DEYVID WILLIAM LEITE

THE EFFECTS OF HUMAN CAPITAL AND PRIVATE INVESTMENT IN TECHNOLOGY ON ECONOMIC STRUCTURE

Thesis submitted to the Applied Economics Graduate Program of the Universidade Federal de Viçosa in partial fulfillment of the requirements for the degree of *Doctor Scientiae*.

Adviser: Leonardo Chaves Borges Cardoso

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ABSTRACT

LEITE, Deyvid William, D.Sc., Universidade Federal de Viçosa, September, 2023. **The effects of human capital and private investment in technology on economic structure.** Adviser: Leonardo Chaves Borges Cardoso.

It is well known that economic structure is linked to human capital, private investment in technology and income growth. Even though disentangling how this relationship happens is crucial for policy screening, this still needs a better understanding. We shed light on this debate by analyzing economic structure in two investigations. The first investigation is on the effect of human capital on economic structure. I exploit a significant expansion in the Brazilian federal network of technological and professional education since 2002 as an instrument for human capital. Data are on human capital for Brazilian micro-regions from 2003 to 2015. Results indicated that higher levels of economic structure are associated with a larger stock of human capital. The second investigation studies the effect of private investment in technology on economic structure. A federal law fostering private investment in research and development is used as an instrument for investment in technology. Data are on investment in technology for Brazilian municipalities from 2002 to 2016. Results showed the federal law was effective and private investment in technology has a positive and significant effect on economic structure. We concluded human capital and investment in technology should be promoted due to their effect on economic structure.

Keywords: Economic structure. Human capital. Technological education. Investment in technology. Economic complexity.

RESUMO

LEITE, Deyvid William, D.Sc., Universidade Federal de Viçosa, setembro de 2023. **Os efeitos do capital humano e do investimento privado em tecnologia na estrutura econômica.** Orientador: Leonardo Chaves Borges Cardoso.

Sabe-se que a estrutura econômica está ligada ao capital humano, ao investimento privado em tecnologia e ao crescimento da renda. Embora desvendar como essa relação acontece seja crucial para a triagem de políticas, isso ainda precisa de um melhor entendimento. Lança-se luz sobre esse debate analisando a estrutura econômica em duas investigações. A primeira investigação é sobre o efeito do capital humano na estrutura econômica. Explora-se uma significativa expansão da rede federal brasileira de educação tecnológica e profissional desde 2002 como instrumento de capital humano. Os dados são de capital humano para as microrregiões brasileiras de 2003 a 2015. Os resultados indicaram que níveis mais elevados de estrutura econômica estão associados a um maior estoque de capital humano. A segunda investigação estuda o efeito do investimento privado em tecnologia na estrutura econômica. Uma lei federal de fomento ao investimento privado em pesquisa e desenvolvimento é utilizada como instrumento para o investimento em tecnologia. Os dados são de investimento em tecnologia para os municípios brasileiros de 2002 a 2016. Os resultados mostraram que a lei federal foi eficaz e o investimento privado em tecnologia tem um efeito positivo e significativo na estrutura econômica. A conclusão é de que o capital humano e o investimento em tecnologia devem ser promovidos devido ao seu efeito na estrutura econômica.

Palavras-chave: Estrutura econômica. Capital humano. Educação tecnológica. Investimento em tecnologia. Complexidade econômica.

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SUMMARY

1 GENERAL INTRODUCTION

Florida et al. (2008) said that if you ask a typical person on the street about what drives economic development, "they will tell you the key is jobs". In this sense, business attraction programs routinely offer fiscal incentives for companies. As a result, states and nations find themselves at war, where tax exemptions, lower tax rates, and larger subsidies are the most used tools (Buss, 2001). An alternative way to attract and create new jobs is to improve the business environment providing better access to finance and infrastructure, fewer business regulations, lower levels of corruption, more innovation, and a better workforce.

About this last, there is a large body of research relating human capital to economic performance, e.g., Barro (1991), Mankiw et al. (1992), and Čadil et al. (2014) to cite a few from a very long list. There are also several papers relating human capital and economic structure, e.g., Rodrik (2006), Hausmann et al. (2007) and Hausmann et al. (2014). The correlation between these variables is undeniable; more human capital is correlated with growth and more diversified economic structure. Moreover, presenting a large stock of human capital may generate upgrades in economic structure as well as the other way around. It might come from the benefits associated with either more human capital, better economic structure or both of them. Hence, possible reversal causality and other issues might lead to endogeneity, pushing the results away from causality in cross-country analysis.

On the other hand, there is a vast literature relating innovation to economic performance (Solow, 1957; Kaldor, 1957; Romer, 1990; Jones, 1995). There is also some papers associating technology with economic structure, e.g., Lall (2000), Montobbio and Rampa (2005) and Castaldi et al. (2015). Investment in technology enhances economic structure, which in turn can require the spread of productive knowledge to maintain its improving pace. Moreover, Crescenzi and Rodríguez-Pose (2013) argued research and development (R&D), socioeconomic features and geographical characteristics play an important role in innovation. They also stated regional policies may have some effects on knowledge and innovation development.

In Brazil, the public debate is guided by the idea a low human capital base constrains the country's development. Consequently, it motivates attempts to raise workforce skills, believing this better business environment attracts schooling-intensive industries, better-paid jobs, output diversity, and other positive externalities (Psacharopoulos and Arriagada, 1989). Moreover, De Oliveira et al. (2021) highlighted the relation between better business environment and high-skilled workforce, stating high-skilled workers are attracted by regions with improved economic structure. In fact, all of these are the *ex-ante* justifications for public investment.

This investigation measures at least one of these expected outputs, observing how local economic structure changes after improvements in two fundamental variables: schooling investment and private investment in technology. Given that, I propose two papers to investigate economic structure at the sub-national level. These papers take into consideration human capital and private investment in technology as drivers of economic structure at the micro-regional and the municipal levels, respectively.

The first article examines the effect of human capital on economic structure at the micro-regional level. An improvement in human capital is supposed to attract firms to the micro-region, expand the existing firms or even create new firms in the region. Thereby, these new or existing firms would employ the larger stock of human capital in

producing new or enhanced products, indicating better economic structure. However, one would say there is a bi-causality between human capital and economic structure or only a correlation. Hence, the use of an exogenous variation in human capital would bypass the bi-causality or correlation issues and present the effect of human capital on economic structure. Thus, the identification strategy is to exploit the expansion of the Brazilian federal network of technological and professional education as an exogenous variation in human capital.

Results of the first article suggested human capital influences economic structure. The proxy for human capital is total labor force working on manufacturing industry and it showed a positive and significant effect on economic structure. The expansion of the Brazilian federal network of technological and professional education presented an effect on human capital, indicating the instrument should be effective.

The second paper concentrates on the effect of private investment in technology on economic structure at the municipal level. An increase in private investment in technology is supposed to boost innovation and firms' output. So, innovation would expand and upgrade firms' output yielding improved economic structure. Nevertheless, private investment in technology and economic structure might cause each other or be only correlated. In these cases using an exogenous variation in private investment in technology would deal with bi-causality and correlation matters, showing the effect of private investment in technology on economic structure. Thus, the identification strategy is to use the approval of the Law No. 11.196/2005, known as *"Lei do Bem"* (the Good Law, in English) as an exogenous variation in private investment in technology.

The outcomes of the second paper indicated private investment in technology determines economic structure. The measure of private investment in technology is total labor force working on research and development area. The approval of the Good Law exhibited an effect on private investment in technology, which stands for the effectiveness of the instrument.

These studies contribute to the literature as they pursue the economic structure determinants, given that better economic structure indicates income growth. Human capital and private investment in technology are set as relevant factors in that relation, shocks in them are used to approach the effect of both on economic structure. Moreover, it is important mentioning that economic structure is explored at both the micro-regional and the municipal levels. Besides, these investigations make *ex-post* evaluations of considerable public investment in both human capital and private investment in technology.

2 THE EFFECT OF HUMAN CAPITAL ON ECONOMIC STRUCTURE

2.1 Introduction

It is widely accepted that human capital is connected with income growth. However, the manner this relationship takes place does not have a unique explanation. Economists diverge in the direction, intensity, and timing of such relation. Here I aim to shed some light on this debate by analyzing the effect of human capital on economic structure. As economic structure I mean what an economy is able to produce. That notion is a little subjective, so I use the concept of economic complexity (Hidalgo et al., 2007; Hidalgo, 2009; Hausmann et al., 2014). Hidalgo and Hausmann (2009) stated that higher levels of economic complexity are associated with higher levels of per capita income. Hence, a more complex economy presenting low per capita income tends to grow faster to be consistent with its economic complexity level. On the other hand, a less complex economy with high per capita income is likely to have diminishing growth to be compatible with its economic complexity level. They suppose those relationship especially when comparing economies presenting similar per capita income.

Romer (1990), Nelson and Pack (1999) and Cimoli (2005) affirmed human capital has a positive effect on income. However, they diverge in the size of the effect of human capital on income growth. They also take into consideration technology, which presents the need for high-skilled worker that can understand and generate technical progress. Furthermore, Zhu and Li (2017) stated human capital is the most important factor associated with economic structure.

According to Rodrik (2014), there are two keys for economic growth, improved human capital with good institutions; and the transition from a lower-productivity sectors to higher-productivity ones, the structural change. He also states these two keys for economic growth might not take place simultaneously, but both of them are required in the process of sustainable growth. Moreover, the structural change may start without the accumulation of human capital and better institutions. However, the improvement in human capital and institutions plays an important role in boosting and maintaining the structural change.

Relating human capital to economic structure brings up an important issue, the similarity in their levels. As similarity, I mean economies with larger stocks of human capital tend to present better economic structures, while economies with smaller stocks of human capital are likely to have worse economic structures. So, a naive comparison would occur because there is a third factor affecting both variables or due to they influence each other. Hence, in this setting, one manner of identifying the causal linkage between those variables is to find a variation that is exogenous to human capital and not related to any other factor that influences economic structure. Thus, an exogenous variation in human capital would alter economic structure, showing the clear effect of the former on the latter.

In this strand, I highlight the expansion of the Brazilian federal network of technological and professional education since 2005. This network grew from 155 units in 2005 to 646 in 2021 and reached all the states in Brazil. In relative terms, in 2005 only 19% of the micro-regions had at least one unit of this network of education, while in

2021 that number went to 70% of the micro-regions[1].

Additionally, that expansion occurred through the creation or redesign of certain types of institutions. They are the federal centers of technological education (Centros Federais de Educação Tecnológica - CEFETs); the technical and agricultural schools linked to federal universities; a primary and secondary school named Colégio Pedro II; the federal technology university of Paraná state (Universidade Tecnológica Federal do Paraná - UTFPR), and the institutes of education, science and technology (Institutos Federais de Educação, Ciência e Tecnologia - IFs). These institutions are organized in units, known as *campus* or advanced *campus*. The major part of the expansion occurred by an increase in the quantity of institutes of education, science and technology. Thus, I henceforth use two terms: "IFs" to refer to all types of institutions, and "new IF" to refer to a new unit of these institutions.

The increase in the quantity of places in IFs may have played an important role in shaping human capital. According to Duflo (2001), large government-administered programs of investing in education may yield significant effects on human capital. Moreover, I take into consideration that expansion because it aimed to spread professional and technological education throughout Brazil, rising the stock of human capital. Then, I ask whether the rise in the stock of human capital influences economic structure at the micro-regional level.

The concept of economic complexity uses the diversity and ubiquity of exports to infer export sophistication, which indicates economic structure. It presents relevant progress related to objectivity and comparability and it can be measured at different levels. Furthermore, Hidalgo and Hausmann (2009) affirm economic complexity is an important predictor of income growth.

This investigation aims to expand the knowledge of economic structure by verifying whether there is an effect of human capital on economic structure in Brazilian micro-regions. That is because human capital tends to be unevenly distributed and locally bound (Audretsch and Feldman, 1996; Andersson and Johansson, 2010), which favors a micro-regional approach. A national or state level analysis could not capture the effect of a new IF on human capital. That is the reason why the analysis is based on micro-regions. Typically, a micro-region is a group of few municipalities that are close and connected to each other[2]. There are 558 micro-regions in Brazil and I aim to use all the micro-regions that have data available.

The hypothesis is that the quantity of places in IFs is associated with human capital, while human capital influences economic structure. Hence, a rise in the quantity of places in IFs will increase the stock of human capital, which in turn will improve economic structure.

