI values of each dataset[9].

At national level, countries that have an ECI value around *0* are medium complex economies, while the ones that have an ECI value higher than *2* are more complex economies and countries that have an ECI value lower than *-2* are less complex economies. For example, in 2016 for the 126 nations that the ECI is available, Germany had an ECI value of 1.9555, making it the 3rd most complex economy in the world. In the same year, Uruguay had an ECI value of 0.1758, which represents the 54th most complex economy in the world. Ghana had an ECI value of -1.4110 for the mentioned year, which means that this country is the 115th most complex economy in the world.

The following figure illustrates the relation among the mentioned nations, their levels of diversity and ubiquity of some groups of products:

Figure 2 - Countries and their ability to produce goods



Source: Elaborated by authors.

Each country is linked to the type of product that it is able to produce and export. Germany, a high complex economy, is related to machines, to textiles and to foodstuffs. Uruguay, a medium level of economic complexity country, is associated to textiles and to foodstuffs. Ghana, a low complex economy, is connected only to foodstuffs. In terms of diversity and

[9] At national level and in terms of the ECI ranking, the distance that separates the first economies to the economies around the median is similar to the distance from the median countries to the last ones. The ECI for some nations is presented in the Appendix D.

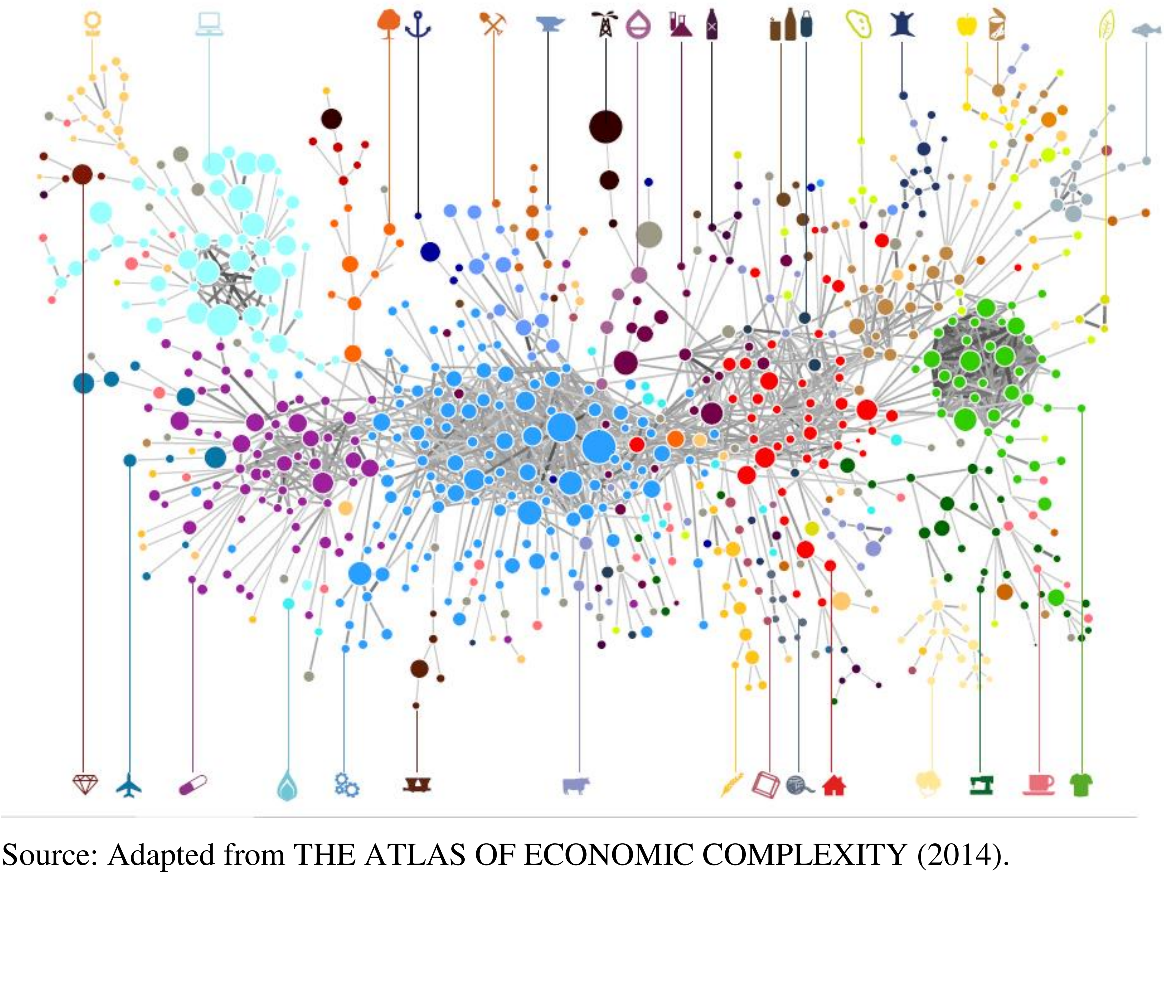
ubiquity, Germany has the highest level of diversity and Ghana the lowest one, while the machine group is the least ubiquitous group of goods and foodstuffs is the most ubiquitous group of products.

This analysis leads us to a network that connects products with revealed comparative advantage to nations. Taking into account a country's export basket and the goods that this country trades with advantages, we can construct the product space. The product space is a net that relates products according to the capabilities required to produce each good, it displays the proximity of goods in consequence of the probability of some products to be co-exported by the same country.

The authors of the index assume that if a nation has two goods that are co-exported, it means that a specific capability is linked to both products. For instance, a nation that has *RCA≥1* in cocoa butter has a high probability of exporting cocoa paste with advantages too, because a number of knowledge of cocoa processing is required, thus, in the product space, these two products are close to each other and there is a line connecting them.

The following figure presents a stylized product space in order to provide a better understanding of how goods are displayed and what to expect when looking at a nation's product space:

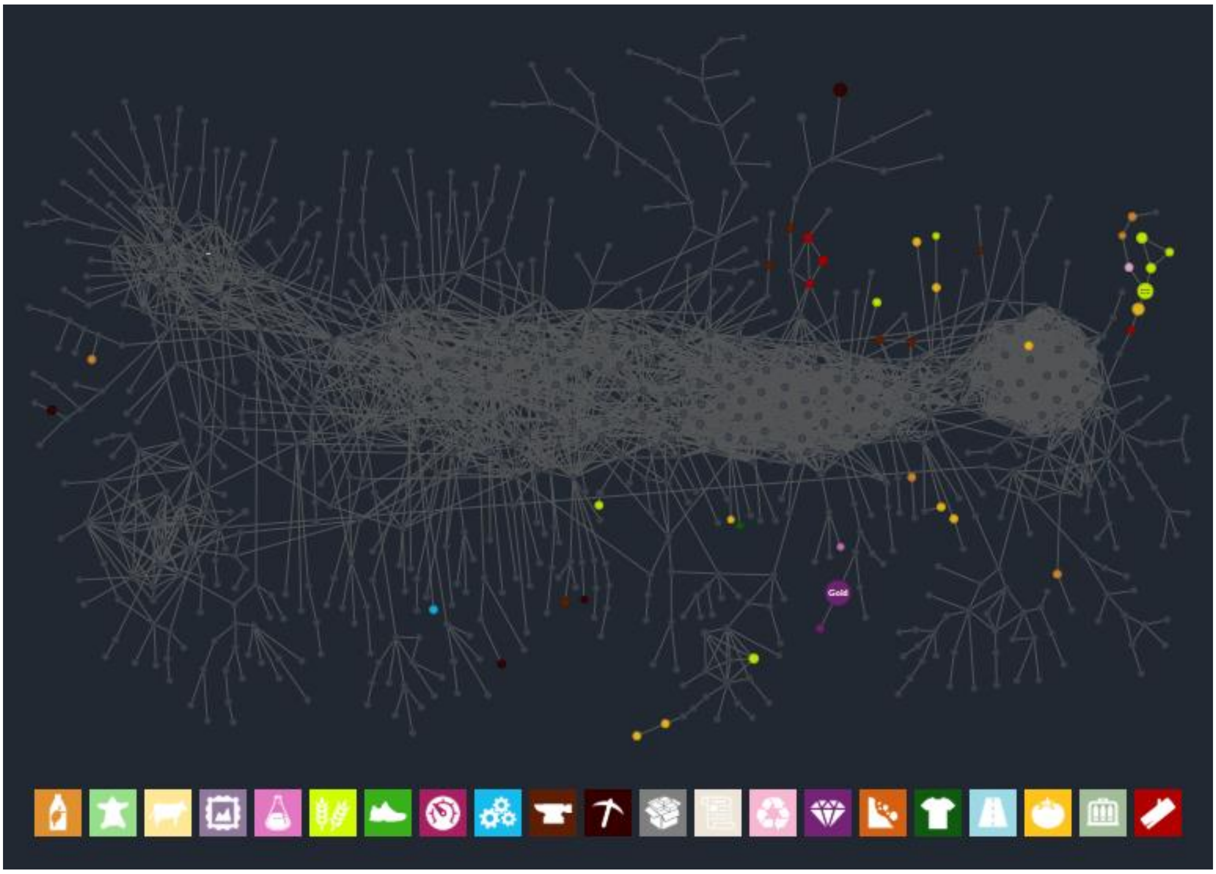
Figure 3 - A stylized product space



Source: Adapted from THE ATLAS OF ECONOMIC COMPLEXITY (2014).

Each node represents a product, the colorful nodes are the products that an economy exports with *RCA≥1*. The larger is the node, the higher is the share of a good in international trade. The colors represent the groups of products. At the bottom of each economy's product space there are the groups with their specific color to facilitate the visualization. Although this stylized product space exhibits a few icons that express some products, a normal product space for a country displays no icons. The following figures present the product space of the three nations mentioned:

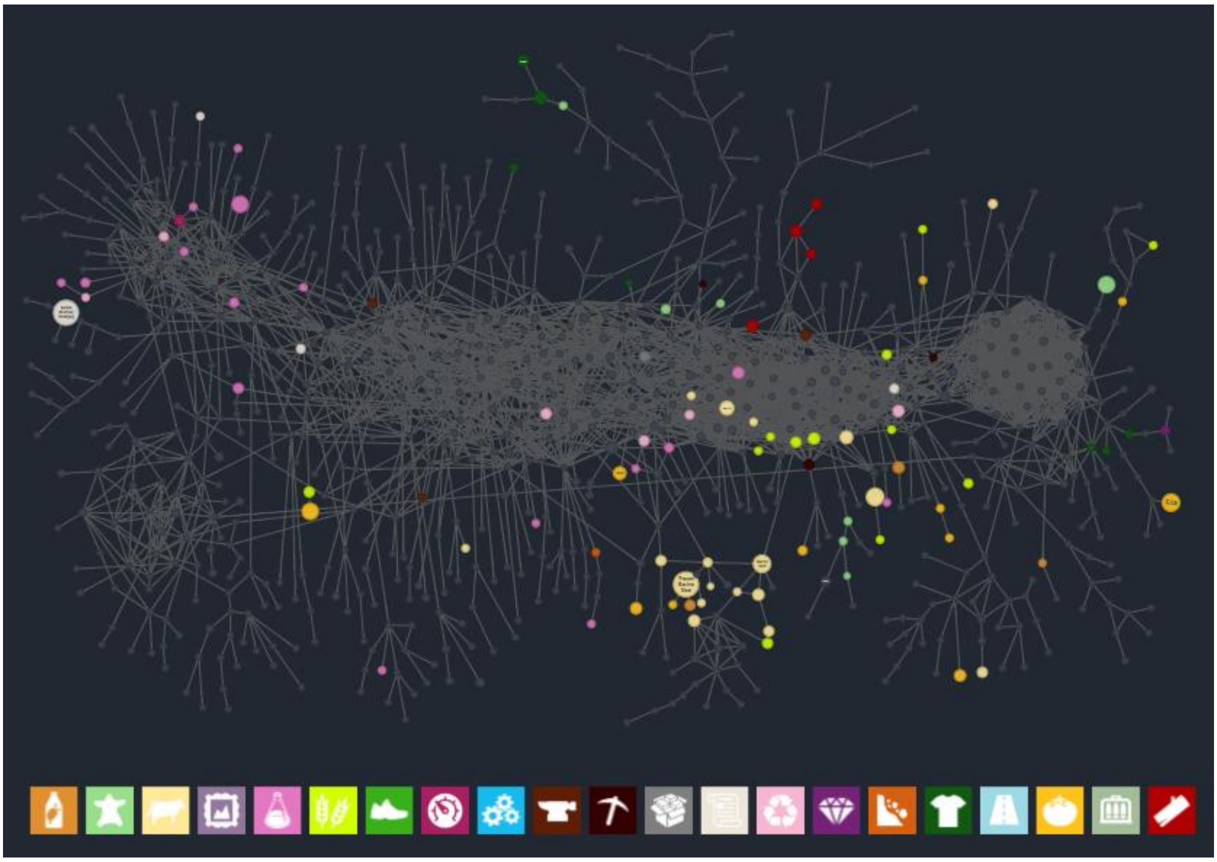
Figure 4 - Ghana's product space in 2016



Source: Simoes and Hidalgo (2011).

Each node represents a product and the colorful nodes are the products in which Ghana has revealed comparative advantage. In 2016, Ghana exported 59 products with *RCA≥1* and the groups of products that exported more goods are foodstuffs; and vegetable products, which, in turn, have products that are more sparsely connected. Following the example given above, Ghana exported with *RCA≥1* cocoa beans; cocoa powder; cocoa butter; cocoa paste; wheat flours; and bran.

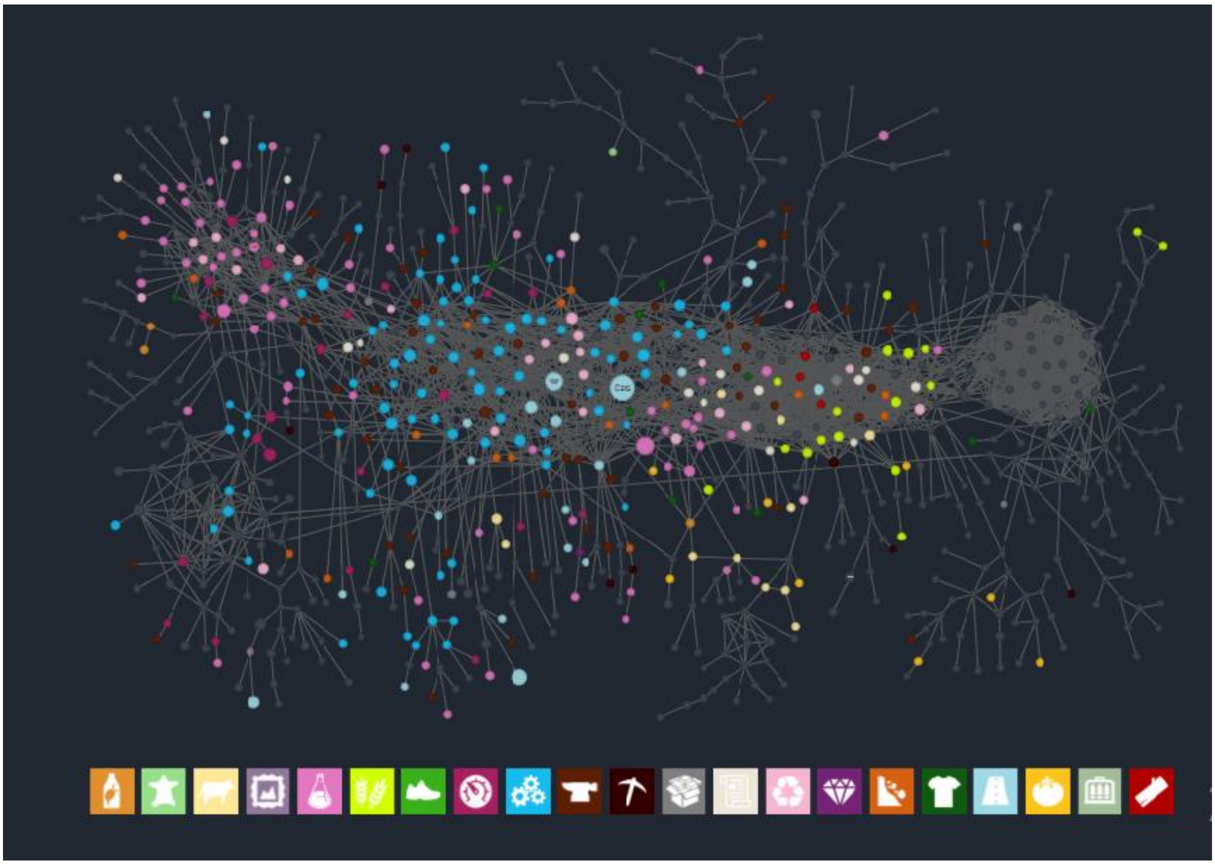
Figure 5 - Uruguay’s product space in 2016



Source: Simoes and Hidalgo (2011).

Each node represents a good and the colorful nodes are the products in which Uruguay has revealed comparative advantage. In 2016, Uruguay exported 133 products with *RCA≥1* and the groups of products that exported more goods are foodstuffs; vegetable products; animal product; textiles; and chemical products. These groups of products have goods that are less scattered. Uruguay exported with *RCA≥1* soybeans; soybean meal; whey; butter; bovine meal; wool; prepared wool or animal hair; phosphatic fertilizers; and other vinyl polymers.

Figure 6 - Germany’s product space in 2016



Source: Simoes and Hidalgo (2011).

Each node represents a good and the colorful nodes are the products in which Germany has revealed comparative advantage. In 2016, Germany exported 518 products with RCA≥1 and the groups of products that exported more goods are machines; chemical products; metals; plastics and rubbers; instruments; and transportation. These groups of products have goods that are more linked to the other products. Germany exported with RCA≥1 transmissions; valves; engine parts; packaged medicaments; pesticides; glues; aluminium pipes; iron cloth; aluminium bars; rubber sheets; rubber belting; rubber pipes; x-ray equipment; non-optical microscopes; cars; vehicle parts; and locomotive parts.

The ECI is a comparative index, which means that an increase in ECI is a gain in capabilities larger than the other economies’ gains and a decrease in ECI is a gain in capabilities smaller than the other economies’ gains. If only one country starts exporting a product that it couldn’t export before, it means this country has learned a capability, thus its ECI will rise. On the other hand, if only an economy stops exporting a good that it could export before, it means this economy has lost a capability, hence its ECI will decline.

3.2 EMPIRICAL MODEL

The empirical model estimates the relationship between economic complexity and human capital, previous level of income, investment in technology, trade openness, and government expenditure. We have used one proxy for each variable, excepting for human capital. For this variable, we have firstly analyzed only a quantitative measure of it, afterward we used both, the quantity and the quality of education.

We have data for 98 countries from 1996 to 2015 averaged over five-year periods. Furthermore, the availability of data restricted the number of nations and the period analyzed. We used five-year intervals and period dummies in order to remove a correlation that comes from business cycle effects (FÖLSTER; HENREKSON, 2001). By doing that we also attempted to eliminate the influence of government changes or economic crisis.

We made use of a fixed-effects panel, because it allowed us to control the non-observable heterogeneity at country level, which remains fixed. As stated by Hsiao (2014), the possible intercept differentiation aims to minimize the omitted variable bias, given that the insertion of a country dummy intends to capture the non-observable fixed effects of each nation. We know that there is both an efficiency loss and a degrees of freedom loss when we use the mentioned methodology. However, this is the proper methodology when we assume that the correlation between non-observed heterogeneity and regressors is not zero[10].

The dependent variable is the economic complexity index over four periods: 1996-2000, 2001-2005, 2006-2010, and 2011-2015. The specified regression is according to the following fixed effects panel:

$$ECI_{it} = \beta_1 GDP_{it-1} + \beta_2 HC_{it} + \beta_3 R\&D_{it} + \beta_4 Tra_{it} + \beta_5 Gov_{it} + \vartheta_i + \omega_{it} \qquad (25)$$

where i means the country and t the period. ECI is the economic complexity index; GDP_{it-1} is the lagged per capita output; HC is human capital; $R\&D$ is investment in technology; Tra is trade openness; Gov is government expenditure; and ϑ and ω are the error terms.

We use the lagged per capita output as a control for the past economic growth. In addition, it is possible to take this measure as a proxy for the stock of capital (YANIKKAYA, 2003). In our first estimate, we use a human capital index based on a quantitative measure of education as a proxy for human capital. Our second estimate included a qualitative measure of human capital. The proxy for investment in technology is the share of output spent on research and development (R&D), because this expenditure aims to evolve the domestic technology level.

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[10] We ran the Hausman test and it showed that the proper estimator is a fixed-effects one. We also ran other econometric tests to validate our estimate, the tests are presented in the following chapter.

In order to access the trade openness level of an economy, we first construct an intermediate measure that is based on the sum of imports and exports as a percentage of output. We regress this measure on country's area and population and separate the error term. The residual of this estimate is about all the other variables that are related to trade openness, excepting country's area and population. Thus, we multiply the residual of the mentioned estimate by a measure of trade terms, which is a ratio of an export price index to an import price index. By doing so, we have a trade openness variable that is controlled for differences in international prices, population and country's area[11].

The proxy for government expenditure is the share of output spent on general government final consumption. This measure includes all government current expenditures for purchases of products and services. It also contains most expenditures on national defense and security, however, it drops government military spending that are part of government capital formation.

We expect a positive relationship between economic complexity and the lagged per capita output, once an increase in output means more capital available for the following period. A positive relation between complexity and human capital is expected, because a more educated labor force may increase the productivity and, consequently, the exports of some goods. We expect that investing in technology is positive related to economic complexity due to more technology may rise the possibilities of learning as well as competing abroad.

Our expectation for the relation between trade openness and complexity is a positive relationship, since the ECI is based on the sophistication of exports and a more open nation may access better inputs and bigger markets. We expect a particular relation between government expenditure and economic complexity across the countries. It is difficult to expect a negative contribution of government on complexity, given that the public spending may be used to favor the production and export of a high complex good as well as to promote opportunities to increase capabilities. On the other hand, government may complicate some issues and bring a worse economic environment to business.

3.3 DATA SOURCE

The economic complexity index is based on the levels of diversity and ubiquity of products exported and as well as on the nations that trade the exported goods. The index is normalized, which means *0* as average and *1* as standard deviation. All of the product data used to elaborate the ECI come either from the Standard International Trade Classification (STIC) or from

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[11] Barro (2003) used a similar approach to capture the impact of trade openness on economic growth.

Harmonized System (HS). Data on complexity is available on the observatory of economic complexity (SIMOES; HIDALGO, 2011).

Our quantitative proxy for human capital is the human capital index in the Penn World Table 9.0[12] (FEENSTRA; INKLAAR; TIMMER, 2015). This index takes into account data on the average years of schooling from Cohen and Soto (2007), Barro and Lee (2013) and Cohen and Leker (2014) as well as the rates of return to education for each level of schooling estimated by Psacharopoulos (1994). We use this index because it combines different datasets on education attainment and has more observations than other measures. According to Hanushek and Kimko (2000), educational quality measures may come from two sources, schooling inputs or cognitive skill tests. Our qualitative measure for human capital comes from the national score in the Programme for International Student Assessment (PISA) executed by the OECD[13].

PISA is an international survey executed by OECD that collects data on student's performances in the 30 members of OECD and some partner countries. The surveys take place every three years and assess the 15-year-old students' knowledge in reading, mathematics and science. PISA provide detailed information on students and school factors. The results of the OECD countries were transformed to a scale with a mean of 500 and a standard deviation of 100.

PISA dataset presented important issues, such as, testing students on three subject while the other international tests do not have a broad result of the education process; and the results are internationally comparable (FUCHS; WÖßMANN, 2004). International surveys, such as PISA, aims to assess the knowledge or skills of a population, however it is not easy to evaluate population's performance by testing a sample of it. A statistical technique for doing this is to use plausible values. According to Wu (2005), plausible values represent the range of abilities that a student might have and they perform well in estimating population parameters. We use the plausible values to estimate population average and population percentiles of PISA 2000, PISA 2003, PISA 2006 and PISA 2012[14].