Results of the first article indicates human capital determines economic structure. The measure of human capital is total labor force working on manufacturing industry and it showed a positive and significant effect on economic structure. The expansion of the IFs presented an effect on human capital, indicating the instrument should be effective.

In addition to this introduction, this paper has been divided into four more sections. The second section presents the framework. The third section describes the identifica-

[1] Figure 3 displays that expansion.

[2] We use the location division provided by Instituto Brasileiro de Geografia e Estatística (1990), which is briefly: a state is divided into meso-regions; a meso-region is separated into micro-regions; and a micro-region is divided into municipalities.

tion strategy, giving some background of the expansion of IFs in the last two decades. Moreover, the third section also brings the database. The fourth section shows the results, providing an analysis of the relation between human capital and economic structure. The fifth section presents the conclusion of the investigation, offering a few remarks on the subject discussed.

2.2 Theoretical Background

We analyze the relation between economic structure and human capital at the micro-regional level in four subsections. In the first subsection, I present the notion of economic structure. In the second subsection, I expose the topic of human capital. In the third subsection, I relate economic structure and human capital at the micro-regional level and how this relationship works in Brazil. In the fourth subsection, I associate theoretically economic structure with human capital and other variables analyzing the relevance of each variable.

2.2.1 Economic structure

In theoretical terms, economic complexity is the total amount of productive knowledge an economy holds and how it uses the set of capabilities available. A capability is the ability to use a specific knowledge for doing something. In the process of expanding complexity, economies get new capabilities. These new capabilities tend to be akin to the already-available ones. In this strand, a larger stock of human capital may facilitate the process of increasing economic complexity by speeding up the acquisition of new capabilities.

A more complex economy has more capabilities, so that it can produce a wider set of goods and goods that few others can. For example, an economy producing bananas, steel bars and x-ray devices may have more capabilities than a similar economy producing only bananas and steel bars. The difference in capabilities is reflected by the quantity of produced goods and the difficulty associated with producing each good. Furthermore, economic complexity is based on both the diversity and the ubiquity of exported goods, as well as the level of connectedness among products.

Ubiquity is related to in how many places a product can be found. The more ubiquitous a product is, the larger the possibility to find it everywhere. For instance, chemical products are less ubiquitous than plastic products, while plastic products are less ubiquitous than vegetables products. The ubiquity level tells us how hard it is to produce and export a product.

Diversity indicates how many different goods an economy can deliver. A diversified economy should have mastered a large set of capabilities in order to produce a wide variety of products. For example, Sweden's exports have a level of diversity larger than New Zealand's, whilst New Zealand's exports are more diversified than Bolivia's. The diversity level provides information on the quantity of capabilities an economy has.

These two abilities can be viewed in a matrix that considers the revealed comparative advantage (RCA). According to Balassa (1965), RCA is a measure of the relevance of a good in an economy's export basket that controls for the economy size itself and each product's market share. Thus, the ubiquity and diversity levels are in the following matrix M_{ep}, in which 1 means that economy e produces good p with RCA, and 0 other-

wise:

$$Ubiquity = k_{p,0} = \sum_{e} M_{ep} \tag{1}$$

$$Diversity = k_{e,0} = \sum_{p} M_{ep} \tag{2}$$

The Equation (1) indicates the number of economies producing each product with RCA, while the Equation (2) shows the number of goods an economy produces with RCA.

The level of connectedness among goods is related to how much knowledge is required for producing them. These three abilities compound the economic complexity, which is inferred by analyzing an economy's export basket[3]. Thus, an economy is considered more complex as products in its export basket are less ubiquitous, more diversified and more connected to other products. Associating the diversity, the ubiquity and the connectedness of exported products leads us to a network that relates goods with $RCA \geq 1$ to economies. Considering an economy's export basket and the products in which it has advantages, the product space can be constructed.

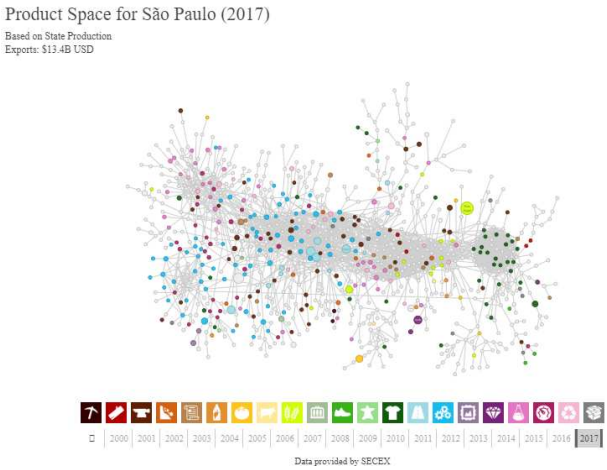
The product space is a net relating goods according to capabilities required to produce each good. It also displays the proximity of products given the probability of certain products to be co-exported. If an economy has two products that are co-exported, it means a specific capability is linking these products. For example, an economy that produces cocoa paste is likely to also produce cocoa butter, since what is needed in both production are similar (Hidalgo et al., 2007). Thus, in the product space these two goods are close to each other and there is a line connecting them, showing they require related capabilities or inputs.

The product space displays in a stylized manner how goods are connected by capabilities and in which group of products the economic development is (Hidalgo, 2009). Products in the interior area of the product space tend to be more connected to other products than peripheral ones. Producing goods that lies in the interior area of the product space indicates the availability of a large set of capabilities, which in turn are required to diversifying and producing non-ubiquitous products. Hence, the product space provides a visualization of the economic structure that is summarized by the economic complexity index.

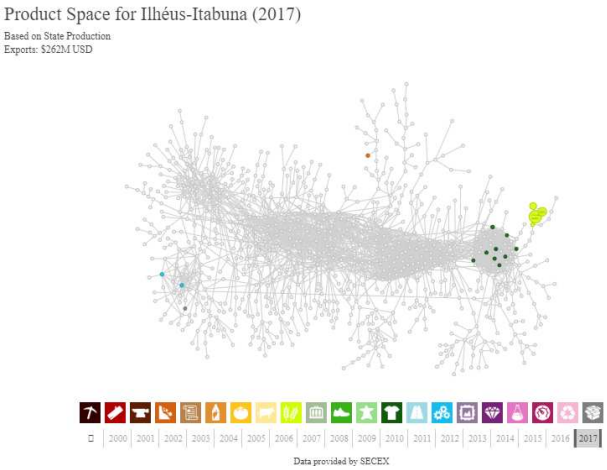
In a product space, each node represents a good; the colorful nodes are the goods that an economy exports with comparative advantages. The larger the node is, the higher the share of that good in international trade is. The colours and the icons at the bottom of the figure represent the groups of products. In order to introduce the product space, I display the product space of two Brazilian micro-regions. The first one is the micro-region of São Paulo-SP, which has the highest level of the economic complexity index (ECI) in 2017. The second one is the micro-region of Ilhéus-Itabuna-BA, which has the lowest level of ECI in 2017.

[3]Data on domestic consumption and employment can also be used to infer economic complexity, but this kind of data are scarce and less comparable than data on exports.

Figure 1: Product Space of the highest and the lowest economic complexity in 2017



(a) São Paulo-SP (Economic complexity = 53.19)



(b) Ilhéus-Itabuna-BA (Economic complexity = -6.206)

Note: The left panel is the product space of the micro-region of São Paulo-SP, the highest economic complexity index in 2017. The right panel is the product space of the micro-region of Ilhéus-Itabuna-BA, the lowest economic complexity index in 2017. In the product space, each node represents a good; the colorful nodes are the goods that the micro-region exports with comparative advantages. The larger the node is, the higher the share of that good in international trade is. The colours and the icons at the bottom of the panels represent the groups of products. The micro-region of São Paulo-SP is able to produce a large set of goods that are from several groups of products and lying in the interior area of the product space. While the micro-region of Ilhéus-Itabuna-BA can produce few peripheral goods. The contrast between these two product spaces displays how these micro-regions differ in their capabilities, which is also represented by their economic complexity indexes.
Source: Dataviva.

The micro-region of São Paulo-SP is able to produce lots of goods, which are from several groups of products and in the interior area of the product space. While the micro-region of Ilhéus-Itabuna-BA can produce few peripheral goods. The contrast between these two product spaces shows how these micro-regions differ in their capabilities, which is also represented by their economic complexity indexes.

In this context, I outline the relation between economic complexity and income growth. I take the micro-regions presenting similar income per capita in 2005[4]. This group of similar income per capita was divided into 10 subgroups according to their levels of economic complexity. Comparing the subgroup with the 10% better economic complexity to the subgroup with 10% worse economic complexity 12 years later yields that income growth was around 25% larger for the former. This result still holds when the comparison is different only in the percentile of better and worse economic complexity, at the 5% better and worse and at the 20% as well[5].

2.2.2 Human capital

Schultz (1961) and Becker (1962) introduced the concept of human capital as the set of skills and knowledge people use at production. According to them, investment

[4]We use 46 micro-regions presenting average income of 8,189 Brazilian reals with a standard-deviation of 352. These micro-regions are in the center of income distribution.

[5]The first appendix displays these relations.

in human capital is a source of economic growth and better earnings[6]. Moreover, they explained certain sorts of investment in human capital and underlined the effects of formal schooling and on-the-job training. Schultz (1961) affirmed formal education is central in the process of economic growth, while Becker (1962) stated schooling and on-the-job training have similar effects on rising a person's earning.

Additionally, Oketch (2006) affirmed investment in human capital presents three sorts of benefits. First, there are the monetary returns to education, which means the individual profitability of human capital. Second, the non-monetary returns to education, that is, effects on individuals' consumption and learning. Third, the external returns to education, which are the social benefits of human capital, such as democracy and political stability.

According to Nelson and Pack (1999) and Cimoli (2005), increasing human capital stock is a way to improve the learning capacity, which predicts the structural change. Moreover, the change in economic structure takes place in economies with plenty of capabilities, not only with machines, tools and blueprints together. Romer (1990) suggested that human capital also affects technology growth by expanding innovative capacity. According to his approach, a few skilled people work for developing technology, rather than making final-output goods. That kind of jobs are related to cognitive skills and not to the quantity of education.

In the international literature, vocational and technological education was associated with human capital and economic growth (Yuen, 1993; Mupimpila and Narayana, 2009; Okafor, 2011). Furthermore, Yuen (1993) and the Ministry of Education of Taiwan (2014) argued there is a causal linkage between the increase in vocational and technological education and the economic growth in Taiwan since 1950s. On the other hand, Yang (1998) and Nilsson (2010) claimed vocational education might be one of the drivers of growth but not more important than general education[7].

In addition, Icart and Rodríguez-Soler (2017) highlighted the strong association between vocational education and training with innovation in industrial small and medium companies. Furthermore, Rosenfeld (1998) underlined the economic role of public technical institutions and described them as a source of expertise and knowledge, which makes their graduates to react to technological change as well as to alter the rate of technology adoption. And, Toner (2011) emphasized the relation between an economy's skilled vocational employees and its performance in exporting products that are intense in those skills.

In Brazil, the vocational and technological education is compounded of private and public institutions and the latter are federal, state or even municipal funded (Souza et al., 2015). Here I focus on the federal-funded institutions because they present certain features of the world's top systems of vocational and technological education. For instance, providing opportunities for students to move from vocational track to academic university track and vice-versa, and providing incentives to attract qualified professors and students (Stewart, 2015). Besides, the federal vocational and technological education is spread all over the country, making the effect of this kind of institution

[6]According to Schultz (1961), the five main categories of investment in human capital are: health facilities; on-the-job training; formal education, as primary, secondary and tertiary levels; extension programs for adults that are not offered by firms; and internal migration to adjust to job circumstances.

[7]The effect of vocational and technological education on economic performance may rely on labor market conditions, educational quality, students' background, economic development and other factors, but the identification of these relations is not the purpose of this investigation. For more details, see El-Hamidi (2006), Wallenborn (2015), Asadullah and Ullah (2018) and Choi et al. (2019).

more general.

According to Kwon (2009), there are three approaches to measure human capital. The first approach is output-based and relies on school enrollment rates, schooling attainments, adult literacy, average years of schooling and indicators akin to them. The second approach is cost-based and uses the cost paid for acquiring knowledge. The third approach is income-based and depends on the benefits reaped by individuals after investing in education and training. The first approach deals with aggregate measures of human capital, while the second and the third ones work at the individual level.