R&D are compounded by the current and capital spending from both public and private sector in activities that aim to systematically increase knowledge of humanities, culture and

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[12] Our period of investigation is from 1996 to 2015, but the Penn World Table 9.0 presents data until 2014. Thus, the human capital index for the interval between 2010 and 2015 considers a four-year averaged period and not a five-year averaged period as the previous periods.

[13] PISA data comes from OECD. Jakubowski and Pokropek (2017) facilitated the approach to the OECD databases by developing a Stata module to access such information.

[14] Although PISA surveys have a three-year interval and our database has a five-year interval, we could use PISA surveys because they matched our five-year periods: PISA 2000 for the interval 1996-2000; PISA 2003 for the interval 2001-2005; PISA 2006 for the interval 2006-2010; and PISA 2012 for the interval 2011-2015.

society. The spending covers the basic and the applied research, as well as the experimental development. R&D are from United Nation Educational, Scientific and Cultural Organization (UNESCO) and the World Bank makes it available[15].

Data on import, export and government expenditure come from OECD. Data on population and land area come from United Nations (UN). Data are made available by the World Bank. The following table presents the summary statistics of our data:

Table 1 - Summary statistics between 1996 and 2015 (five-year intervals)

	Observations	Mean	Standard deviation	Minimum	Maximum
ECI[a]	482	-0.0191	0.9942	-2.4411	2.5391
GDP[b]	481	8.0500	1.5648	4.8552	11.3443
HC[c]	442	2.5185	0.6621	1.1232	3.7226
PISA Ave[d]	178	473.4156	54.7060	317.956	573.4683
PISA 75th[e]	178	536.4628	58.4754	367.713	649.5949
PISA 90th[f]	178	590.3397	57.3100	437.895	706.8001
PISA 95th[g]	178	621.3815	55.8045	485.925	737.4124
R&D[h]	350	0.9173	0.9256	0.0092	4.1851
TRA[i]	473	2051.34	5715.14	-10788.67	35550.86
GOV[j]	468	15.4965	5.0435	4.9104	31.5272

a) ECI = the economic complexity index;
b) GDP = the natural logarithm of per capita output (current US dollars);
c) HC = the human capital index in the Penn World Table 9.0;
d) PISA Ave = the average score in the Programme for International Student Assessment;
e) PISA 75th = the 75th percentile score in the Programme for International Student Assessment;
f) PISA 90th = the 90th percentile score in the Programme for International Student Assessment;
g) PISA 95th = the 95th percentile score in the Programme for International Student Assessment;
h) R&D = the share of output spent on research and development;
i) TRA = the measure of trade openness;
j) GOV = the share of output spent on general government final consumption;

Source: The World Bank; the Penn World Table 9.0; Simoes and Hidalgo (2011)

Our measures of lagged income; human capital; investment in technology; trade openness; and government expenditure were standardized[16]. The economic complexity index and PISA data come already in a standardized form.

[15] Azevedo (2011) facilitated the approach to the World Bank databases by developing a Stata module to access such information.

[16] The standardizing process was: $X^{*} = (X - \mu)/\sigma$, where X^{*} is the standardized value, X is the initial value, μ is the mean of X, and σ is the standard deviation of X.

4 RESULTS AND DISCUSSION

This chapter presents the results, which are separated into two sections: 1) Main results; and 2) Focus on human capital.

4.1 MAIN RESULTS

We made some statistical tests to examine the validity of the outcomes. To confirm the proper panel estimator, we ran the Hausman test. The test statistic was 14.61 and its p-value was 0.0671[17]. To check for the serial autocorrelation in our panel, we made the Wooldridge test. The test statistic was 68.387 and its p-value was 0.0000[18]. To check for the groupwise heteroskedasticity, we used the modified Wald test. The test statistic was 2.3e+30 and its p-value was 0.0000[19]. To check for the multicolinearity, we verified the variance inflation factors (VIF). The VIF values were around 3, which indicates the absence of a high multicolinearity.

We tried to run two different cross-section dependence tests, but it was not possible, because the panel was highly unbalanced and there was not enough common observations for that. We also ran a unit-root test for panel data, this test checks for 4 aspects of data. The test statistics of each aspect were 329.9020; -4.4324; -4.1533; and 4.1034, their p-values were 0.0001; 0.0000; 0.0000; and 0.0000[20].

Given that the residual of our estimate was heteroskedastic and serial autocorrelated, we estimated a variance-covariance matrix that permits an intragroup correlation. By doing this we assume that observations are independent across groups, however the observations may not be independent within groups. This procedure influence the standard errors and the variance-covariance matrix, but not the estimated coefficients. We specify that each country is a group.

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[17] This test verifies whether the correlation between the non-observed heterogeneity and the explanatory variables is statistically not zero. The null hypothesis is that there is not a systematic difference between fixed and random effects estimators and, under this hypothesis, random effects are efficient and consistent, which makes the random effects estimators proper. Under the alternative hypothesis, random effects are inconsistent. Fixed effects are consistent under both hypothesis, which makes them adequate under the alternative one. Given the test statistic, at 0.10 significance level, we reject the null hypothesis. Thus, we concluded that the fixed-effect estimator is the adequate one.

[18] At 0.01 significance level, we reject the null hypothesis that the there is no first-order correlation. Hence, we conclude that the errors are serial correlated.

[19] At 0.01 significance level, we reject the null hypothesis that the unobserved heterogeneity variance is equal for all the individuals. So, we conclude that there is heteroskedasticity for groupwise.

[20] This test verifies if the panel datasets are stationary. We used the Fisher-type test and its null hypothesis is that all the panels contain a unit root. Given the test statistics, at 0.01 significance level, we reject the null hypothesis. Therefore, we conclude that the panel data is stationary.

In this context, after an error-correction, the following table displays the results of the specification presented in Equation (24):

Table 2 - Economic complexity between 1996 and 2015 (five-year intervals)

	ECI[a]
Constant	0.34123*** (0.02681)
GDP[b]	0.18108 (0.11051)
HC[c]	0.51350*** (0.17132)
R&D[d]	0.17161** (0.06704)
TRA[e]	0.11965*** (0.04448)
GOV[f]	-0.00474 (0.03256)
N	317
Adjusted-R^2	0.214

Significant at ***1%, **5%, *10%. Standard errors in parentheses. All standard errors clustered at country level.
a) ECI = the economic complexity index
b) GDP = the natural logarithm of per capita output (current US dollar)
c) HC = the human capital index in the Penn World Table 9.0
d) R&D = the share of output spent on research and development
e) TRA = the measure of trade openness
f) GOV = the share of output spent on general government final consumption
Source: Elaborated by the authors

According to Table 2, hereafter considering at least the 0.05 significance level, previous per capita output had a positive, but insignificant, coefficient. Although this measure is an important control in this kind of study, it was not statistically significant in explaining economic complexity. Moreover, government expenditure presented a negative, but insignificant, coefficient either. On the other hand, human capital, investment in technology and trade openness presented positive and significant effects on complexity. We tested the possibility of diminishing returns of human capital to R&D and the opposite too, but they showed no significance.

In a general manner, two countries that have the same lagged per capita output or the same government expenditure present a positive influence of human capital, R&D and trade openness on economic complexity. Although government expenditure and previous per capita output showed no significance, they are relevant variables, given the cross-country differences in them. The absence of a significant statistical effect of these two explanatory variables on economic complexity may have come from the high cross-country variability in government expenditure and per capita income.

In numerical terms, an increase of one standard deviation in the human capital index is associated with a rise in economic complexity index of 0.5135 standard deviation. For instance, to depict the effect of human capital on economic complexity, we found that, from 1990 until 2014, a one-standard-deviation increase in human capital occurred in Singapore in a period of 7 years. Other nations that presented a one-standard-deviation rise in the human capital index were Brazil and Qatar, nevertheless they did so in a period of 13 years.

A positive change of one standard deviation in R&D is associated with an expansion in economic complexity index of 0.1716 standard deviation. For example, to illustrate that, we found that, from 1996 until 2015, a one-standard-deviation increase in R&D occurred in Israel and Estonia in a period of two years. In Portugal and China a one-standard-deviation rise in R&D took place in a period of 11 years. Furthermore, several countries presented an R&D level below the standard deviation of the full sample, which makes such a change more difficult.

An increment of one standard deviation in trade openness is associated with a gain in economic complexity index of 0.1197 standard deviation. For instance, to elucidate that, we found that, from 1980 until 2016, a one-standard-deviation increase in trade openness occurred in a period of one year in Liberia, Iraq, Panama, Qatar, Angola and other 15 nations. It suggests that an increase in trade openness does not require a hard slog or is not associated with traditional economic factors.

When it comes to the economic complexity index changes, we analyzed nations from 1964 until 2016 in at most 20-year periods. Out of 125 nations, 35 obtained at least a one-standard-deviation rise in complexity. Among these 35, the time average for an increase of one standard deviation was 6.25 years.

We attempted to test if the relation between human capital, investment in technology and economic complexity is robust to a different sample of nations. The countries were separated into 7 groups according to their geographical region. The regions were: East Asia and Pacific; Europe and Central Asia; Latin America and Caribbean; Middle East and North Africa; North America; South Asia; and Sub-Saharan Africa. We ran the Equation (24) on 8 different samples and we also examined the validity of these 8 estimates[21]. The first one took the full sample into account; the second one used the full sample excepting the countries of East Asia and Pacific; the third sample took the full sample into consideration excluding the nations of Europe and Central Asia; the other 5 samples followed the same pattern, dropping one region per estimate from the full sample.

For all the 8 estimates with different samples and at 0.05 significance level, the results for trade openness and government expenditure were equal in terms of signs and significance. Investments in technology showed a positive and significant effect in all samples excepting the

[21] The econometric tests are presented in the Appendix B right below the tables of estimates.

one which took the countries of East Asia and Pacific out. Human capital presented a positive and significant impact in 6 of the 8 estimates. For two samples human capital was not significant, one of these two estimates was when we removed the countries of East Asia and Pacific from the full sample, the other estimate was when the nations of Europe and Central Asia were out of the full sample. Considering a 0.10 significance level, lagged per capita output displayed a positive and significant effect in three of the 8 estimates. It happened when we eliminated, one group of countries at a time, the economies of East Asia and Pacific, the economies of Middle East and North Africa, and the economies of Sub-Saharan Africa from the full sample[22].

In order to not lose degrees of freedom, we removed from the full sample one group of countries at a time, instead of estimating the proposed relation separately for each group of countries. Under these circumstances and focusing on the coefficients of human capital, we believe that human capital has a smaller effect on economic complexity in countries of Latin America and Caribbean and countries of Sub-Saharan Africa. We suppose that because the human capital index displayed the two largest coefficients when we put those countries out of the full sample.

In this context, we believe that investment in technology has a larger effect on complexity in the countries of East Asia and Pacific. We assume that because R&D showed no significance when we removed those countries from the full sample. We also believe that investment in technology has a smaller effect on complexity in the countries of Europe and Central Asia. We presume that because R&D presented a larger coefficient when we took those countries out of the full sample.

4.2 FOCUSING ON HUMAN CAPITAL

In order to check the robustness of the results, we used alternative proxies for human capital once there are other indicators available for this variable. Specifically, we ran the Equation (24) using the gross enrolment rate and the net enrolment rate in primary, secondary and tertiary education[23] as the human capital measure. Moreover, we also checked the validity of these 5 estimates[24]. The results of these 5 alternative estimates were worse in terms of significance, number of observations or variability explained. The gross enrolment rate and the net enrolment rate in secondary performed as well as our human capital proxy, the outcomes of both

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[22] See the Tables 1B and 3B in Appendix B.

[23] All data on enrolment rate come from UNESCO.

[24] The econometric tests are presented in the Appendix A right below the tables of estimates.

specifications are similar[25]. We believe these results happened because our measure of human capital partly uses the average years of schooling, which normally follows the trends of enrolment rates.

In addition, secondary education seemed to play an important role in a country's productive structure. However, Holsinger and Cowell (2000) affirmed that there are three sorts of secondary school. The first type is known as general or academic secondary. The second one is recognized as vocational or technical secondary. The third type is famous as diversified or comprehensive secondary[26]. These differences might influence the relationship between human capital and complexity, nevertheless, we have no data on it at country level.

We also took as an approximation of human capital stock the percentage of population with completed primary, secondary or tertiary education, the average years of total schooling[27] and an alternative human capital index[28]. The results indicated that the share of population with completed primary education presented a significant effect on complexity, although trade openness exhibited no significance and the R&D impact fell down. The other alternative measures of human capital were not significant. All the other estimates displayed a loss in degrees of freedom[29]. We suppose that completing primary education might be the threshold for human capital that Azariadis and Drazen (1990) explained.

We tested the same measures exposed above, but now for different gender samples. We did so because Barro (2003) presented different returns of education to growth according to gender. A sample that took into account only female students and a sample with only male students. We did it to check for if there is any significant difference between the effects of each gender on economic complexity. The results for female and male samples were similar to the main specification. The female and male net enrolment rates in secondary showed significance and a larger explained variability, but smaller degrees of freedom. The percentage of female

[25] See the Table 1A in Appendix A.

[26] In academic secondary schools the focus is on the development of abilities in language arts, sciences and humanities. In this type of model, education is for university entrance. Vocational secondary schools are geared to prepare students to specific occupations. In this model, schools provide students minimal theory and specific skills. Students are trained to assume certain occupations in the labor market. The third system of secondary combines academic and technical goals. However, there are two subtypes of schools within this type of secondary. The first subtype permits students to undertake activities concentrated on both university entrance and labor market entrance. While in the second subtype the choice between general or vocational activities relies on achievement tests and teacher recommendations (HOLSINGER; COWELL, 2000).

[27] All data on both percentage of population with a completed level of education and average years of schooling come from Barro and Lee (2013).

[28] This alternative human capital index is developed by Cohen and Soto (2007).

[29] See the Table 3A in Appendix A.

population with complete primary schooling presented comparable outcomes to the percentage of whole population with complete primary education[30].

At the first section of this chapter we presented the main results of our model. These results were based on a set of variables, in which only a quantitative measure of human capital was included. Hereafter, we attempt to improve our analysis by including in the set of variables a qualitative measure of human capital. In order to do so, we make use of the Programme for International Student Assessment (PISA) data.

This qualitative measure of human capital is limited to a smaller sample of countries. Thus, there is a loss in the degrees of freedom and a selection bias[31]. It biased the results toward an overestimate of the proposed relation here. It happens because most surveyed economies are OECD members and they share certain similarities. Although our sample is smaller, the coefficients performed well to this specification.

We used the data of PISA 2000, PISA 2003, PISA 2006 and PISA 2012[32]. We make use of the performance in mathematics[33] for the PISA surveys mentioned, excepting for the year of 2000, for which we used the performance in reading. The population average and the population percentiles of 75th, 90th, and 95th were the scores of PISA used in the estimates[34].

We also tested validity of the outcomes with a qualitative measure of human capital. To check for the multicolinearity, we analyzed the variance inflation factors (VIF). The VIF values were around 2.33, which indicates the absence of a high multicolinearity. The following table shows the other testes run:

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[30] See the Tables 5A, 7A and 9A in Appendix A.

[31] The selection bias comes from the similarity of the countries that compound the OECD group. The average of their human capital index might be higher than the other countries, so effect of education on economic complexity within this group may be lowered. It may happen when we analyze the share of their output spent in research and development. Only 54 nations participated in PISA surveys, our full sample without PISA data is compounded of 98 countries.

[32] We used a 5-year interval data from 1996 to 2015, which makes the use of only 4 PISA surveys. We used PISA 2006 for the interval 2006-2010, nevertheless the use of PISA 2009 does not change the results in terms of coefficients and signs. Using PISA 2009 instead of PISA 2006 alters the standard errors of the parameters, which may cause divergence between coefficients in terms of significance. The estimate results using PISA 2009 for the interval 2006-2010 is presented in Appendix C.

[33] We used the performance in mathematics due to the statistical results were better with this subject than with science or reading.

[34] These scores were chosen arbitrarily.

TABLE 3 - Statistical tests of the estimate presented in TABLE 4

TEST	**IT CHECKS FOR**	**NULL HYPOTHESIS**	**P-VALUE (1)**	**P-VALUE (2)**	**P-VALUE (3)**	**P-VALUE (4)**	**P-VALUE (5)**
Hausman test	Proper painel estimator	Random effects are proper	0.0024	0.0054	0.0057	0.0063	0.0071
Wooldridge test	Serial autocorrelation	No first-order correlation	0.0000	0.0000	0.0000	0.0000	0.0000
Modified Wald test	Groupwise heteroskedasticity	The error variance is equal for all individuals	0.0000	0.0000	0.0000	0.0000	0.0000
Fischer-type test	Stationary	All panels contain a unit root	-*	-	-	-	-
Pesaran test	Cross-section dependence	Error independency across cross-sections	-	-	-	-	-

*No observations available to run the test.

Source: Elaborated by the authors

Considering that the residual of our estimate was heteroskedastic and serial autocorrelated, we estimated a variance-covariance matrix that allows an intragroup correlation, as we did at the beginning of this chapter. In this context, we ran the specification presented in Equation (24), but we added a qualitative measure of human capital in it. Thus, human capital has two components, the human capital index and the scores in PISA surveys. After the error-correction, the results of this specification are displayed in the following table:

TABLE 4 - Economic complexity between 1996 and 2015 with PISA data (five-year intervals)

	ECI[b] (1)	ECI (2)	ECI (3)	ECI (4)	ECI (5)
Constant	1.18069*** (0.06611)	0.33457 (0.48205)	0.23295 (0.54600)	0.01004 (0.59846)	-0.07510 (0.64148)
GDP[c]	0.13150* (0.07109)	0.12468* (0.07344)	0.12783* (0.07504)	0.12715 (0.07656)	0.13009* (0.07745)
HC[d]	0.43214* (0.24293)	0.39916 (0.24391)	0.39380 (0.24393)	0.38537 (0.23914)	0.37966 (0.23781)
R&D[e]	0.19268** (0.08744)	0.17628** (0.08605)	0.16833** (0.08275)	0.15985* (0.08008)	0.15809* (0.07956)
TRA[f]	0.24674*** (0.05877)	0.24099*** (0.05752)	0.23400*** (0.05537)	0.22698*** (0.05284)	0.22394*** (0.05194)
GOV[g]	0.03522 (0.08317)	0.05042 (0.08334)	0.04640 (0.08348)	0.04555 (0.08308)	0.04558 (0.08296)
PISA average score		0.00174* (0.00094)			
PISA 75th percentile score			0.00171* (0.00094)		
PISA 90th percentile score				0.00193** (0.00096)	
PISA 95th percentile score					0.00198** (0.00098)
N	171	171	171	171	171
Adjusted-R^2	0.425	0.434	0.435	0.440	0.443

Significant at ***1%, **5%, *10%. Standard errors in parentheses. All standard errors clustered at country level.
a) PISA = Programme for International Student Assessment of 2000, 2003, 2006 and 2012
b) ECI = the economic complexity index
c) GDP = the natural logarithm of per capita output based on purchasing power parity (constant international dollars of 2011)
d) HC = the human capital index in the Penn World Table 9.0
e) R&D = the share of output spent on research and development
f) TRA = the measure of trade openness
g) GOV = the share of output spent on general government final consumption

Source: Elaborated by the authors.

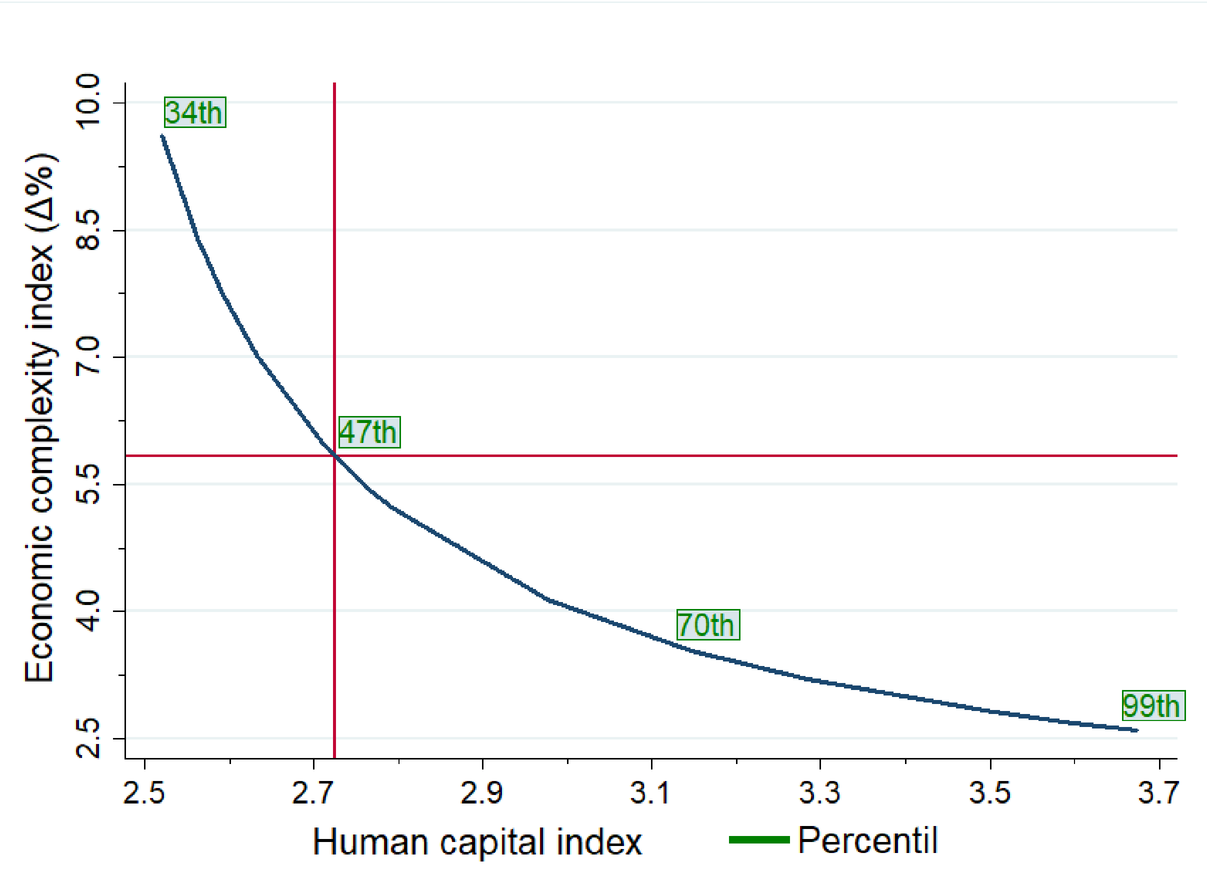
According to Table 4, hereafter considering at least the 0.10 significance level, government expenditure presented positive, but insignificant, coefficients in all 5 estimates. Furthermore, investment in technology and trade openness displayed positive and significant coefficients in all 5 estimates. Lagged per capita income showed positive and significant coefficients in 4 of the 5 estimates. Human capital exhibited positive coefficients, but they were insignificant when we included PISA data. The scores of PISA presented positive and significant coefficients in all the 4 estimates they were inserted in. In addition, the coefficients of the percentiles 90th and 95th of PISA scores are larger in significance and values.

Including PISA surveys to our dataset, specifications (2), (3), (4) and (5) of Table 4 yielded lower, and less significant, coefficients of both human capital and investment in technology comparing to the first specification of the same table. Lower coefficients suggest that human capital index and R&D rely on the quality of education. Moreover, Hanushek and Kimko (2000) stated that educational quality improves the power to explain the economic growth. Thus, when we consider the quality of education, the amounts of years of schooling or money spent on research and development lose their relevance a bit. The results here indicate that achieving higher scores in PISA is associated with presenting higher levels of economic complexity.