In this context, total labor force can be used as an aggregate measures of human capital. Jameel and Naeem (2016) used total labor force and other indicators as proxies for human capital in panel estimates. They found that total labor force showed a positive and significant effect on economic growth in all analyses. Sankay et al. (2010) also made use of total labor force as one of the measures of human capital and it presented a significant impact on economic performance in the short-run. Furthermore, Butt and Hassan (2008) employed total labor force as a human capital proxy and it had a significant effect on economic growth in both the short-run and the long-run.

In line with this, employment data can also be used as human capital measures. Ahmed and Ridzuan (2013) used the number of employment as proxy for human capital. Awokuse and Christopoulos (2009) used manufacturing employment as proxy for labor. In this investigation, I use manufacturing employment as proxy for human capital.

2.2.3 Economic structure and human capital at the micro-regional level

According to Hidalgo (2009) and Hidalgo and Hausmann (2009), an economy that presents a large set of capabilities can produce a diversified and non-ubiquitous mix of goods, which is associated with income growth. These capabilities come from certain productive factors such as: human and physical capital, labor, land, institutions and infrastructure. However, I focus on the relation between human capital and economic structure once human capital benefits innovation building and innovation use (Benhabib and Spiegel, 1994).

Income is related to economic structure, which in turn depends on human capital. However, how does this relation happens at the micro-regional level? As stated by Andersson and Johansson (2010), the accessibility of human capital is what matters for understanding regional economic structure in Sweden. They make a positive association between human capital availability and exports average unit prices. Then, the more available human capital is, the higher exports average unit prices are, which indicates quality upgrading in exports when human capital stock increases.

Andersson and Johansson (2010) also associate positively human capital with the extensive margins of exports. Increasing exports via extensive margin stands for a wider set of either exported goods, exporting firms or trading partners. Hence, the larger the stock of human capital is, the more diversified exports are. Additionally, Hummels and Klenow (2005) suggested the level of diversity is the major export growth channel.

Teixeira and Queirós (2016) used data on OECD countries and Mediterranean and Eastern Europe economies to analyze the relation between human capital, economic structure and economic growth. They concluded human capital and economic structure matter for income growth as well as their interaction. Additionally, if economic structure cannot employ the high-skilled workers, economic growth tends to be weak.

Čadil et al. (2014) used data on European regions[8] to analyze the effect of human capital on economic growth according to the regional economic structure. They concluded there is no clear effect of human capital on economic performance.

For Brazilian economy, Bandeira Morais et al. (2021) analyzed economic structure and income distribution at the state level. They concluded economic structure plays a relevant role in explaining income distribution. Furthermore, Lima and Silveira Neto (2016) used data on Brazilian micro-regions and concluded human capital is important in understanding income growth.

Analysing the relationship between human capital and economic structure at the micro-regional level can bring up relevant issues. That is, economic structure is directly influenced by human capital that is inside its own micro-region. It happens due to the spatially tightness of human capital to municipalities and micro-regions (Simon and Nardinelli, 2002). Moreover, there is a need for disaggregated analysis of human capital (Sianesi and Reenen, 2003). In this context, the following figure exhibits the relationship between the labor force working on manufacturing industry, the measure of human capital, and economic structure for Brazilian micro-regions from 2003 to 2014. In Figure 2 each point indicates normalized human capital (on vertical axis) and normalized economic structure (on horizontal axis) for micro-regions in the years at the top of each sub-figure. Moreover, human capital and economic structure are significantly correlated to each other $(r = 0.7227,\ p - value < 0.01)$.

In a micro-region, human capital faces less constraints to move among municipalities than in a meso-region or in a state. Given this ability to move among municipalities in a micro-region, economic structure is influenced by the availability of human capital in the micro-region. Hence, the micro-regional spillover effect[9] should be considered.

2.2.4 Economic structure and other variables

In this section, I bring up the theoretical debate over economic structure, growth and certain factors. I focus on human capital and its interaction with physical capital, natural resources, technology and institutions due to the possible relation these factors have with economic structure and growth. That is, better economic structures are associated with higher stocks of physical capital, technological progress and better institutions. While, worse economic structure are related to lower stocks of physical capital, technological stagnation, abundance of natural resources[10] as well as poor institutions.

In addition, even among the factors associated with economic structure, a direct relationship might be expected (Mayer, 2001; Storper, 2010; Li et al., 2015), e.g. higher stocks of physical capital boost human capital productivity. Thereby, human capital tends to increase in order to follow physical capital expansion, indicating a bi-causality relation between them. Similar relations may occur between human capital and institutions or human capital and technology.

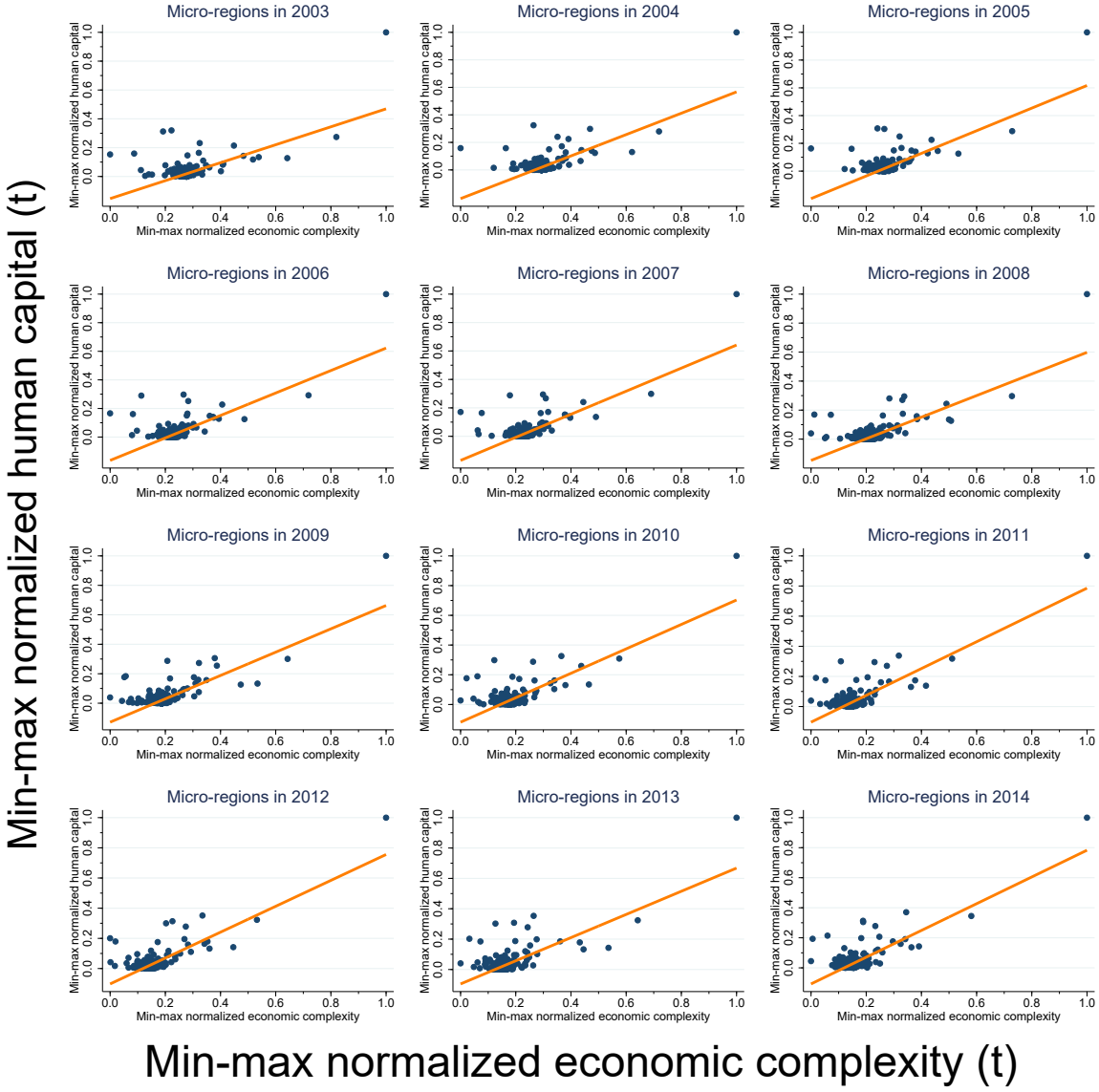
Starting with the relation between economic growth and physical and human capital. Li et al. (2015) stated the economic role of physical capital declines as economy

[8] They used the Nomenclature of Territorial Units for Statistics (NUTS) at the level 2. In NUTS 2, a region stands for a basic unit for the application of regional policies.

[9] In a micro-region, the spillover effect happens when human capital of a municipality favors economic structure of another municipality.

[10] The Dutch disease associates abundant natural resources, worse economic structure and overvalued exchange rates (Bresser-Pereira, 2008).

Figure 2: Normalized human capital and economic complexity in micro-regions between 2003 and 2014



Note: I used the min-max normalization, in which all values are transformed into the range of 0 and 1 meaning that the minimum and maximum value of each variable is going to be 0 and 1, respectively. The points indicate normalized human capital (on vertical axis) and normalized economic structure (on horizontal axis) for micro-regions in the years at the top of each graph. The orange line represents the fitted values of the two variables. Human capital and economic structure are significantly correlated to one another $(r = 0.7227,\ p - value < 0.01)$.
Source: Elaborated by author.

grows. In spite of that, human capital keeps its contribution to economic growth when development takes place. Furthermore, Pablo-Romero and Gómez-Calero (2013) concluded that the elasticity of private physical capital to economic growth declines as its stock increases, while the elasticity of human capital to growth increases when its endowments rises.

Another possible association is between natural resources, economic growth and human capital or institutions. Zallé (2019) affirmed human capital and institutions de-

termine economic growth. They also argued natural resource abundance may be a curse if an economy does not invest in human capital as well as in institutional quality. Moreover, Amiri et al. (2019) stated there is a negative relation between natural resources and economic growth in economies where the institutional quality is low. On the other hand, when a country presents good institutions, natural resources show positive effects on growth. Hence, the natural resource curse only takes place where there are poor institutions.

Drawing attention to technology and human capital, Mayer (2001) stated government should invest in both human capital and technology adoption because they influence economic growth positively. However, investing only in human capital reduces the returns of education, while increasing only technology makes income inequality to grow. Furthermore, Bilbao-Osorio and Rodríguez-Pose (2004) argued a low level of human capital might influence the relation between R&D and innovation. That is, where human capital is low, R&D expenditures may not cause innovation.

Additionally, Marvel and Lumpkin (2007) affirmed both general and specific human capital play fundamental roles in explaining radical innovation. This kind of innovation is the one that increases the possibilities of economic growth. They also stated formal education has an important positive association with radical innovation.

Turning to the relationship between institutions, human capital and economic growth, Faria et al. (2016) affirmed institutions cause economic growth. However, it is investment in human capital that increases institutional quality, which in turn leads to higher income. Moreover, Acemoglu et al. (2014) argued institutions are the determinants of growth and human capital is linking them.

In addition, Dias and Tebaldi (2012) affirmed that only structural institutions matter to long-run economic performance. According to them, the first institutions set in an economy stimulates or discourages investment in education, which influences human capital accumulation and then economic growth. In a second moment, the growth of human capital affects structural institutions.

Among the mentioned factors, human capital and institutions seem to play the most important factors associated with economic structure and growth. Given the effect of human capital and institutions, both would be used in explaining economic structure. However, there is a lack of data on institutions at the regional level (Storper, 2010; Acemoglu et al., 2014). That lack complicates the use of institutions in this kind of analysis and favor the use of human capital. Furthermore, institutional quality influences the long-term growth (Rodrik and Subramanian, 2003; Dias and Tebaldi, 2012), which is not the core of this investigation.

In this context, the omission of institutions would be surpassed by using an exogenous variation in human capital. This exogenous variation in human capital would show the effect of human capital on economic structure. Moreover, Sianesi and Reenen (2003) stated there is a need for studies of exogenous change in human capital.

The use of exogenous variation in a variable would be the proper way to capture its effect on another variable when other important variables are omitted[11]. An exogenous variation might also deal with bi-causality issues. Thereby, exogenous variation in human capital should be used as an instrument to address the possibility of endogeneity coming from the omission of institutions as well as the bi-causality between human capital and economic structure.

[11] Acemoglu et al. (2001) used European mortality as instrument for institutions. Caldera (2010) employed the public support for research and development as instrument for innovation.