4.3 ANALYSIS OF ELASTICITIES

Taking into account that there are differences in both human capital and investment in technology across countries, we analyzed the elasticities of the two variables with respect to economic complexity. These analyses used panel data, not pooled data and are based on Equation (24). We used data in their level form and showed for a few percentiles of human capital index and of R&D their impact on economic complexity. The following figures present the human capital and economic complexity elasticities; the R&D and complexity elasticities:

Figure 7 - Elasticities of human capital with respect to economic complexity



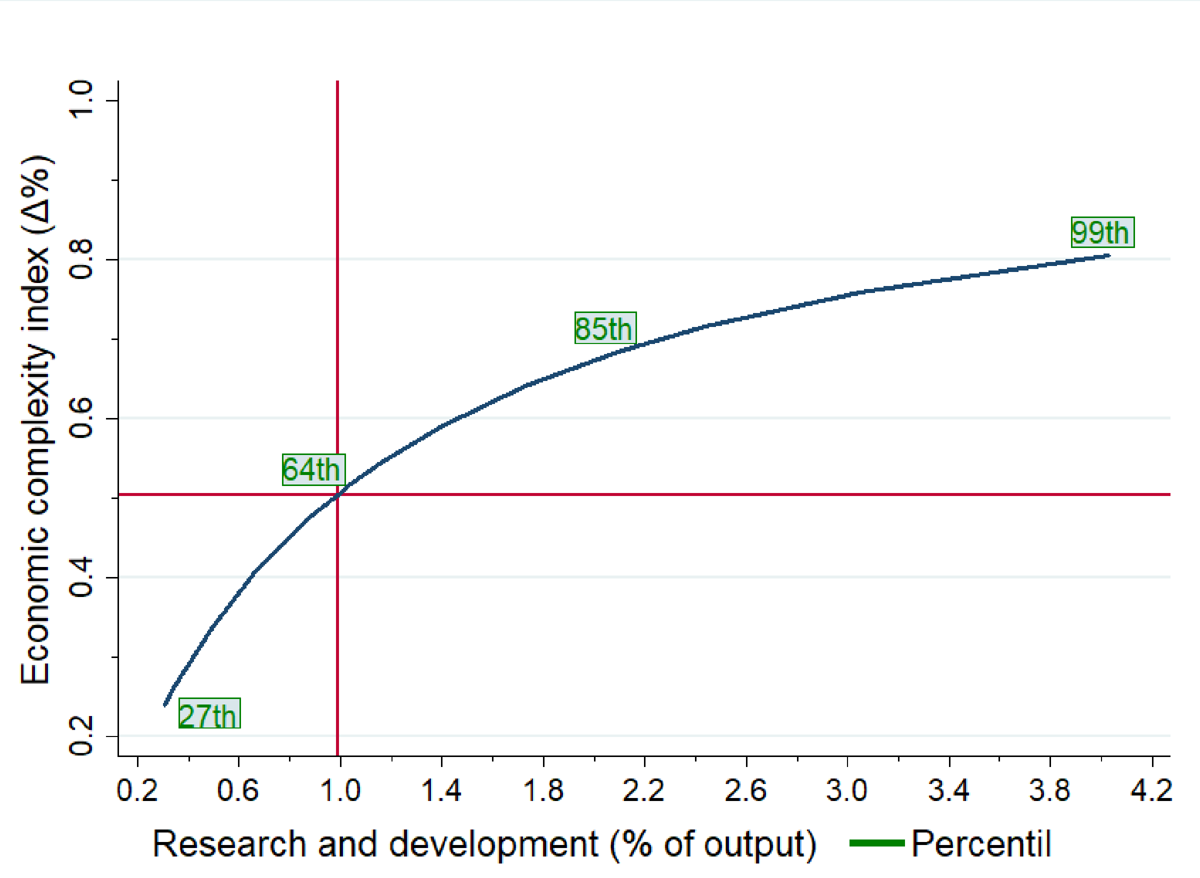
Source: Elaborated by the authors.

The Figure (7) displays the elasticities of human capital index with respect to economic complexity index. We used the percentiles from 34th to 99th due to the other ones presented no significant effect on complexity at least at 0.10 significance level. The average value of human capital index is 2.7253. For countries around this average, a one percent increase in human capital index is associated to an addition of 5.8270 % to economic complexity index. The two constant red lines presented the relation between human capital and complexity at mean.

Concerning the nations around the lowest percentile analyzed for human capital, 34th, a one percent increase in this measure is associated with an addition of 9.6055% to economic complexity, while among the 99th percentile of human capital index the expansion is 2.5947%. As shown in the figure and considering the percentiles from 34th to 99th of human capital, given an initial one percent variation in human capital index, the smaller is human capital, the larger is the percentage change on complexity.

The human capital index is mostly based on the quantity of education. However, Hanushek (2013) affirmed that the quality of schooling explains income growth better than the quantity of education. Furthermore, we consider that the relationship between the quality of education and economic complexity is similar to the relation stated by Hanushek (2013). Thus, the gradual decreasing of human capital coefficient suggests that, after a specific point, the human capital index may not be the best measure to capture the human capital contribution to economic complexity.

Figure 8 - Elasticities of investment in technology with respect to economic complexity



Source: Elaborated by the authors.

The Figure (8) shows the elasticities of R&D with respect to economic complexity index. We made use of the percentiles from 27th to 99th because the other percentiles had no significant effect at least at 0.10 significance level. The average rate of R&D is 0.9866%. For countries around this average rate, a one percent increase in R&D is associated with a rise of 0.5043% in economic complexity index. The two constant red lines present the relation between R&D and complexity at mean.

Regarding the countries that are in the 27th percentile, the lowest significant percentile for R&D, a one percent increase in this rate is associated with a rise of 0.2387% in complexity, whilst among the 99th percentile of R&D the expansion is 0.8058%. Moreover, in Figure (8), we see a positive, but decreasing, slope in its curve as R&D rises. The positive slope means that more investment in technology is associated with a larger percentage effect on economic complexity. However, the decreasing of the slope, as R&D increases, stands for smaller changes in the effects on complexity. For instance, for lower-R&D countries, given a one percent change in investment in technology, the effect on complexity rises faster as R&D increases. And, for higher-R&D economies, the same effect rises slower as R&D goes up.

R&D is based on basic and applied research as well as experimental development. Thus, this measure represents at least two effects of investing in technology on economic complexity. Cohen and Levinthal (1990) argued that investments in research and development raise absorptive capacity and innovation. And, where the innovative activity is low, investments in technology facilitates learning and adaptation to new scenarios.

We take the positive decreasing slope of the curve as a result of the returns of learning and innovation to economic complexity. We believe that lower-R&D countries use their investment in technology for learning and absorptive capacities. These two capacities boost the speed of adaptation to new technologies, yielding for lower-R&D economies the larger changes in the effect of investment in technology.

In this context, it is acceptable that higher-R&D nations already present the learning and absorptive capacities. Hence, for these countries, investment in technology is toward innovative activity, which, in turn, is more difficult and time-consuming. It can be the reason for the smaller changes in the effect of R&D on economic complexity as investment rises. So, lower-R&D economies have more incentives to increase investment in technology than higher-R&D economies.

5 CONCLUSION

This investigation contributes to the debate over the importance of both human capital and investment in technology on a country's productive structure. Once export sophistication reflects the productive structure, hence, this study focused on finding export sophistication determinants, and related them to productive structure and to per capita output. We use the economic complexity index as a measure of export sophistication. The index is based on the levels of ubiquity and diversity of exported products, the share of international trade and the connections between goods. Our estimate is for the period of 1996-2015 with a sample of 98 countries.

According to the results presented in the fourth chapter, given data and used methodology, human capital, investment in technology, and trade openness are important factors in explaining productive structure. All of the three factors showed a positive effect on economic complexity. On the other hand, lagged per capita income and government expenditure are not key elements in determining a country's productive structure. Thereafter, we present the validation tests, the robustness checks and elasticity analyses. In robustness checks, we tested if there were any differences in education of male and female that affect economic complexity and we found none.

In addition, we included a qualitative measure of human capital in our main estimate and it presented promising outcomes. As the quality of human capital, we used the average score and the score of the percentiles of 75th, 90th and 95th of PISA surveys. All the four scores of PISA were relevant components in explaining productive structure. The four scores displayed a positive effect on economic complexity, notwithstanding, the percentiles of 90th and 95th showed the largest effects in terms of significance and values.

Our findings suggest that expansions in human capital are conducive to enhancements to a country's productive structure. So, investments in increasing both the average years of schooling and the quality of education should be promoted, especially the latter one. And, countries with a lower level of human capital should invest more, given that a rise in human capital yields larger effects on complexity to these kind of nations. Moreover, the efforts used to rise the human capital stock, besides aiming to increase economic complexity, are direct factors of income growth.

The learning and innovative capacities lead to improvements in productive structure. Both capacities come from investing in technology. Hence, rises in R&D should be encouraged. Furthermore, R&D also aims to increase the economy's level of knowledge. Trade openness promotes upgrades in productive structure as well. Therefore, investments in opening international trade should receive certain incentives. On the other hand, we cannot indicate the influence of both government expenditure and lagged per capita output on productive structure.

The main limitation of the study is the availability of data, particularly on human capital and R&D. Furthermore, the first suggestion for further research is to seek among the differences in educational system if any of them are important in explaining economic complexity. Although it is difficult to find disaggregated data on R&D, the second suggestion is to separate R&D according to its resource, given that public and business enterprise investments may differ in their effects on complexity. The final suggestion is to separate R&D according to its objectives, given that basic and applied research may vary their effects on economic complexity.

REFERENCES

AZARIADIS, Costas; DRAZEN, Allan. Threshold Externalities in Economic Development. **The Quarterly Journal of Economics**, [S.l.], v. 105, n. 2, p.501-526, May 1990.

AZEVEDO, Joao Pedro. **Wbopendata:** Stata module to access World Bank databases. 2011. Statistical Software Components S457234, Boston College Department of Economics. Available on: <http://ideas.repec.org/c/boc/bocode/s457234.html>. Accessed: 9th Nov. 2018.

BALASSA, Bela. Trade Liberalisation and "revealed" comparative advantage. **The Manchester School**, [S.l.], v. 33, n. 2, p.99-123, May. 1965

BARRO, Robert J.. Determinants of Economic Growth in a Panel of Countries. **Annals of Economics and Finance: China Economics and Management Academy.** [S.l.], p. 231-274. Dec. 2003.

BARRO, Robert J.. Economic Growth in a Cross Section of Countries. **The Quarterly Journal of Economics**, [S.l.], v. 106, n. 2, p.407-443, May 1991.

BARRO, Robert J.; LEE, Jong Wha. A new data set of educational attainment in the world, 1950–2010. **Journal of Development Economics**, [S.l.], v. 104, p.184-198, Sep. 2013.

BENHABIB, Jess; SPIEGEL, Mark M.. The role of human capital in economic development evidence from aggregate cross-country data. **Journal of Monetary Economics**, [S.l.], v. 34, n. 2, p.143-173, Oct. 1994.

BONTIS, Nick et al. The knowledge toolbox: A review of the tools available to measure and manage intangible resources. **European Management Journal**, [S.l.], v. 17, n. 4, p.391-402, Aug. 1999.

CHEN, Baizhu; FENG, Yi. Determinants of economic growth in China: Private enterprise, education, and openness. **China Economic Review**, [S.l.], v. 11, n. 1, p.1-15, Mar. 2000.

CIMOLI, Mario et al. Cambio estructural, heterogeneidad productiva y tecnología en América Latina. **Heterogeneidad Estructural, Asimetrías Tecnológicas y Crecimiento en América Latina.** Santiago, p. 9-39. nov. 2005.

CIMOLI, Mario et al. Structural change, technology, and economic growth: Brazil and the CIBS in a comparative perspective. **Economic Change and Restructuring**, [S.l.], v. 44, n. 1-2, p.25-47, 14 Aug. 2010.

COHEN, Daniel; LEKER, Laura. Health and education: another look with the proper data. **CEPR**: Discussion paper No. DP9940, [S.l.], p.1-25, Apr. 2014.

COHEN, Daniel; SOTO, Marcelo. Growth and human capital: good data, good results. **Journal of Economic Growth**, [S.l.], v. 12, n. 1, p.51-76, 27 Mar. 2007.

COHEN, Wesley M.; LEVINTHAL, Daniel A.. Absorptive Capacity: A New Perspective on Learning and Innovation. **Administrative Science Quarterly**, [S.l.], v. 35, n. 1, p.128-152, Mar. 1990.

DODARO, Santo. Comparative advantage, trade and growth: Export-Led growth revisited. **World Development**, [S.l.], v. 19, n. 9, p.1153-1165, Sep. 1991.

FEENSTRA, Robert C.; INKLAAR, Robert; TIMMER, Marcel P.. The Next Generation of the Penn World Table. **American Economic Review**, [S.l.], v. 105, n. 10, p.3150-3182, Oct. 2015.

FELIPE, Jesus et al. Product complexity and economic development. **Structural Change and Economic Dynamics**, [S.l.], v. 23, n. 1, p.36-68, Mar. 2012.

FUCHS, Thomas; WÖßMANN, Ludger. What accounts for international differences in student performance? A re-examination using PISA data. **CESifo**: Working Paper 1235, [S.l.], p.1-29, Mar. 2004.

FÖLSTER, Stefan; HENREKSON, Magnus. Growth effects of government expenditure and taxation in rich countries. **European Economic Review**, [S.l.], v. 45, n. 8, p.1501-1520, Aug. 2001.

GABRIEL, Luciano Ferreira. **CRESCIMENTO ECONÔMICO, HIATO TECNOLÓGICO, ESTRUTURA PRODUTIVA E TAXA DE CÂMBIO REAL:** ANÁLISES TEÓRICAS E EMPÍRICAS. 2016. 293 f. Tese (Doutorado) - Curso de Doutorado em Economia, Centro de Desenvolvimento e Planejamento Regional da Faculdade de Ciências Econômicas, Universidade Federal de Minas Gerais, Belo Horizonte, 2016

GOULD, David M.; RUFFIN, Roy J.. Human capital, trade, and economic growth. **Weltwirtschaftliches Archiv**, [S.l.], v. 131, n. 3, p.425-445, Sep. 1995.

GROSSMAN, Gene M.; HELPMAN, Elhanan. Technology and Trade. **NBER**: Working paper no. 4926, [S.l.], p.1-84, Nov. 1994.

HANUSHEK, Eric A.. Economic growth in developing countries: The role of human capital. **Economics of Education Review**, [S.l.], v. 37, p.204-212, Dec. 2013.

HANUSHEK, Eric A.; KIMKO, Dennis D.. Schooling, Labor-Force Quality, and the Growth of Nations. **American Economic Review**, [S.l.], v. 90, n. 5, p.1184-1208, Dec. 2000.

HAUSMANN, Ricardo et al. **THE ATLAS OF ECONOMIC COMPLEXITY:** Mapping paths to prosperity. [S.l.]: MIT Press, 2014.

HAUSMANN, Ricardo; HWANG, Jason; RODRIK, Dani. What You Export Matters. **Journal of Economic Growth**, [S.l.], v. 12, n. 1, p.1-25, Mar. 2007.

HIDALGO, César A.. The Dynamics of Economic Complexity and the Product Space over a 42 year period. **Cid Working Paper 189**: Center for International Development at Harvard University, [S.l.], p.1-19, Dec. 2009.

HIDALGO, César A.; HAUSMANN, Ricardo. The building blocks of economic complexity. **Proceedings of the National Academy of Sciences**, [S.l.], v. 106, n. 26, p.10570-10575, May 2009.

HOBDAY, Mike. East Asian latecomer firms: Learning the technology of electronics. **World Development**, [S.l.], v. 23, n. 7, p.1171-1193, Jul. 1995.

HOLSINGER, Donald B.; COWELL, Richard N.. **Positioning secondary school education in developing countries:** expansion and curriculum. Paris: IIEP Publications, 2000.

HSIAO, Cheng. **Analysis of panel data**. 3rd. ed. [S.l.]: Cambridge University Press, 2014.

HUMMELS, David; KLENOW, Peter J. The Variety and Quality of a Nation's Exports. **American Economic Review**, [S.l.], v. 95, n. 3, p.704-723, May 2005.

JAKUBOWSKI, Maciej; POKROPEK, Artur. **PISATOOLS:** Stata module to facilitate analysis of the data from the PISA OECD study. 2017. Boston College Department of Economics. Available on: <Statistical Software Components>. Accessed: 14th Nov. 2018.

JARREAU, Joachim; PONCET, Sandra. Export sophistication and economic growth: Evidence from China. **Journal of Development Economics**, [S.l.], v. 97, n. 2, p.281-292, Mar. 2012.

JONES, Charles I.; VOLLRATH, Dietrich. **Introduction to Economic Growth.** 3rd. ed. [S.l.]: W. W. Norton., 2013.

KOOPMAN, Robert; WANG, Zhi; WEI, Shang-jin. How Much of Chinese Exports is Really Made in China? Assessing Domestic Value-Added When Processing Trade is Pervasive. **NBER**: Working Paper 14109, [S.l.], p.1-49, Jun. 2008.

KRUGMAN, Paul R.. Intraindustry Specialization and the Gains from Trade. **Journal of Political Economy**, [S.l.], v. 89, n. 5, p.959-973, Oct. 1981.

LALL, Sanjaya. The Technological Structure and Performance of Developing Country Manufactured Exports, 1985-98. **Oxford Development Studies**, [S.l.], v. 28, n. 3, p.337-369, Oct. 2000.

LALL, Sanjaya; WEISS, John; ZHANG, Jinkang. The “sophistication” of exports: A new trade measure. **World Development**, [S.l.], v. 34, n. 2, p.222-237, Feb. 2006.

LEVINE, Ross; RENELT, David. A Sensitivity Analysis of Cross-Country Growth Regressions. **The American Economic Review**, [S.l.], v. 82, n. 4, p.942-963, Sep. 1992.

LICHTENBERG, Frank. R&D Investment and International Productivity Differences. **NBER**: Working paper no. 4161, [S.l.], p.1-39, Sep. 1992.

MANKIW, N. Gregory; ROMER, David; WEIL, David N.. A Contribution to the Empirics of Economic Growth. **The Quarterly Journal of Economics,** [S.l.], v. 107, n. 2, p.407-437, May 1992.

NELSON, Richard R.; PACK, Howard. The Asian Miracle and Modern Growth Theory. **The Economic Journal**, [S.l.], v. 109, n. 457, p.416-436, Jul. 1999.

NELSON, Richard R.; PHELPS, Edmund S.. Investment in Humans, Technological Diffusion, and Economic Growth. **The American Economic Review**, [S.l.], v. 56, n. 1/2, p.69-75, Mar. 1966.

PENEDER, Michael. Industrial structure and aggregate growth. **Structural Change and Economic Dynamics**, [S.l.], v. 14, n. 4, p.427-448, Dec. 2003.

PIÑERES, Sheila Amin Gutiérrez de; FERRANTINO, Michael. Export diversification and structural dynamics in the growth process: The case of Chile. **Journal of Development Economics**, [S.l.], v. 52, n. 2, p.375-391, Apr. 1997.

PRITCHETT, Lant. Divergence, Big Time. **Journal of Economic Perspectives**, [S.l.], v. 11, n. 3, p.3-17, Aug. 1997

PSACHAROPOULOS, George. Returns to investment in education: A global update. **World Development**, [S.l.], v. 22, n. 9, p.1325-1343, Sep. 1994.

RODRIK, Dani. What's So Special about China's Exports? **China & World Economy**, [S.l.], v. 14, n. 5, p.1-19, Jan. 2006.

RODRIK, Dani; SUBRAMANIAN, Arvind. From "Hindu Growth" to Productivity Surge: The Mystery of the Indian Growth Transition. **NBER**: Working Paper No. 10376, [S.l.], p.1-45, Mar. 2004.

ROMER, Paul M.. Endogenous Technological Change. **Journal of Political Economy**, [S.l.], v. 98, n. 5, Part 2, p.S71-S102, Oct. 1990.

SALA-I-MARTIN, Xavier X.. I Just Ran Four Million Regressions. **NBER:** Working Paper 6252, [S.l.], p.1-21, Nov. 1997.

SIMOES, Alexander J. G.; HIDALGO, César A.. The Economic Complexity Observatory: An Analytical Tool for Understanding the Dynamics of Economic Development. In: CONFERENCE ON ARTIFICIAL INTELLIGENCE, 25th, 2011, [S.l.]. **Workshops.** [S.l.]: AAAI, 2011. p. 39 - 42.

SOLOW, Robert M.. Technical Change and the Aggregate Production Function. **The Review of Economics and Statistics**, [S.l.], v. 39, n. 3, p.312-320, Aug. 1957.

THE ATLAS OF ECONOMIC COMPLEXITY. 2014. Disponível em: <http://atlas.cid.harvard.edu/>. Access on: 07th Nov. 2017.

THIRLWALL, A. P.. The balance of payments constraint as an explanation of international growth rate differences. **PSL Quarterly Review**, [S.l.], v. 32, n. 128, p.45-53, Oct. 1979.

TIMMER, Marcel P.; SZIRMAI, Adam. Productivity growth in Asian manufacturing: the structural bonus hypothesis examined. **Structural Change and Economic Dynamics**, [S.l.], v. 11, n. 4, p.371-392, Dec. 2000.

WU, Margaret. The role of plausible values in large-scale surveys. **Studies in Educational Evaluation**, [S.l.], v. 31, n. 2-3, p.114-128, Jan. 2005.

YANIKKAYA, Halit. Trade openness and economic growth: a cross-country empirical investigation. **Journal of Development Economics**, [S.l.], v. 72, n. 1, p.57-89, Oct. 2003.

APPENDIX A - ALTERNATIVE HUMAN CAPITAL PROXIES

TABLE 1A - ECONOMIC COMPLEXITY FROM 1996 TO 2015 (5-YEAR INTERVALS)

	ECI[a] (1)	ECI (2)	ECI (3)	ECI (4)	ECI (5)	ECI (6)
Constant	0.34123***	0.23744	0.01356	-0.08398	-0.21059	0.35263***
	(0.02681)	(0.26516)	(0.46296)	(0.18566)	(0.25876)	(0.07195)
GDP[b]	0.18108	0.02587	-0.00488	0.09167	0.10856	-0.00110
	(0.11051)	(0.15593)	(0.18170)	(0.10754)	(0.12526)	(0.15877)
R&D[c]	0.17161**	0.21169**	0.23387***	0.19036**	0.17392*	0.17203*
	(0.06704)	(0.08485)	(0.08798)	(0.07831)	(0.09408)	(0.08734)
TRA[d]	0.11965***	0.12870**	0.13753**	0.12076**	0.16641***	0.15861***
	(0.04448)	(0.05829)	(0.06458)	(0.05290)	(0.05635)	(0.05115)
GOV[e]	-0.00474	-0.02045	-0.02354	-0.06148	-0.06700	-0.01960
	(0.03256)	(0.04077)	(0.04149)	(0.03938)	(0.04652)	(0.04287)
HC[f]	0.51350***					
	(0.17132)					
PRI_G[g]		0.00158				
		(0.00253)				
PRI_N[h]			0.00432			
			(0.00518)			
SEC_G[i]				0.00638***		
				(0.00220)		
SEC_N[j]					0.00927**	
					(0.00353)	
TER[k]						0.00255
						(0.00258)
N	317	327	290	306	234	296
Adjusted-R^2	0.214	0.137	0.176	0.221	0.279	0.137

Significant at ***1%, **5%, *10%. Standard errors in parentheses. All standard errors clustered at country level.
a) ECI = the economic complexity index
b) GDP = the natural logarithm of per capita output (current US dollars)
c) R&D = the share of output spent on research and development
d) TRA = the measure of trade openness
e) GOV = the share of output spent on general government final consumption
f) HC = the human capital index in the Penn World Table 9.0
g) PRI_G = the gross enrolment rate in primary
h) PRI_N = the net enrolment rate in primary
i) SEC_G = the gross enrolment rate in secondary
j) SEC_N = the net enrolment rate in primary
k) TER = the enrolment rate in tertiary

Source: Elaborated by the authors

TABLE 2A - ECONOMETRIC TESTS OF THE ESTIMATE PRESENT IN TABLE 1A

TEST	IT CHECKS FOR	NULL HYPOTHESIS	P-VALUE (2)	P-VALUE (3)	P-VALUE (4)	P-VALUE (5)	P-VALUE (6)
Hausman test	Proper painel estimator	Random effects are proper	0.0000	0.0000	0.0000	0.0163	0.0000
Wooldridge test	Serial autocorrelation	No first-order correlation	0.0000	0.0000	0.0000	0.0000	0.0000
Modified Wald test	Groupwise heteroskedasticity	The error variance is equal for all individuals	0.0000	0.0000	0.0000	0.0000	0.0000
Fischer-type test	Stationary	All panels contain a unit root	0.0001	0.0001	0.0001	0.0001	0.0001
Pesaran test	Cross-section dependence	Error independency across cross-sections	-*	-	-	-	-

*No observations available to run the test.