2.3 Methodology

In methodological terms, comparing human capital and economic structure without considering the possibility of omitted variables or bi-causality between human capital and economic structure would yield inconsistent estimates. On one hand, omitted variables, such as institutions or geographical issues, would influence both human capital and economic structure simultaneously. That is, good institutions improve human capital as well as economic structure, putting aside the possibility of an effect of the former on the latter. Another alternative is that the omitted variables alter the effect of human capital on economic structure. It would happen if human capital and institutions affect economic structure but the former is considered and the latter is not, mistaking their effects. On another hand, there is a possibility of economic structure to influence human capital first or to present a bi-causality relation with it. Hence, it would be difficult to establish the causal effect of one variable on another.

The ideal experiment to estimate the effect of human capital on economic structure would be to improve human capital randomly across micro-regions. By doing so, I assume micro-regions are on average similar in observable and non-observable characteristics. Then, a comparison of economic structure between the micro-regions that had their human capital improved and the ones that did not would show the effect of human capital on economic structure. However, I do not have such experiments.

Economic structure may be explained by human capital and a group of other variables. However, certain variables are omitted and influence the analysis, institutions is one of them. The omission of institutions from the regression overestimates the effect of human capital on economic structure. That is, human capital would exhibit a larger effect on structure because institutions are not taken into consideration.

In the context of omitted variables, a manner of capturing the effect of human capital on economic structure would be an exogenous variation in the former. An exogenous variation in human capital would show its direct effect on economic structure because the other variables, including the omitted ones, do not change when an exogenous variation happens. Thus, the identification strategy uses a natural experiment as an exogenous variation in human capital, which bypasses the omitted variables issue.

2.3.1 Identification strategy

The identification strategy in this study is to exploit a variation in human capital that is exogenous to its own micro-region. If an exogenous variation happens in human capital, a change in economic structure is expected to take place. This relation does not depend on the omitted variables but solely on the direct effect of human capital on economic structure. Hence, the use of an exogenous variation leads us to the instrumental variable method, which in this case is the adequate manner to capture the effect of human capital on economic structure.

The instrument is the expansion in the Brazilian federal network of technological and professional education. As expansion, I mean the establishment of 491 new IF units, going from 155 units in 2005 to 646 in 2021 and reaching all the states in Brazil. In 2005 only 19% of the micro-regions had at least one IF unit, while in 2021 that number went to 70% of the micro-regions. This expansion increased the quantity of

places offered in IFs[12]. I believe such expansion would alter the stock of human capital in a micro-region because investment in technical or vocational education improves the workforce skills (Bradley and Taylor, 1996; Ismail and Abiddin, 2014). Moreover, Hanushek et al. (2017) also affirmed vocational education favors the entry into the labor market.

In addition, Arriagada et al. (1992) suggested vocational schooling in Brazil has better effects on labor market than expected. According to them, completing the technical or vocational education provides higher earnings when people are employed in occupations linked to their field of study. However, when this distinction between occupations and related field of study is not taken into account, as in Tannen (1991), vocational schooling seems to make no differences on students' earnings.

The only channel IFs influence economic structure is through its causal effect on human capital. There is a correlation between IFs and economic structure and what is behind this correlation is the causal effect of IFs on human capital. Hence, IFs do not cause economic structure directly. Given that, this paper takes advantage of the increase in places in IFs to evaluate the effect of human capital on economic structure.

In econometric terms, two assumptions are needed for a good instrument. The first assumption is that the instrument must have a direct effect on the endogenous variable. The second assumption is the exclusion restriction, which is divided into two parts: the first part is that the instrument has no influence on the dependent variable, except via the endogenous variable channel; the second part is that the instrument is randomly assigned.

The second assumption has two parts and I attempt to accomplish both of them. The first part is that places in IFs are not direct related to economic structure. According to Toner (2011), when the quality of labour is improved by education and training, the complementary between human capital and physical capital grows. That is, it is human capital that influences the productivity and marginal returns of physical capital and all other output factors.

Furthermore, IFs offers technical and technological courses, which are intended to increase the possibilities of local people. To an IF unit influence directly the micro-regional economic structure, it should produce and export final goods instead of training and improving local people's capabilities. Even though IF laboratories are able to produce a small amount of certain products, these products are not planned to be treated as market goods (Corrêa et al., 2017). Thus, increasing places in IFs is a way of affecting human capital but not economic structure directly.

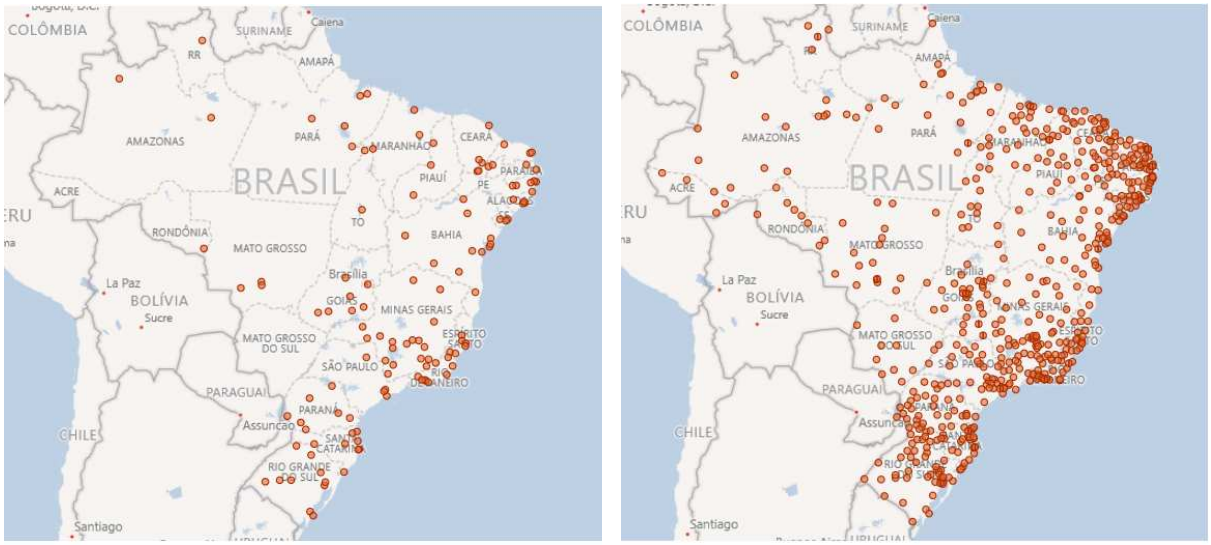
The second part of the second assumption is that places in IFs are unrelated to the other non-observable variables or to the error term. Then, I argue that the establishment of the new IF units was conditionally random. And, I present below the three aspects that underpin that conviction.

The first aspect is that funding sources for the IFs are federal, decreasing the probability of a strong correlation between regional income and this extra schooling investment. The second aspect is that establishing a new IF is beyond both the influence of the micro-regional government on the federal government goals and the micro-regional characteristics, such as the share of agriculture, industry, or government services in output. And, third, the expansion of IF network was not solely located in a state or

[12]We consider that the quantity of places in a micro-region is constant unless a new IF unit is established in the micro-region. Although constant places in IFs might not be real for a few micro-regions, a case study for each IF unit should be done if constant places are not assumed.

country region but happens throughout Brazil. Figure 3 displays the distribution of IFs in 2005 and 2021.

Figure 3: Expansion in Brazilian federal network of technological and professional education



(a) IF Units in 2005

(b) IF Units in 2021

Note: Each red dot indicates a municipality where there is at least one unit of the Brazilian federal network of technological and professional education. The left panel exhibits those municipalities presenting at least one IF unit in 2005. The right panel shows those municipalities presenting at least one IF unit in 2021.
Source: Brazilian Ministry of Education.

As displayed in the Figure 3, the IFs are scattered all over the country. Hence, I assume the rise in IFs is not related to non-observable micro-regional characteristics[13], which means the instrument is at least conditionally random at the micro-regional level.

Besides the fact that new IFs were established randomly, I also assume that the rise in IFs is not directly related to economic structure. Although the increase in IFs displays a positive correlation with economic structure in micro-regions, it only happens because human capital is linking them. In other words, the expansion in IFs affects human capital, which in turn influences economic structure.

We use a panel with 430 micro-regions from 2003 to 2015 and the dependent variable is economic structure. The estimator used is the Two Stage Least Squares (2SLS), which has the two following equations:

$$HC_{it} = \delta_i + \iota_t + \gamma_1 IF_{it-1} + \gamma_2 Phys.Cap_{it} + \gamma_3 Tra_{it} + \sum_{a=1}^{a=3} \gamma_{4a} Sect_{ait} + \mu_{it} \tag{3}$$

$$Eco.Struc_{it} = \delta_i + \iota_t + \rho_1 \widehat{HC_{it}} + \rho_2 Phys.Cap_{it} + \rho_3 Tra_{it} + \sum_{a=1}^{a=3} \rho_{4a} Sect_{ait} + \vartheta_{it} \tag{4}$$

[13]Brazilian population is spread in a manner that there are more people living closer to the coast than in the interior area. Thus, more new IF units were established around the coast.

Where i stands for the micro-region, t for the year and a for the economic sectors: agriculture (a=1), industry (a=2) and government services (a=3). $Eco.Struc$ is economic structure; IF is the quantity of places in IFs in the micro-region; HC is human capital; $Phys.Cap$ is physical capital; Tra is a measure of trade openness; $Sect$ is the value of each economic sector; δ is the intercept of each micro-region; μ is the error term of the first stage; and ϑ is the error term of the structural equation .

The proxy for economic structure is the economic complexity index (ECI). The concept of economic complexity is based on productive knowledge an economy holds (Hidalgo et al., 2007; Hidalgo, 2009; Hidalgo and Hausmann, 2009). In theoretical terms, economic complexity brings a different glance at income growth process. However, as all economic measures, complexity has certain limitations and Salles et al. (2018) point out three of them. The first limitation is not using data on services; the second limitation is analyzing only the supply side of economy; and the third limitation is ignoring the output that is not exported. Although the limitations, Salles et al. (2018) considered the economic complexity index the proper approach to analyze economic structure and export sophistication.

In addition, ECI was initially developed for analyzing countries. Taking ECI at the subnational level may bring up some issues to the analysis, one of them is the difference between international trade data and intra-national trade data. In order to cope with it, Freitas and Paiva (2015) proposed the inclusion of two terms in the ECI calculation[14]. These two terms are: the share of a micro-region's exports of a product to the country's total exports of that product; and the micro-region's RCA in exporting that product. By doing so, the ECI is taking into consideration the micro-region's share of a product in country's total exports and also the relevance of a product in the micro-region's export basket.

Although the adjustment made by Freitas and Paiva (2015), the ECI available at the subnational level for Brazil does not take into consideration the relationship between micro-regions inside the country. To do so, detailed trade data across micro-regions should be used. In this strand, Reynolds et al. (2018) used input-output tables to calculate the ECI for Australian states and territories, while Gao and Zhou (2018) estimated the ECI for Chinese provinces using data at the firm level. And, Balland and Rigby (2017) used patent records to measure the complexity of knowledge at the city level in the United States.

The measure of human capital is total labor force working on manufacturing industry. The proxy for physical capital is the micro-regional output share spent on gross fixed capital formation weighted by micro-region's total establishments[15].

A measure is constructed to access the trade openness level of an economy. It is based on the sum of imports and exports as a percentage of output, and micro-region's population. The sum of imports and exports as a percentage of output is regressed on the micro-region's population and the error term is separated. The estimate's residual is about all the other variables related to trade openness, except the micro-region's export, imports and population. Afterward, the residual of the mentioned estimate is multiplied by a measure of trade terms, which is a ratio of an export price index to an import price index. Thus, the trade openness variable is controlled for differences in

[14]The micro-regional ECI used in the research follow the formula proposed by Freitas and Paiva (2015).

[15]Carmo et al. (2017) used the same way to infer the variation in physical capital at the micro-regional level.

international prices, population, output, imports and exports[16].

Economic sector is compounded of three variables. These variables are the gross value-added that comes from the economic sectors (agriculture; industry; and government services).

2.3.2 Data source

The ECI values lies between -∞ and ∞ with 0 average and 1 as standard deviation. Data used to elaborate the ECI come from the Brazilian Ministry of Development, Industry and Trade (MDIC). Data on economic complexity goes from 2002 to 2017 and is made available by *Dataviva*[17] site. The site employs the same methodology Simoes and Hidalgo (2011) used to calculate the ECI. Complexity data needs no aggregation because it is available at the micro-regional level.

The labor force working on manufacturing industry is provided by the Annual Social Information Report (RAIS). RAIS is an annual administrative record of Brazilian formal labor market. It presents data on jobs, wages, industries, among others. These data are divided according to the National Classification of Economic Activities (CNAE). Brazilian Ministry of Labor and Employment (MTE) collects this information from all formal businesses and *Dataviva* makes it available.

Data on the Brazilian federal network of technological and professional education are made available by Brazilian Ministry of Education (MEC). Brazilian Institute of Geography and Statistics (IBGE) provides data on gross domestic product, population and the value-added of each economic sector. All these data needed aggregation, once they were not available at the micro-regional level. The Table I presents information on variables, proxies and sources of data.

Table I: Data source and explanation for micro-regions

Variable	Proxy	Uses data on	Source
Economic Structure	Economic Complexity Index	World's, country's and micro-region's exports	Dataviva
Human Capital	Total labor force working on manufacturing industry	Jobs, wages, industries and the classification of economic activities	MTE
Instrument	Places in IFs	Federal network of technological and professional education	MEC
Physical Capital	Micro-regional output share of gross fixed capital formation adjusted by establishments	Gross fixed capital formation and micro-regional data on establishments and output	IBGE and MTE
Trade Openness	A calculated measure of trade openness	Terms of trade and micro-regional data on exports, imports and output	MDIC, IBGE and FUNCEX
Economic Sector	Value-added of each economic sector	Value-added by agriculture, industry and non-government services	IBGE

Note: MTE means Brazilian Ministry of Labor and Employment; MEC means Brazilian Ministry of Education; IBGE means Brazilian Institute of Geography and Statistics; MDIC means Brazilian Ministry of Development, Industry and Trade; and FUNCEX means Foundation Center for Foreign Trade Studies.
Source: Elaborated by author.

Table II and III show the summary statistics of two groups of micro-regions.The first group is the micro-regions that have no IF units, while the second is of micro-regions that have at least one IF unit.

From Tables II and III, I can highlight the micro-regions that have at least one IF unit present in average better economic structure, human capital, trade openness and economic sectors when compared to micro-regions with no IF units.

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

[17] *Dataviva* is an open search platform promoted by the Government of the State of Minas Gerais, the State of Minas Gerais foundation for research funding and support (FAPEMIG), Minas Gerais Investment and Trade Promotion Agency (INDI) and Datawheel.

Table II: Summary statistics for micro-regions with no IF units between 2002 and 2015

	Observation	Mean	Std.Dev.	Minimum	Maximum
Economic structure	3368	-0.07052	2.3009	-17.280	30.405
Human capital	3299	9498.5	17972.4	1	239686
Places in IFs	3591	0	0	0	0
Physical capital	3089	0.00059	0.00028	0.00003	0.00202
Trade Openness	3028	-3312.3	60921.6	-32481.6	1190825
Agriculture	3368	317266.3	298591.3	3475	2615894
Industry	3368	979204.9	2285281.0	2832	33668760
Government services	3368	500904.5	636527.7	30733	7928515

Note: IFs means the Brazilian federal network of technological and professional education.
Source: Dataviva; Brazilian Ministry of Labor and Employment; Brazilian Ministry of Education; Brazilian Institute of Geography and Statistics; Brazilian Ministry of Development, Industry and Trade; and Foundation Center for Foreign Trade Studies.

Table III: Summary statistics for micro-regions with at least one IF unit between 2002 and 2015

	Observation	Mean	Std.Dev.	Minimum	Maximum
Economic structure	2875	0.1277	4.4401	-19.140	55.140
Human capital	3947	14165.1	49362.3	0	759021
Places in IFs	2318	1003.1	1558.8	40	16603
Physical capital	2157	0.00048	0.00038	0.000002	0.00259
Trade Openness	2724	4129	67362	-32489	1032021
Agriculture	2875	490826.4	674753.8	4670	8283140
Industry	2875	6422684	27632094	3184	440834688
Government services	2875	7020159	50392437	26990	980025856

Note: IFs means the Brazilian federal network of technological and professional education.
Source: Dataviva; Brazilian Ministry of Labor and Employment; Brazilian Ministry of Education; Brazilian Institute of Geography and Statistics; Brazilian Ministry of Development, Industry and Trade; and Foundation Center for Foreign Trade Studies.

2.4 Results and Discussion

In order to try to satisfy the first assumption of a 2SLS estimator, I have run a regression of the first stage, as in Equation 3. Table IV shows the results of regressing employment in manufacturing industry on places in IFs and control variables.

As exposed in Table IV, places in IFs have a positive and significant effect on human capital. Then, the first assumption for a good instrument is fulfilled and the instrument is relevant. Furthermore, statistical tests were made and indicated instrument is not weak[18].

Table V shows the results of the structural form. Furthermore, three other estimators are presented to be compared with the 2SLS estimator. The first estimator is the

[18]The first statistical test was the underidentification test, which detects whether the first-stage equation is identified. The second test was the weak identification test, which verifies whether the instrument is weak or not. Both tests suggested the instrument is not weak.

Table IV: Economic structure regression for micro-regions (First stage)

	Human capital	
Places in IFs	0.09696***	(1.324)
Physical capital	0.04230***	(2531888.9)
Trade Openness	0.01938	(0.00860)
Agriculture	-0.00724	(4066.2)
Industry	0.02935	(58544.0)
Government services	-0.35807**	(111559.6)
Observation	4284	
F-statistic [p-value]	9.61	[0.0046]
Anderson-Rubin Wald Test-Statistic [p-value]	3.17	[0.0749]

Note: I used two-way fixed effects. Places in IFs are in period t-1, all other regressors are in period t. Standardized beta coefficients; standard errors in parentheses and clustered at the state and the micro-regional levels; * $p < .1$, ** $p < .05$, *** $p < .01$
Source: Elaborated by author.

Ordinary Least Squares one, which could be efficient and consistent under exogenous regressors. The second estimator is the Panel (A) one, which assumes the unobservable heterogeneity is constant over the period so that including a micro-region fixed effect would bring up the causal effect. The third estimator is the Panel (B) one, which considers the unobservable heterogeneity is not constant but could be solved by using a two-way fixed effect. These estimators have different assumptions but similar outcomes.

Hereafter and for the 2SLS estimator, I consider the significance level at 0.10. According to Table V, human capital and government services presented significant effects on economic structure. Moreover, physical capital, trade openness and the economic sectors of agriculture and industry showed no significance at all. I believe the differences in factor endowment across micro-regions explain the absence of an effect of physical capital, trade openness and economic sectors on economic structure. Other explanation is that these variables influence economic structure through human capital.

The coefficients are in standard deviation terms. A one-standard-deviation increase in human capital is associated with a 1.057 standard-deviation increase in the economic structure. The micro-regions presented different one-standard-deviation increasing paces in human capital.

Among the 17 micro-regions that presented a one-standard-deviation increase in human capital from 2003 to 2014, the fastest ones were the micro-regions of São Paulo-SP, Belo Horizonte-MG, Campinas-SP and Rio de Janeiro-RJ, while the slowest ones were the micro-regions of Caxias do Sul-RS, Blumenau-SC and Goiânia-GO. The increase of one standard-deviation in human capital occurred in one year in the micro-region of São Paulo-SP, three years in the micro-regions of Belo Horizonte-MG, Campinas-SP and Rio de Janeiro-RJ and in eleven years in the micro-region of Caxias do Sul-RS, Blumenau-SC and Goiânia-GO. Furthermore, considering all the Brazilian micro-regions, 541 micro-regions did not present a one-standard-deviation increase in

Table V: Economic structure regression

	OLS	Panel (A)	Panel (B)	2SLS
Human capital	0.75286***	0.28389*	0.33871**	1.05667**
	(0.000012)	(0.000011)	(0.000012)	(0.00003)
Physical capital	0.09158***	0.01697**	-0.00933	-0.04100
	(354.6)	(96.95)	(134.9)	(318.5)
Trade Openness	0.00511	0.01033	0.00924	-0.00455
	(0.0000014)	(0.00000084)	(0.00000082)	(0.00000075)
Agriculture	-0.03638	0.04470***	0.03838**	0.04390
	(0.939)	(0.419)	(0.519)	(1.063)
Industry	0.01735	0.04551	0.05302	0.02805
	(8.088)	(3.952)	(4.032)	(3.256)
Government services	-0.03603	-1.91760***	-1.91492***	-1.59667***
	(4.204)	(13.55)	(13.44)	(24.61)
Observation	4765	4765	4765	4265
F-statistic	9.1406	16.8994	19.8250	51.5141
P-value	0.0000	0.0000	0.0000	0.0000
Micro-region FE	No	Yes	Yes	Yes
Year FE	No	No	Yes	Yes

Note: OLS is Ordinary Least Squares and 2SLS is Two Stages Least Squares. Standardized beta coefficients; standard errors in parentheses and clustered at the micro-regional level; standard errors are also clustered at the state level in the 2SLS estimate; * $p < .1$, ** $p < .05$, *** $p < .01$.
Source: Elaborated by author.

human capital from 2003 to 2014.

In order to check the robustness of the results, I tested alternative proxies for the right-hand variables of Equation 4. The first alternative measure is total labor force working in the micro-region as a proxy for human capital instead of the labor force working in manufacturing industry. Even though that measure is not specific, using the total labor force as the measure of human capital yielded similar results.

Drawing attention to trade openness, two measures might be utilized instead of the proxy used. The first measure is the sum of imports and exports as a percentage of output. The second measure is the effective diversity of exports destinations, which depends on the quantity of locations importing a micro-region's products as well as on the share of each importing location. Despite the differences in calculations, the use of each of the proxies for trade openness produced similar results when comparing to the constructed measure based on imports, exports, output, population and trade terms.

Regarding physical capital, I used two alternative measures for this variable. The first proxy was lagged gross domestic product and the second one was the quantity of establishments in the micro-region. Both alternative measures turned the relation between human capital and economic structure insignificant.

The identification strategy takes advantage of the exogenous variation to capture the effect of human capital on economic structure. In spite of that, we used I also used

2.5 Concluding Remarks

This study contributes to the debate on the relevance of human capital on micro-regional economic structure, suggesting the latter indicates future income growth. I assume economic structure is revealed by exports sophistication (Hidalgo et al., 2007; Hidalgo, 2009; Hausmann et al., 2014).

The economic complexity index was the proxy for export sophistication. This measure is based on the ubiquity and diversity levels of exports, the share of international trade, the connections between goods, the relevance of the micro-region in the country's total exports and the importance of the product in the micro-regional export basket. The estimate is for the period of 2003 to 2015 with a sample of 430 micro-regions.

Results suggested human capital affects economic structure. Human capital showed a positive and significant effect on economic structure. The expansion of the Brazilian federal network of technological and professional education presented an effect on human capital, indicating the instrument should be effective. Hence, human capital is a central key in explaining economic structure in micro-regions where the quantity of places in IFs increased. In these micro-regions, the quantity of places in IFs was an adequate instrument for micro-regional human capital, setting a positive and significant effect of places in IFs on human capital.

Our findings indicate increases in places in IFs, which are investment in micro-regional human capital, lead to economic structure upgrading. Thus, policies such as the expansion of Brazilian federal network of technological and professional education should be promoted. Additionally, increasing the supply of qualifications might improve the stock of human capital, leading to better economic structures.

One limitation that I still have to deal with is data availability, especially in terms of human capital observations. Another limitation is only taking data on formal labor market. Moreover, it is possible that the quantity of observation is influencing the estimate efficiency. A suggestion for further studies is to include the quality of human capital in the analysis as Leite and Cardoso (2023).

3 THE EFFECT OF PRIVATE INVESTMENT IN TECHNOLOGY ON ECONOMIC STRUCTURE

3.1 Introduction

Understanding the mechanisms through which the same inputs yield higher output has been a fundamental aspect of previous growth debates (Solow, 1956; Kaldor, 1957; Romer, 1990), as well as recent discussions on sustainability (Hall and Jones, 1999; Bayarcelik and Taşel, 2012). Consequently, fostering technological progress remains widely recognized as the primary driving force behind economic expansion. Within this discourse, investment in research and development (R&D) is established as a key variable (Aghion and Howitt, 1992). However, economic results of such investment may vary based on the sources of funding. Private R&D expenditure might diverge from public R&D in terms of goals, execution and timing. Furthermore, private R&D has a definite purpose while the purpose of public R&D is not widely known or accepted.