Source: Elaborated by the authors

TABLE 3A – ECONOMIC COMPLEXITY FROM 1996 TO 2015 (5-YEAR INTERVALS)

	ECI[a] (1)	ECI (2)	ECI (3)	ECI (4)	ECI (5)	ECI (6)
Constant	0.34123*** (0.02681)	0.23593*** (0.03691)	0.45353*** (0.05734)	0.42723*** (0.05322)	0.42565* (0.23359)	-1.35875 (.)
GDP[b]	0.18108 (0.11051)	0.33712*** (0.09192)	0.30769*** (0.09561)	0.31774*** (0.09347)	0.31295*** (0.09513)	0.34832 (.)
R&D[c]	0.17161** (0.06704)	0.11028* (0.06381)	0.08522 (0.06701)	0.10851 (0.06838)	0.09856 (0.06858)	0.09512 (.)
TRA[d]	0.11965*** (0.04448)	0.04649 (0.03766)	0.05556 (0.03919)	0.04195 (0.04220)	0.04666 (0.04048)	0.06150 (.)
GOV[e]	-0.00474 (0.03256)	-0.02445 (0.03285)	-0.01676 (0.03198)	-0.01795 (0.03236)	-0.01757 (0.03222)	-0.03577 (.)
HC[f]	0.51350*** (0.17132)					
PER_PRI[g]		0.00854*** (0.00189)				
PER_SEC[h]			-0.00260 (0.00217)			
PER_TER[i]				-0.00442 (0.00513)		
AVE_YEAR[j]					-0.00490 (0.02809)	
EDU[k]						0.21443 (.)
N	317	231	231	231	231	109
Adjusted-R^2	0.214	0.181	0.116	0.111	0.105	0.311

Significant at ***1%, **5%, *10%. Standard errors in parentheses. All standard errors clustered at country level.
a) ECI = the economic complexity index
b) GDP = the natural logarithm of lagged per capita output (current US dollars)
c) R&D = the share of output spent on research and development
d) TRA = the measure of trade openness
e) GOV = the share of output spent on general government final consumption
f) HC = the human capital index in the Penn World Table 9.0
g) PER_PRI = the percentage of population age 25 or more with completed primary schooling
h) PER_SEC = the percentage of population age 25 or more with completed secondary schooling
i) PER_TER = the percentage of population age 25 or more with completed tertiary schooling
j) AVE_YEAR =the average years of total schooling among people over age 25
k) EDU = the human capital index elaborated by Cohen and Soto (2007)

Source: Elaborated by the authors

TABLE 4A - ECONOMETRIC TESTS OF THE ESTIMATE PRESENT IN TABLE 3A

TEST	**IT CHECKS FOR**	**NULL HYPOTHESIS**	**P-VALUE (2)**	**P-VALUE (3)**	**P-VALUE (4)**	**P-VALUE (5)**	**P-VALUE (6)**
Hausman test	Proper painel estimator	Random effects are proper	0.0000	0.0000	0.0001	0.0003	0.1136
Wooldridge test	Serial autocorrelation	No first-order correlation	0.0001	0.0000	0.0000	0.0000	-*
Modified Wald test	Groupwise heteroskedasticity	The error variance is equal for all individuals	0.0000	0.0000	0.0000	0.0000	-
Fischer-type test	Stationary	All panels contain a unit root	0.0001	0.0001	0.0001	0.0001	0.0001
Pesaran test	Cross-section dependence	Error independency across cross-sections	-	-	-	-	-

*No observations available to run the test.

Source: Elaborated by the authors

TABLE 5A – ECONOMIC COMPLEXITY FROM 1996 TO 2015 (5-YEAR INTERVALS)

	ECI[a] (1)	ECI (2)	ECI (3)	ECI (4)
Constant	0.34123*** (0.02681)	-0.03329 (0.39620)	-0.16459 (0.25217)	0.36820*** (0.07096)
GDP[b]	0.18108 (0.11051)	-0.04681 (0.17865)	0.10135 (0.12763)	-0.04467 (0.15949)
R&D[c]	0.17161** (0.06704)	0.25219*** (0.09045)	0.17944* (0.09391)	0.15074* (0.08374)
TRA[d]	0.11965*** (0.04448)	0.13768** (0.06791)	0.17596*** (0.05472)	0.15618*** (0.05316)
GOV[e]	-0.00474 (0.03256)	-0.04229 (0.04205)	-0.07131 (0.04743)	-0.02446 (0.04360)
HC[f]	0.51350*** (0.17132)			
PRI_F[g]		0.00479 (0.00453)		
SEC_F[h]			0.00839** (0.00339)	
TER_F[i]				0.00232 (0.00235)
N	317	275	230	287
Adjusted-R^2	0.214	0.206	0.291	0.133

Significant at ***1%, **5%, *10%. Standard errors in parentheses. All standard errors clustered at country level.
a) ECI = the economic complexity index
b) GDP = the natural logarithm of lagged per capita output (current US dollars)
c) R&D = the share of output spent on research and development
d) TRA = the measure of trade openness
e) GOV = the share of output spent on general government final consumption
f) HC = the human capital index in the Penn World Table 9.0
g) PRI_F = the net enrolment rate in primary among female
h) SEC_F = the net enrolment rate in secondary among female
i) TER_F = the enrolment rate in tertiary among female

Source: Elaborated by the authors

TABLE 6A - ECONOMETRIC TESTS OF THE ESTIMATE PRESENT IN TABLE 5A

TEST	IT CHECKS FOR	NULL HYPOTHESIS	P-VALUE (2)	P-VALUE (3)	P-VALUE (4)
Hausman test	Proper painel estimator	Random effects are proper	0.0001	0.0091	0.0001
Wooldridge test	Serial autocorrelation	No first-order correlation	0.0000	0.0000	0.0000
Modified Wald test	Groupwise heteroskedasticity	The error variance is equal for all individuals	0.0000	0.0000	0.0000
Fischer-type test	Stationary	All panels contain a unit root	0.0001	0.0001	0.0001
Pesaran test	Cross-section dependence	Error independency across cross-sections	-*	-	-

*No observations available to run the test.

Source: Elaborated by the authors

TABLE 7A – ECONOMIC COMPLEXITY FROM 1996 TO 2015 (5-YEAR INTERVALS)

	ECI[a] (1)	ECI (2)	ECI (3)	ECI (4)	ECI (5)
Constant	0.34123*** (0.02681)	0.24195*** (0.03560)	0.43997*** (0.05475)	0.43073*** (0.04804)	0.43079** (0.21530)
GDP[b]	0.18108 (0.11051)	0.32934*** (0.09110)	0.30663*** (0.09575)	0.32195*** (0.09284)	0.31297*** (0.09513)
R&D[c]	0.17161** (0.06704)	0.10782* (0.06416)	0.08658 (0.06809)	0.11053 (0.06903)	0.09844 (0.06867)
TRA[d]	0.11965*** (0.04448)	0.04643 (0.03796)	0.05407 (0.03935)	0.04138 (0.04229)	0.04652 (0.04043)
GOV[e]	-0.00474 (0.03256)	-0.02677 (0.03268)	-0.01762 (0.03183)	-0.01873 (0.03247)	-0.01788 (0.03210)
HC[f]	0.51350*** (0.17132)				
PER_PRI_F[g]		0.00818*** (0.00187)			
PER_SEC_F[h]			-0.00225 (0.00221)		
PER_TER_F[i]				-0.00543 (0.00514)	
AVE_YEAR_F[j]					-0.00581 (0.02721)
N	317	231	231	231	231
Adjusted-R²	0.214	0.187	0.113	0.114	0.105

Significant at ***1%, **5%, *10%. Standard errors in parentheses. All standard errors clustered at country level.
a) ECI = the economic complexity index
b) GDP = the natural logarithm of lagged per capita output (current US dollars)
c) R&D = the share of output spent on research and development
d) TRA = the measure of trade openness
e) GOV = the share of output spent on general government final consumption
f) HC = the human capital index in the Penn World Table 9.0
g) PER_PRI_F = the percentage of female population age 25 or more with completed primary schooling
h) PER_SEC_F = the percentage of female population age 25 or more with completed secondary schooling
i) PER_TER_F = the percentage of female population age 25 or more with completed tertiary schooling
j) AVE_YEAR_F = the average years of total schooling among female over age 25

Source: Elaborated by the authors

TABLE 8A - ECONOMETRIC TESTS OF THE ESTIMATE PRESENT IN TABLE 7A

TEST	IT CHECKS FOR	NULL HYPOTHESIS	P-VALUE (2)	P-VALUE (3)	P-VALUE (4)	P-VALUE (5)
Hausman test	Proper painel estimator	Random effects are proper	0.0000	0.0000	0.0001	0.0004
Wooldridge test	Serial autocorrelation	No first-order correlation	0.0002	0.0000	0.0000	0.0000
Modified Wald test	Groupwise heteroskedasticity	The error variance is equal for all individuals	0.0000	0.0000	0.0000	0.0000
Fischer-type test	Stationary	All panels contain a unit root	0.0001	0.0001	0.0001	0.0001
Pesaran test	Cross-section dependence	Error independency across cross-sections	-	-	-	-

*No observations available to run the test.

Source: Elaborated by the authors

TABLE 9A – ECONOMIC COMPLEXITY FROM 1996 TO 2015 (5-YEAR INTERVALS)

	ECI[a] (1)	ECI (2)	ECI (3)	ECI (4)
Constant	0.34123*** (0.02681)	0.38234 (0.49630)	-0.06940 (0.27506)	0.35757*** (0.07098)
GDP[b]	0.18108 (0.11051)	-0.02551 (0.17084)	0.10008 (0.12792)	-0.04522 (0.15704)
R&D[c]	0.17161** (0.06704)	0.25174*** (0.08945)	0.17434* (0.09297)	0.15484* (0.08512)
TRA[d]	0.11965*** (0.04448)	0.14096** (0.06741)	0.17398*** (0.05364)	0.15460*** (0.05208)
GOV[e]	-0.00474 (0.03256)	-0.03666 (0.04231)	-0.06619 (0.04605)	-0.02607 (0.04242)
HC[f]	0.51350*** (0.17132)			
PRI_M[g]		0.00021 (0.00547)		
SEC_M[h]			0.00730* (0.00375)	
TER_M[i]				0.00302 (0.00275)
N	317	275	230	287
Adjusted-R^2	0.214	0.199	0.276	0.134

Significant at ***1%, **5%, *10%. Standard errors in parentheses. All standard errors clustered at country level.
a) ECI = the economic complexity index
b) GDP = the natural logarithm of lagged per capita output (current US dollars)
c) R&D = the share of output spent on research and development
d) TRA = the measure of trade openness
e) GOV = the share of output spent on general government final consumption
f) HC = the human capital index in the Penn World Table 9.0
g) PRI_M = net enrolment rate in primary among male
h) SEC_M = net enrolment rate in secondary among male
i) TER_M = enrolment rate in tertiary among male

Source: Elaborated by the authors

TABLE 10A - ECONOMETRIC TESTS OF THE ESTIMATE PRESENT IN TABLE 9A

TEST	IT CHECKS FOR	NULL HYPOTHESIS	P-VALUE (2)	P-VALUE (3)	P-VALUE (4)
Hausman test	Proper painel estimator	Random effects are proper	0.0000	0.0113	0.0001
Wooldridge test	Serial autocorrelation	No first-order correlation	0.0000	0.0000	0.0000
Modified Wald test	Groupwise heteroskedasticity	The error variance is equal for all individuals	0.0000	0.0000	0.0000
Fischer-type test	Stationary	All panels contain a unit root	0.0001	0.0001	0.0001
Pesaran test	Cross-section dependence	Error independency across cross-sections	-*	-	-

*No observations available to run the test.