Becker (2015) stated government may runs out of resources given a crisis or economic austerity needs, so public investment in R&D is uncertain. While the private R&D has the major role in contributing to the growth of developing economies (Hu, 2001; Zhang et al., 2003; Kuppusamy et al., 2009). My research problem is to study the effect of private R&D on economic structure. The idea of economic structure is about the mix of goods an economy can produce (Hidalgo et al., 2007; Hidalgo, 2009; Hidalgo and Hausmann, 2009; Hausmann et al., 2014).

Justman and Teubal (1991) declared there is a link between technological progress and structural change and this relation holds for both industrialized and developing countries. According to them, structural change is a major precondition for economic growth. Moreover, Pan (2006) affirmed investment in R&D drives technological development, which in turn shapes economic structure. And Ngoc and Hai (2019) stated economic development is associated with a positive change in economic structure.

Adak (2015) analyzed the structural change in Turkey from 1980 to 2015. According to him, the political change in 1983 focused on trade openness and it played an important role in increasing competitiveness. Although the slowdown during the 1990s and the beginning of 2000, in 2003 new policies took place and changed Turkish economy. A remarkable change was proposed by a new act fostering firms' R&D. That act boosted private R&D, which in turn improved Turkish economic structure. A better economic structure stands for technology accumulation and innovation producing, two abilities related to economic growth.

Associating private R&D to economic structure is challenging due to the interaction of these variables. By interaction, I mean economies with more private R&D tend to have better economic structures, whilst economies with less private R&D are likely to present worse economic structures. In both cases, private R&D and economic structure would be either determined by a third factor or influence each other, blurring the effect of private R&D on structure.

In this context, if there is a third factor affecting both private R&D and economic structure, this factor should be taken into account. Further, if there is not a third factor but a bi-causality between private R&D and economic structure, a variation in private R&D that is exogenous and not related to any other factor influencing the economic structure would be used. Hence, this exogenous variation in private R&D would change

economic structure, displaying the effect of the former on the latter.

In this strand, I exploit an exogenous variation in private R&D to capture its effect on economic structure. This exogenous variation takes place at the end of 2005 after the implementation of a Brazilian federal law fostering private investment in technology. It was the Law No. 11.196/2005, known as *"Lei do Bem"*. This law provides a few incentives for firms to invest in R&D, consolidating the relationship between private R&D and economic structure. Furthermore, I believe the approval of the mentioned law influences private R&D without any direct effect on economic structure. It happens because private investment should be made in advance and then the tax exemption is given. Hence, if no private investment is carried out, nothing is granted.

Although it is satisfactory to investigate the effect of private R&D on economic structure at the national level, I believe a disaggregate analysis would yield important policy implications. That is, considering the localization issues of knowledge would provide relevant insights for local policy (Breschi and Lissoni, 2009). Thus, given that data on economic structure are provided at the municipal level, the analysis focuses on the municipalities[19].

In this line, this study proposes to increase the knowledge of economic structure in Brazilian municipalities and to check for the effect of private R&D on structure. It is expected that municipalities differ in certain characteristics that facilitate or complicate private R&D, such as the municipal law system, tax exemptions and the municipality's government.

The hypothesis of the investigation is that private investment in technology determines economic structure. Moreover, it is the Law No. 11.196/2005 that will increase the incentives for firms to invest in technology. Hence, in the following periods technological improvements will be available and more sophisticated goods will be produced. And, since an increase in private R&D is related to economic structure enhancements, public policies such as incentives for R&D would be useful in promoting better economic structure and income growth. On the other hand, if no relation between private investment in technology and economic structure is found, other factors would be analyzed for direct effects on the municipal economic structure.

The outcomes of this paper suggested private investment in technology shapes economic structure. The proxy for private investment in technology is total labor force working on research and development area. The approval of the Law No. 11.196/2005 showed an effect on private investment in technology, meaning the instrument is effective.

The remainder of this investigation is organized as follows. The second section describes the theoretical issues, relating technology and economic structure at the municipal level. The third section shows the methodology, providing the identification strategy, a brief explanation of the Law No. 11.196/2005 and data sources. The fourth section presents the results and the analysis of the relation discussed. The fifth section brings the conclusion of the study and offers certain remarks on the debate presented.

3.2 Theoretical Background

This study investigates the effect of private R&D on economic structure at the municipal level in four subsections. The first one introduces the concept of economic

[19]There are more than five thousand municipalities in Brazil. I use data on private R&D and economic structure for all municipalities that have them available.

structure, while the second one analyzes the issues related to private R&D. The third subsection associates economic structure with private R&D at the municipal level and the fourth one brings up the debate over public and private investment differences.

3.2.1 Economic structure

Hidalgo et al. (2007), Hidalgo (2009), Hidalgo and Hausmann (2009) proposed the concept of economic complexity, which is a manner to assess the knowledge and capabilities the labor force has and uses at producing goods. Economic complexity depends on the levels of ubiquity and diversity of exports, the share in international trade and the level of connectedness between products. They link economic complexity to per capita income.

The level of ubiquity takes into account the product existence in the world. Non-ubiquitous goods are found in few places, whilst ubiquitous goods are found everywhere. Thus, non-ubiquitous products tend to be more complex than ubiquitous ones. Furthermore, the level of diversity considers how diversified the export basket is. The more diversified the export basket is, the more complex that economic is likely to be. In this context, a high complex economy has the ability to make a product basket in which products are both diversified and non-ubiquitous.

According to Hidalgo et al. (2007), producing non-ubiquitous and diversified goods is positively related to per capita income. They suppose an economy's per capita income corresponds to its economic complexity, expressing subsequent growth. Hence, if an economy presents more per capita income than its economic complexity predicts, it would have slower, or even negative, income growth. On the other hand, if an economy has less per capita income than its economic complexity predicts, it would have faster income growth.

Besides the relation between economic structure and per capita income, what an economy can produce is related to certain features, such as: human capital, investment in technology, trade openness, government's attitude towards economy and others (Gould and Ruffin, 1995; Chen and Feng, 2000; Hausmann et al., 2007; Hidalgo, 2009). Focusing on investment in technology and its association with economic structure bring up important issues. When technology grows, an economy is able to produce more sophisticated goods with the same previous endowment in terms of human capital, trade openness and public spending. Thus, investment in technology influences directly economic structure.

3.2.2 Investment in technology

Technology has been underlined as an important element in expanding production (Solow, 1957; Romer, 1990; Lichtenberg, 1992). Moreover, it is expected that an economy with a high level of investment in technology could have faster access to new ideas of manufacturing products. These new ideas are related to better machines, different designs or even new products (Grossman and Helpman, 1991).

Following the endogenous economic growth model proposed by Jones (1995) and leaving out physical capital for simplicity[20], I relate production, human capital and tech-

[20] Including physical capital does not make much difference in the theoretical relations I want to discuss.

nology:

$$Y_t = A_t^{\alpha} L_{Y_t} \quad , \quad \alpha > 1 \tag{5}$$

$$\frac{\dot{A}_t}{A_t} = \theta L_{A_t} A_t^{-\beta} \quad , \quad \beta > 0 \tag{6}$$

$$L_{Y_t} + L_{A_t} = L_t = L_0 e^{nt} \tag{7}$$

$$L_{A_t} = \overline{s} L_t \tag{8}$$

Where subscript t and subscript 0 mean time and initial time, respectively; Y is total output; A is technology; L is total labor force, which can be divided into labor force producing final output, L_Y, and labor force working on technical progress, L_A. The parameter α is the degree of returns to scale in the production function of goods, β is the difficulty level of finding new ideas, and n is the population growth rate.

Equation (5) is the production function of goods. According to it, output has constant returns to labor and increasing returns to technology, once $\alpha > 1$. The new ideas present increasing returns to scale because they are non-rival inputs[21]. According to Romer (1989), investments in technology present increasing returns to scale. It happens because technology is a non-rival input, which makes it have a convex relation to output. Thus, given convexity, as more new ideas are developed, larger will be their effect on output.

Equation (6) is the production function of ideas. According to it, the rate of technology growth depends on the labor force working on technical progress and the distance to technological frontier. The technical progress presents constant returns to the labor force working on technology expansion and decreasing returns to the level of technology, since $\beta > 0$. As the distance to technological frontier decreases, it becomes harder and harder to accumulate technology. Hence, there is a concave relation between the rate of technology growth and the level of technology (Jones, 2019).

Equation (7) shows how labor force is divided and its growth. Labor force is used to make either final output or new ideas. The growth rate of labor force is n, an exogenous parameter. Furthermore, Equation (8) displays how labor force is allocated to technical progress. The parameter $\overline{s}$ is the share of total labor force working on technology growth. Thus, $1 - \overline{s}$ is the share of labor force that produces final goods.

In terms of output per person, that is $y \equiv Y/L$, I rewrite Equation (5) as:

$$y_t = A_t^{\alpha}(1 - \overline{s}) \tag{9}$$

Where output per capita is a function of the total stock of technology and the proportion of labor working on the the production of goods. The main difference from a basic Solow model is that a new idea will increase the overall productivity by being used everywhere, once it is a non-rival input. On the other hand, an additional unit of a rival productive factor cannot increase output per person everywhere. For instance, to increase output per person by expanding the stock of physical capital, a new machine should be given to each worker. While, the expansion of output per capita could be

[21] Non-rivalry stands for a simultaneous use of a resource by any number of people (e.g. the sunlight, the ideas related to making a cake or the process of building a house). While rivalry means that the use of a resource by a person decreases the amount left for other person (e.g. a pair of sunglasses, a liter of milk or a hundred of bricks).

achieved by a new idea spread everywhere.

Rearranging Equation (6) and taking logs and derivatives in relation to time of Equation (9), I have:

$$g_A = \theta \frac{L_{A_t}}{A_t^{\beta}} \tag{10}$$

$$g_y = \alpha g_A \tag{11}$$

Where g stands for the growth rate. In order to have a g_A constant in the long run, the right side of Equation (10) has to be constant too. Thus, equaling the numerator and the denominator of the right side of Equation (10) and taking logs and derivatives in relation to time, I have:

$$g_A = \frac{g_{L_A}}{\beta} = \frac{n}{\beta} \tag{12}$$

Combining the Equations (11) and (12), I have:

$$g_y = \frac{\alpha n}{\beta} \tag{13}$$

Then, it shows that the long-run growth rate of income per capita relies on the degree of returns to scale of technology (α), the difficult level of finding new ideas (β) and the population growth (n).

We can infer two main outcomes from this framework. The first outcome is that the interaction between the non-rivalry of new ideas (α) and the increasing difficulty to expand technology (β) will determine the growth rate of output per capita. The second outcome is that the labor growth rate (n) has a positive effect on the long-run growth rate of output per capita (g_y). It happens because a larger population growth rate means more labor allocated in finding new ideas, which in turn rises output per person.

3.2.3 Economic structure and private investment in technology at the municipal level

Hidalgo et al. (2007) stated output per capita is associated with economic structure, which in turn relies on technology. Nevertheless, how does this relationship takes place at the municipal level? It is reasonable to assume that private investment in technology can improve economic structure in terms of more diversified and less ubiquitous exports. However, it is not so clear the manner they are connected at the municipal level.

Private investments responds to economic incentives, which in turn may come from market as well as government. Private investment in technology is the total amount firms spend at expanding technology, normally referred as investment in research and development. According to Geiger and Sá (2005), private investment in technology complements public investments in technology at the sub-national level, especially where fiscal constraints are bound. Moreover, they emphasized the state's role at presenting and facilitating innovative capabilities given its closeness to firms.

Considering the relation between private investment in technology and economic structure can lead to relevant features, especially about the diffusion of new ideas. Breschi and Lissoni (2009) stated knowledge is locally tied, that is, taking a sub-national measure of investment in technology would yield oriented public policies. Fur-

thermore, Almeida and Kogut (1999) affirmed creation and transference of ideas should vary spatially, which is the core notion of tacit knowledge. Tacit knowledge is one of the supporting concept of economic complexity, the proxy for economic structure (Hausmann et al., 2014).

In this context, I suppose certain factors influence municipal economic structure, such as physical capital, human capital, institutions, and investment in technology. Concentrating on investment in technology, it could be divided into public and private investment in technology. Both types are important, but the private investment deals with less regulation than the public one. The private R&D depends on firms' economic choices, while the public R&D relies on both politic and budget issues.

Taking into account the difference between the municipalities, it is worth noting the national law and tax systems present different effects on private investment in technology across municipalities. For instance, a change in a national tax might generate different incentives for R&D for certain municipalities or even a disincentive for R&D for others. Hence, the investigation focuses on the relation between private investment in technology and economic structure at the municipal level.

3.2.4 Private and public investment in technology

It is widely accepted that investment in R&D has a positive effect on innovation, productivity and economic growth. However, there is no consensus on the relevance of public and private R&D, causing this debate to remain open. Private R&D has a clear and established purpose, while the purpose of public R&D is not broadly known or accepted.

According to Guellec and van Pottelsberghe de la Potterie (2003), there are three reasons for public R&D. First, government needs such as national defense. Second, the imperfect appropriability of new technologies, which comes from the difficulty to exclude others from using the developed knowledge. Thereby, private returns to R&D are lower than social returns. Third, the high risk associated with R&D, which prevents firms from investing in technology, especially small firms.

Ishibashi and Matsumura (2006) affirmed public institutions should decrease their investments in R&D for private firms to increase their R&D expenditures. Two reasons are the main drivers of this conclusion. First, public and private investments in R&D are substitute inputs, so higher public R&D is associated with lower private R&D. Second, there is a positive external effect of public R&D on private R&D, which makes private R&D to a kind of free-riding on public R&D. Thus, both reasons lead to underinvestment in private R&D.

As stated by David et al. (2000), firms use an analysis of expected cost and benefit when deciding whether invest in R&D or not, and if so, how much. There is a downward sloping curve that is related to the marginal benefits of R&D, while the marginal cost curve of R&D has an upward slope. These two curves are equalized at the profit maximizing equilibrium for R&D. Although public investment influences both the marginal benefit and cost curves, it is the latter that is shifted or changed by receiving much of the effect of government's R&D.

Bilbao-Osorio and Rodríguez-Pose (2004) analyzed the effect of public, private and higher education R&D on innovation and economic performance. According to them, private R&D tends to be more applied given it is profit-oriented, while public and higher education R&D are likely to be more basic. In peripheral regions, however, higher education institutions are also engaged in more applied R&D activities. That could

be in response of the lack of private R&D in peripheral regions. Furthermore, they concluded public and higher education R&D may take time for economy to reap the benefits.

According to Cohen et al. (2002), public R&D, which stands for universities and government R&D laboratories, influences private industrial R&D by providing projects, instruments or techniques to firms. Moreover, public research may lead to technology progress once it contributes towards firms with basic science or ways of solving problems. In addition to this point of view, Coccia (2010) stated public and private R&D are complementary inputs. However, public R&D will present a positive effect on productivity growth only if it is lower than private R&D.

3.3 Methodology

A comparison between private R&D and economic structure without taking into consideration omitted variables would generate inconsistent estimates. Omitted variables would be institutions, public investment in technology or geographical features. Those omitted variables would determine private R&D and economic structure simultaneously. That is, more public investment in technology improves private R&D as well as economic structure, removing the possibility of an effect of private investment in technology on economic structure. Another alternative is that the omitted variables change the effect of private R&D on economic structure. It would occur if private R&D and public investment in technology influence economic structure but private R&D is used and the public one is not, mistaking their effects.

In order to estimate the effect of private R&D on economic structure, the ideal experiment would be to increase the former randomly across a large number of municipalities presenting on average similar observable and non-observable characteristics. Thus, such experiment would compare economic structure between municipalities that had their private R&D increased and municipalities that did not. That comparison would exhibit the influence of private R&D on economic structure at the municipal level. Nonetheless, such experiment is not available now.

Economic structure may be explained by private R&D and a group of other variables. Nevertheless, some variables are omitted and affect the analysis, public investment in technology is one of them. The omission of public investment in technology from the regression overestimates the effect of private R&D on economic structure. That is, private R&D would display a larger effect on structure due to public investment in technology is not taken into account.

In the context of omitted variables in the analysis, a way of capturing the effect of private R&D on economic structure would be an exogenous variation in the former. An exogenous variation in private R&D would exhibit its direct effect on economic structure since the other variables, including the omitted ones, do not change when an exogenous variation takes place. Thus, the identification strategy uses a natural experiment as a source of exogenous variation in private R&D so that the omitted variables issue is bypassed.

3.3.1 Identification Strategy

The identification strategy takes advantage of a variation in private R&D that is exogenous to its own municipality. I assume exogenous variation in private R&D would

cause a shift in economic structure. Although there is an omitted variable, public investment in technology, using the approach of a natural experiment is a proper way to deal with this omission. Thus, the use of an exogenous variation brings us to the instrumental variable (IV) method, which is for this setting an appropriate procedure to capture the effect of private R&D on economic structure.

The instrument is the moment of approval of the Law No. 11.196/2005, which was in November of 2005. This law is known as *"Lei do Bem"*, and henceforth referred to as "the Good Law". The Good Law is a federal law on incentives to private investment in capital goods, technological innovation and other issues. The firms choose if they will use the incentives granted or not, the law is not binding[22]. The Good Law has 17 chapters and each chapter is related to a specific subject. However, I am particularly interested in the first three chapters and the incentives granted for firms in them. Table VI displays the summary of the first three chapters of the Good Law.

Table VI: Summary of the first three chapters of the Good Law

	First chapter	**Second chapter**	**Third chapter**
Type of firms	Exporting information technology services firms	Exporting firms	Technological innovative firms
Benefits on	Fixed assets	Domestic sales; and import of capital goods.	Total amount spent in technology; registering or keeping brands or patents abroad.
Type of incentives	Total tax exemption	Total tax exemption	Tax deductions; tax reductions; accelerated depreciation; and subventions.
Without the Good Law	PIS: 1.65%; COFINS: 7.6%	PIS: 1.65%; COFINS: 7.6%; Import-PIS: 1.65%; Import-CONFINS: 7.6%.	IRPJ calculated over the net profit; CSLL calculated over the net profit; IPI: from 0% to 30%; IRRF for brands or patents abroad: 25%; Normal depreciation for capital goods used at R&D activities.
With the Good Law	PIS: 0%; COFINS: 0%	PIS: 0%; COFINS: 0%; Import-PIS: 0%; Import-COFINS: 0%	Total amount spent in technology can be deducted by the net profit, then IRPJ and CSLL is calculated over a smaller amount; IPI: from 0% to 15% (reduction of 50%); IRRF for brands or patents abroad: 0%; Integral depreciation at the same purchase year for capital good used at R&D activities; Subventions and deductions may be given according to the quantity of researchers in R&D activities.

Note: The Law No. 11.196/2005, known as *"Lei do Bem"*, and referred to as "the Good Law". The Good Law is a federal law on incentives to private investment in capital goods, technological innovation and other issues. The Good Law has 17 chapters and each chapter is related to a specific subject. However, I am particularly interested in the first three chapters and the incentives granted for firms in them.
Source: The Law No. 11.196/2005.

[22]Being optional is a source of possible selection bias because choosing to use the incentives might be related to firms' characteristics that also influence economic structure.

The first chapter establishes the special taxation regime for exports of information technology services (Regime Especial de tributação para a Plataforma de Exportação de Serviços de tecnologia da informação - REPES). Opting for REPES grants the firms a total exemption on two federal taxes on fixed assets, they are the social integration program (Programa de Integração Social - PIS) and the contribution to social security financing (Contribuição para o Financiamento da Seguridade Social - COFINS). Without REPES, the normal percentage of these two taxes are around 1.65% for PIS and 7.6% for COFINS.

The second chapter establishes the special regime for acquisition of capital goods for exporting companies (Regime Especial de aquisição de bens de Capital para empresas exportadoras - RECAP). Opting for RECAP grants the firms a total exemption on four federal taxes, two on domestic sales and two on import of machines, tools and equipment. These exemptions are on PIS, COFINS for domestic sales and on import-PIS and import-COFINS for imports. Without RECAP, the normal percentage of import-PIS and import-COFINS are the same applied to PIS and COFINS.

The incentives granted by the special regimes (REPES and RECAP) are intended for exporting firms. According to the law, an exporting firm should present at least 50% of its net revenue coming from exports. The incentives mentioned in the first two chapters are export-oriented, while the incentives in the third chapter is more general.

The third chapter establishes the incentives for technological innovation. According to this chapter, the firms can have deductions, tax reductions, accelerated depreciation and subventions. The total amount spent in technology can be deducted from the net profit so that taxes will be applied to a smaller amount. This deduction affects the income tax for firm (Imposto sobre a Renda da Pessoa Jurídica - IRPJ) and the social contribution on net income (Contribuição Social sobre o Lucro Líquido - CSLL). Moreover, there is a reduction of 50% on industrialized products tax (Imposto sobre Produtos Industrializados - IPI) applied to machines, tools and equipment used at R&D activities. Without the incentives in the third chapter, the normal percentage of IPI varies from 0% to 30% according to the product.

Still in the context of the third chapter, there is an integral depreciation at the same purchase year for machines, tools and equipment used at R&D activities. This integral depreciation influences IRPJ and CSLL. Furthermore, if a firm spends any resource abroad at registering or keeping brands or patents, there will be a total tax exemption of the withholding income tax (Imposto de Renda Retido na Fonte - IRRF). Subventions and deductions may be given to firms according to the quantity of researchers allocated for R&D activities.

In this line, I assume incentives can foster companies to increase their investment in R&D. Thus, I take the incentives as a source of exogenous variation in private R&D, once it may be at least economically reasonable. Moreover, I believe the approval of the Good Law would influence private R&D without any direct effect on economic structure. It happens because private investment should be made in advance and then the tax exemption is given. Hence, if no private investment is carried out, nothing is granted. And, the incentives are equal to all companies[23] so there is no association

[23]The first chapter of the the Good Law is dedicated to exporting firms of the information technology sector (IT), which does not include all companies, making a distinction between IT companies and other companies. However, the second and especially the third chapter of the Good Law offer incentives to all firms, excepting the ones opting for the differentiated, simplified and favored tax regime named "Simples Nacional". The Simples Nacional tax regime is possible only for firms with a revenue of 4,8 million Brazilian reals (BRL) in the last 12 months.

between the other variables and the incentives or the approval of the Good Law. Given that, I evaluate the effect of investment in R&D on economic structure by exploiting the approval of the Good Law.

The Good Law influences firms' investment in R&D, which in turn determines municipalities' economic structure. I assume the approval of the Good Law is not related to non-observable municipal characteristics due to it is a federal law and has effects over all municipalities. Thus, the incentives is at least conditionally random at the municipal level. Given that, I use a two-stage least squares (2SLS) estimator. The use of a 2SLS estimator will display the local effect of private investment in technology on economic structure through the Good Law.

Data are for 1459 municipalities from 2002 to 2016 averaged over three-year periods. Furthermore, the data availability restricted the number of municipalities and period analyzed. I used three-year intervals in order to mitigate the correlation coming from business cycles effects (Fölster and Henrekson, 2001). By doing that, I tackle the influence of economic crisis or electoral cycles.

The dependent variable is the economic complexity index, while the endogenous regressor is the private R&D, both at the municipal level and from 2002 to 2016. The first stage and the structural equation of the 2SLS estimator are specified as proceed:

$$RD_{it} = \theta_i + Trend + \beta_1 Incent_t + \beta_2 HC_{it} + \beta_3 Phys.Cap_{it} + \beta_4 Tra_{it} + \sum_{a=1}^{a=4} \beta_{5a} Sect_{ait} + \epsilon_{it} \tag{14}$$

$$Eco.Struc_{it} = \theta_i + \kappa_t + \lambda_1 \widehat{RD_{it}} + \lambda_2 HC_{it} + \lambda_3 Phys.Cap_{it} + \lambda_4 Tra_{it} + \sum_{a=1}^{a=4} \lambda_{5a} Sect_{ait} + \eta_{it} \tag{15}$$

Where i stands for the municipality, t for the period and a for the economic sectors: agriculture (a=1), industry (a=2), non-government services (a=3) and government services (a=4). $Eco.Struc$ is economic structure; $Trend$ is a trend variable; $Incent$ is a dummy variable that is 1 if the Good Law was already implemented in the period and 0 otherwise; RD is private investment in technology; HC is human capital; $Phys.Cap$ is physical capital; Tra is trade openness; $Sect$ is a vector of the share of each economic sector; θ is the intercept for each municipality; κ is the intercept for each period; ϵ is the error term of the first stage; and η is the error term of the structural equation.