Source: Elaborated by the authors

APPENDIX B - ALTERNATIVE COUNTRY SAMPLES

TABLE 1B – ECONOMIC COMPLEXITY FROM 1996 TO 2015 (5-YEAR INTERVALS)

	ECI[a,b] (1)	ECI[c] (2)	ECI[d] (3)	ECI[e] (4)	ECI[f] (5)
Constant	0.34123***	0.38027***	0.18333*	0.32618***	0.37460***
	(0.02681)	(0.02835)	(0.09398)	(0.03883)	(0.03696)
GDP[g]	0.18108	0.20145*	0.13990	0.20730	0.19008*
	(0.11051)	(0.11679)	(0.17464)	(0.13297)	(0.11366)
R&D[h]	0.17161**	0.06405	0.24372***	0.17289**	0.19316***
	(0.06704)	(0.05568)	(0.08939)	(0.06909)	(0.07261)
TRA[i]	0.11965***	0.13423**	0.11215**	0.10471**	0.12504**
	(0.04448)	(0.05772)	(0.04716)	(0.05243)	(0.04748)
GOV[j]	-0.00474	-0.03622	0.02724	0.00096	-0.01477
	(0.03256)	(0.03172)	(0.04191)	(0.03568)	(0.04078)
HC[k]	0.51350***	0.25819	0.35398	0.68272***	0.46710**
	(0.17132)	(0.22686)	(0.21758)	(0.13855)	(0.19477)
N	317	265	186	262	288
Adjusted-R^2	0.214	0.227	0.161	0.239	0.224

Significant at ***1%, **5%, *10%. Standard errors in parentheses. All standard errors clustered at country level.
a) ECI = the economic complexity index
b) For this estimate we took the full sample into account
c) For this estimate we took the full sample into account excepting the countries of East Asia and Pacific
d) For this estimate we took the full sample into account excepting the countries of Europe and Central Asia
e) For this estimate we took the full sample into account excepting the countries of Latin America and Caribbean
f) For this estimate we took the full sample into account excepting the countries of Middle East and North Africa
g) GDP = the natural logarithm of lagged per capita output (current US dollars)
h) R&D = the share of output spent on research and development
i) TRA = the measure of trade openness
j) GOV = the share of output spent on general government final consumption
k) HC = the human capital index in the Penn World Table 9.0

Source: Elaborated by the authors

TABLE 2B - ECONOMETRIC TESTS OF THE ESTIMATE PRESENT IN TABLE 1B

TEST	IT CHECKS FOR	NULL HYPOTHESIS	P-VALUE (2)	P-VALUE (3)	P-VALUE (4)	P-VALUE (5)
Hausman test	Proper painel estimator	Random effects are proper	0.0005	0.5061	0.0886	0.0846
Wooldridge test	Serial autocorrelation	No first-order correlation	0.0000	0.0000	0.0000	0.0000
Modified Wald test	Groupwise heteroskedasticity	The error variance is equal for all individuals	0.0000	0.0000	0.0000	0.0000
Fischer-type test	Stationary	All panels contain a unit root	0.0000	0.0029	0.0002	0.0003
Pesaran test	Cross-section dependence	Error independency across cross-sections	-*	-	-	-

*No observations available to run the test.

Source: Elaborated by the authors

TABLE 3B – ECONOMIC COMPLEXITY FROM 1996 TO 2015 (5-YEAR INTERVALS)

	ECI[a,b] (1)	ECI[c] (2)	ECI[d] (3)	ECI[e] (4)
Constant	0.34123***	0.34359***	0.33649***	0.32773***
	(0.02681)	(0.02341)	(0.03315)	(0.05065)
GDP[f]	0.18108	0.17073	0.17290	0.19830*
	(0.11051)	(0.11191)	(0.10934)	(0.10647)
R&D[g]	0.17161**	0.16676**	0.18226***	0.18636***
	(0.06704)	(0.06837)	(0.06600)	(0.06466)
TRA[h]	0.11965***	0.11739**	0.13534***	0.11300**
	(0.04448)	(0.04513)	(0.04034)	(0.04583)
GOV[i]	-0.00474	-0.00514	0.00266	-0.00556
	(0.03256)	(0.03255)	(0.03424)	(0.03401)
HC[j]	0.51350***	0.49384***	0.57198***	0.61900***
	(0.17132)	(0.17285)	(0.16833)	(0.17826)
N	317	309	305	287
Adjusted-R^2	0.214	0.195	0.239	0.272

Significant at ***1%, **5%, *10%. Standard errors in parentheses. All standard errors clustered at country level.
a) ECI = the economic complexity index
b) For this estimate we took the full sample into account
c) For this estimate we took the full sample into account excepting the countries of North America
d) For this estimate we took the full sample into account excepting the countries of South Asia
e) For this estimate we took the full sample into account excepting for countries of Sub-Saharan Africa
f) GDP = the natural logarithm of lagged per capita output (current US dollars)
g) R&D = the share of output spent on research and development
h) TRA = the measure of trade openness
i) GOV = the share of output spent on general government final consumption
j) HC = the human capital index in the Penn World Table 9.0

Source: Elaborated by the authors

TABLE 4B - ECONOMETRIC TESTS OF THE ESTIMATE PRESENT IN TABLE 3B

TEST	IT CHECKS FOR	NULL HYPOTHESIS	P-VALUE (2)	P-VALUE (3)	P-VALUE (4)
Hausman test	Proper painel estimator	Random effects are proper	0.0659	0.0991	0.0093
Wooldridge test	Serial autocorrelation	No first-order correlation	0.0000	0.0000	0.0000
Modified Wald test	Groupwise heteroskedasticity	The error variance is equal for all individuals	0.0000	0.0000	0.0000
Fischer-type test	Stationary	All panels contain a unit root	0.0001	0.0002	0.0026
Pesaran test	Cross-section dependence	Error independency across cross-sections	-*	-	-

*No observations available to run the test.

Source: Elaborated by the authors

APPENDIX C - ALTERNATIVE PISA SAMPLE

TABLE 1C – ECONOMIC COMPLEXITY BETWEEN 1996 AND 2015 WITH PISA[a] DATA (5-YEAR INTERVAL)

	ECI[b] (1)	ECI (2)	ECI (3)	ECI (4)	ECI (5)
Constant	1.17010*** (0.05673)	0.41980 (0.51254)	0.36371 (0.59887)	0.13409 (0.68413)	0.12628 (0.70847)
GDP[c]	0.11327 (0.06866)	0.10569 (0.07176)	0.10578 (0.07259)	0.10640 (0.07399)	0.10938 (0.07431)
HC[d]	0.46505** (0.20096)	0.43896** (0.20560)	0.43635** (0.20558)	0.42802** (0.20260)	0.42598** (0.20167)
R&D[e]	0.19422** (0.08517)	0.17972** (0.08349)	0.17300** (0.08113)	0.16472** (0.07848)	0.16453** (0.07839)
TRA[f]	0.25612*** (0.05084)	0.24947*** (0.05132)	0.24383*** (0.04978)	0.23625*** (0.04775)	0.23397*** (0.04693)
GOV[g]	0.03259 (0.08295)	0.04738 (0.08447)	0.04114 (0.08387)	0.04077 (0.08347)	0.03961 (0.08306)
PISA average score		0.00155 (0.00102)			
PISA 75th percentile score			0.00146 (0.00106)		
PISA 90th percentile score				0.00171 (0.00111)	
PISA 95th percentile score					0.00165 (0.00110)
N	175	175	175	175	175
Adjusted-R²	0.443	0.449	0.449	0.453	0.453

Significant at ***1%, **5%, *10%. Standard errors in parentheses. All standard errors clustered at country level.
a) PISA = Programme for International Student Assessment of the years 2000, 2003, 2009 and 2012
b) ECI = the economic complexity index
c) GDP = the natural logarithm of lagged per capita output (current US dollars)
d) HC = the human capital index in the Penn World Table 9.0
e) R&D = the share of output spent on research and development
f) TRA = the measure of trade openness
g) GOV = the share of output spent on general government final consumption

Source: Elaborated by the authors

TABLE 2C - ECONOMETRIC TESTS OF THE ESTIMATE PRESENT IN TABLE 1C

TEST	IT CHECKS FOR	NULL HYPOTHESIS	P-VALUE (1)	P-VALUE (2)	P-VALUE (3)	P-VALUE (4)	P-VALUE (5)
Hausman test	Proper painel estimator	Random effects are proper	0.0008	0.0023	0.0024	0.0026	0.0029
Wooldridge test	Serial autocorrelation	No first-order correlation	0.0000	0.0000	0.0000	0.0000	0.0000
Modified Wald test	Groupwise heteroskedasticity	The error variance is equal for all individuals	0.0000	0.0000	0.0000	0.0000	0.0000
Fischer-type test	Stationary	All panels contain a unit root	-*	-	-	-	-
Pesaran test	Cross-section dependence	Error independency across cross-sections	-	-	-	-	-

*No observations available to run the test.

Source: Elaborated by the authors

APPENDIX D - ECONOMIC COMPLEXITY INDEXES

TABLE 1D – THE ECONOMIC COMPLEXITY INDEX FOR SOME BRAZILIAN MUNICIPALITIES IN 2015

Municipality	ECI	Ranking
São Paulo - SP	30.603	1
São Bernardo do Campo - SP	9.215	2
Manaus - AM	8.585	3
São José Dos Campos - SP	7.287	4
Guarulhos - SP	6.997	5
Barueri - SP	6.91	6
Campinas - SP	6.751	7
Sorocaba - SP	6.62	8
Suzano - SP	6.305	9
Diadema - SP	6.08	10
Louveira - SP	-0.0328	336
Rancharia - SP	-0.0329	337
Crissiumal - RS	-0.0333	338
Paranaíba - MS	-0.0334	339
Toledo - PR	-0.034	340
Almirante Tamandaré - PR	-0.0344	341
Alfenas - MG	-0.0353	342
Jandaia do Sul - PR	-0.0355	343
Paranatinga - MT	-0.0355	344
Mamanguape - PB	-0.0366	345
Paranaguá - PR	-2.91	670
Guajará-Mirim - RO	-3.532	671
Petrolina - PE	-3.562	672
Castanhal - PA	-3.622	673
Ilhéus - BA	-4.208	674
Fortaleza - CE	-4.35	675
Corumbá - MS	-5.735	676
Blumenau - SC	-6.00213	677
Itajaí - SC	-6.207	678
Belém - PA	-6.245	679

Source: dataviva.info

TABLE 2D – THE ECONOMIC COMPLEXITY INDEX FOR SOME NATIONS IN 2016

COUNTRY	ECI	Ranking
Japan	2.22938	1
Switzerland	2.05440	2
Germany	1.95551	3
South Korea	1.79864	4
Sweden	1.75485	5
Singapore	1.71625	6
Austria	1.61209	7
United Kingdom	1.59265	8
United States	1.58101	9
Czech Republic	1.57717	10
Jordan	0.06871	59
Trinidad and Tobago	0.00787	60
Colombia	-0.00253	61
Oman	-0.00356	62
South Africa	-0.02925	63
Kyrgyzstan	-0.04614	64
Egypt	-0.07027	65
Qatar	-0.13160	66
Georgia	-0.13684	67
Kazakhstan	-0.14057	68
Sudan	-1.43747	117
Yemen	-1.46949	118
Cote d'Ivoire	-1.51738	119
Nigeria	-1.54415	120
Mauritania	-1.59462	121
Mozambique	-1.61157	122
Malawi	-1.64990	123
Cameroon	-1.65947	124
Papua New Guinea	-1.74395	125
Guinea	-1.98580	126

Source: Simoes and Hidalgo (2011)