The economic structure proxy is the economic complexity index (ECI). The ECI relies on productive knowledge each economy has (Hidalgo et al., 2007; Hidalgo, 2009; Hidalgo and Hausmann, 2009). Economic complexity introduces a different way of looking at income growth, but it still presents few limitations. According to Salles et al. (2018), the three most important limitations are: not using data on services; analyzing only the supply side of economy; and ignoring the output that is not exported. Despite these limitations, Salles et al. (2018) concluded the ECI is the adequate approach to examine economic structure and the sophistication of exports.

The ECI was originally designed for national analysis, but the investigation focuses on municipalities. Hence, Freitas and Paiva (2015) proposed some adjustments to use the ECI at the subnational levels. They included in the calculation the share of the municipality's exports of a good to the country's total exports of that good and the

municipality's RCA in exporting that good. By doing so, the ECI is considering the municipality's share of a good in the country's total exports and also the importance of a good in the municipality's export basket.

Although the modification allows us to use the ECI at the municipal level, it does not take into account the relation between municipalities inside the country. To consider that relation, detailed trade data across municipalities should be used. In this aspect, Reynolds et al. (2018) used input-output tables to infer the ECI for Australian states and territories, whilst Gao and Zhou (2018) measured the ECI for Chinese provinces using data on firms. Moreover, Balland and Rigby (2017) used patent records to evaluate the complexity of knowledge for United States' cities.

The proxy for private investment in technology is the labor force working on research and scientific development area in each municipality. The proxy for human capital is the estimated total labor force in each municipality. The measure of physical capital is gross fixed capital formation weighted by municipality's total establishments as municipal output share[24].

The trade openness proxy is based on three measures: the sum of imports and exports as output share; the municipal population; and international trade terms. The first measure is regressed on the second one and the error term is put aside. The estimate's residual is related to all the other variables associated with trade openness, excepting municipal exports, imports and population. Then, the residual is multiplied by a measure of international trade terms, that is, the ratio of an export price index to an import price index. Hence, the trade openness proxy is adjusted for differences in imports, exports, population and international prices[25].

The vector of the economic sector has four variables. In order to consider the importance of each economic sector, the measure used is the municipal output share in terms of gross value-added by each sector. Thus, each variable is related to one of the four economic sectors, which are: agriculture; industry; non-government services; and government services.

3.3.2 Data source

The ECI value is between -∞ and ∞ with mean and standard deviation around 0 and 1, respectively. The ECI uses data from Brazilian Ministry of Development, Industry and Trade (MDIC). Data on economic complexity goes from 2002 to 2017 and *Dataviva*[26] made them available.

The measure of municipal private R&D is the labor force working on research and scientific development area. The number of jobs in that area depends on the municipality and lies between 0 and 7,585. Data on the labor force working on research and scientific development area come from the Annual Social Information Report (RAIS)[27] and is provided by Dataviva.

[24] Carmo et al. (2017) utilized a similar approach to infer the variation in physical capital at the micro-regional level.

[25] Our procedure for dealing with trade openness measures is akin to Barro (2003).

[26] *Dataviva* is a platform that is open. It is provided by the Government of the State of Minas Gerais, the State of Minas Gerais foundation for research funding and support (FAPEMIG), Minas Gerais Investment and Trade Promotion Agency (INDI) and Datawheel.

[27] RAIS is an annual administrative record of Brazilian formal labor market. It presents data on jobs, wages, industries, among others. These data are divided according to the National Classification of Economic Activities (CNAE). The Ministry of Labor and Employment (MTE) collects this information from all formal businesses.

The measure of human capital is the estimated total labor force in the municipality. The estimated quantity of workers[28] is between 118 and 1,399,537. Data on the estimated total labor force also come from RAIS and is provided by Dataviva.

The measure of the economic sectors is the output share of each economic sector. These output shares are between almost zero and something around 0.9, revealing possible disparities among municipalities in terms of economic sectors. Data on the output share of economic sectors are provided by the Brazilian Institute of Geography and Statistics (IBGE).

The proxies for physical capital and trade openness are calculated measures. Data on the variables used to calculated those measures come from IBGE, MDIC and the Foundation Center for Foreign Trade Studies (FUNCEX). The Table VII shows information on variables, proxies and sources.

Table VII: Data source and explanation for municipalities

Variable	Proxies	Uses data on	Source
Economic Structure	Economic Complexity Index	World's, country's and municipality's exports	Dataviva
Private R&D	The labor force working on research and scientific development	Jobs, wages, industries and the classification of economic activities	MTE
Instrument	The Good Law	The Law No. 11.196/2005	Brazilian Law System
Human Capital	The estimated total labor force in each municipality	Jobs, wages, industries and the classification of economic activities	MTE
Physical Capital	Gross fixed capital formation weighted by municipality's total establishments as municipal output share	Gross fixed capital formation and municipal data on establishments and output	IBGE and MTE
Trade Openness	A calculated measure of trade openness	Terms of trade and municipal data on exports, imports and output	MDIC, IBGE and FUNCEX
Economic Sector	Share of each economic sector in value-added	Value-added by agriculture, industry, government and non-government services	IBGE

Note: Dataviva is an open plataform that provides plenty of economic Brazilian data; MTE means Brazilian Ministry of Labor and Employment; IBGE means Brazilian Institute of Geography and Statistics; MDIC means Brazilian Ministry of Development, Industry and Trade; and FUNCEX means Foundation Center for Foreign Trade Studies.
Source: Elaborated by author.

Table VIII and IX exhibit the summary statistics of two periods, before and after the Good Law was approved. The first period is from 2002 to 2005, while the second period is from 2006 until 2015.

From Table VIII and IX, I can draw that the period after the approval of the Good Law was marked of improvements in economic structure, human capital and trade openness when compared with the period before the approval of the law.

3.4 Results and Discussion

Trying to satisfy the first assumption of a 2SLS estimator, I have run a regression of the endogenous variable on the instrument and the control variables, as in Equation 14. Table X presents the results of regressing the labor force working on research and development area on a dummy representing the existence or not of the Good Law and control variables.

As exposed in Table X, the Good Law has a significant effect on research and development. Hence, the first assumption for a good instrument is satisfied and the instrument is relevant. Though statistical tests do not back up the analysis properly, two of them were made. The first test was the underidentification test, which uncover

[28]This proxy is considering the quantitative aspect of human capital. The use of the quality of human capital would enhance the analysis as Leite and Cardoso (2023) did when studying countries' economic structure.

Table VIII: Summary statistics for municipalities between 2002 and 2005

	Observation	Mean	Std.Dev.	Minimum	Maximum
Economic structure	2085	-0.0017	0.855	-10.87	12.28
Research and Development	5558	5.5796	91.869	0	4019.7
Good Law	5560	0	0	0	0
Human capital	5558	11287	19281	6268	1103688
Physical capital	5558	0.0003	0.0002	0.000004	0.001
Trade Openness	1391	-2109	38671	-22696	701359
Agriculture	5560	0.2588	0.1669	0	0.8091
Industry	5560	0.1328	0.1459	0.01093	0.9561
Non-government services	5560	0.2918	0.1227	0.01307	0.8768
Government services	5560	0.3166	0.1664	0.01207	0.9410

Note: The Good Law stands for the federal Law No. 11.196 passed in 2005, which fosters private investment in research and development.
Source: Dataviva; Brazilian Ministry of Labor and Employment; Brazilian Institute of Geography and Statistics; Brazilian Ministry of Development, Industry and Trade; and Foundation Center for Foreign Trade Studies.

Table IX: Summary statistics for municipalities between 2006 and 2016

	Observation	Mean	Std.Dev.	Minimum	Maximum
Economic structure	5772	0.0165	1.068	-10.07	18.65
Research and Development	22262	8.2561	141.5	0	7585.3
Good Law	22264	1	0	1	1
Human capital	22262	12956	22120	118	1399537
Physical capital	22262	0.0002	0.0001	0.000003	0.0011
Trade Openness	6433	-1855	57868	-25366	3094721
Agriculture	22264	0.2132	0.1522	0	0.8674
Industry	22264	0.1384	0.1439	0.005233	0.9522
Non-government services	22264	0.3131	0.1264	0.01237	0.8945
Government services	22264	0.3352	0.1720	0.0096	0.9497

Note: The Good Law stands for the federal Law No. 11.196 passed in 2005, which fosters private investment in research and development.
Source: Dataviva; Brazilian Ministry of Labor and Employment; Brazilian Institute of Geography and Statistics; Brazilian Ministry of Development, Industry and Trade; and Foundation Center for Foreign Trade Studies.

whether the first-stage equation is identified or not. The second test was the weak-identification test, which checks whether the instrument is weak or not.

The null hypothesis of the underidentification test is that the equation is underidentified. The LM statistic was 10.787 and Chi² p-value was 0.001, which rejects the null hypothesis at the 0.01 significance level, so the first-stage equation is not underidentified. Then, the model is identified and the instrument has a direct effect on the endogenous variable, which means the instrument is relevant. Putting the underidentification test aside, I emphasize the positive and significant relation between the Good Law and the labor force working on research and development area.

Table X: Economic structure regression for municipalities (First stage)

	Research and Development
The Good Law	0.03135*** (3.902)
Human capital	-0.26929** (0.000761)
Physical capital	0.01241 (15885.3)
Trade Openness	0.00205* (0.00000493)
Agriculture	0.05252*** (26.61)
Industry	-0.01263 (14.12)
Non-government services	-0.01450 (16.50)
Government services	0.01781 (23.48)
Observation	5618
F-statistic [p-value]	26.22 [0.0000]
Anderson-Rubin Wald Test-Statistic [p-value]	4.35 [0.0371]

Note: I used municipal fixed effects and a trend variable. Standard errors in parentheses and clustered at the municipal level; * $p < .1$, ** $p < .05$, *** $p < .01$
Source: Elaborated by author.

After the identification, the instrument effectiveness is tested. The critical values for this test are 16.38, 8.96, 6.66 and 5.53 for, respectively, maximal of 10%, 15%, 20% and 25% bias the 2SLS estimator is taking when compared to a similar Ordinary Least Squares (OLS) estimator. Thus, comparing the F-statistic of both Cragg-Donald Wald test, 25.420, and Kleibergen-Paap rk Wald test, 11.407, to the critical values yields I am assuming 15% maximal bias[29]. Hence, the instrument is not weak only if I consider 15% or more maximal bias.

Table XI displays the structural form outcomes. Moreover, the 2SLS estimator is compared to three alternative estimators. The first on is the Ordinary Least Squares estimator, which is efficient and consistent under exogenous regressors. The second one is the Panel (A) estimator that presumes the unobservable heterogeneity is constant over time, so including a municipal fixed effect brings up the causal effect. The third one is the Panel (B) estimator, which considers the unobservable heterogeneity is not constant but could be dealt with the use of a municipal fixed effect and a time trend. The three alternative estimators have different assumptions but their results are similar to the 2SLS estimator.

Henceforth and for the 2SLS estimator, I consider the significance level at 0.10. According to Table XI, only research and development showed a significant effect on economic structure at the municipal level. Furthermore, human capital, physical capital, trade openness and the economic sectors of agriculture, industry, non-government services and government services had no significant effect at all. I suppose the Brazilian municipalities are different in human and physical capital as well as in trade openness and economic sectors so that the effects of these variables on economic structure

[29]Both tests check for the possibility of a weak instrument. However, the Cragg-Donald Wald test is indicated when the residual is assumed to be independent and identically distributed (i.i.d.). When the assumption is that residual is not i.i.d., the Kleibergen-Paap rk Wald test is recommended.

Table XI: Economic structure regression

	OLS	Panel (A)	Panel (B)	2SLS
Research and Development	-0.04274	0.11609*	0.11591*	0.42647**
	(0.000412)	(0.000252)	(0.000251)	(0.000809)
Human capital	0.39334***	-0.04678**	-0.04683**	0.03742
	(0.000002)	(0.0000006)	(0.0000006)	(0.000002)
Physical capital	-0.08158***	-0.01692	-0.01382	-0.01484
	(202.8)	(111.0)	(178.7)	(194.9)
Trade Openness	-0.04159	-0.02345	-0.02347	-0.02521
	(0.000001)	(0.0000004)	(0.0000004)	(0.000001)
Agriculture	0.05518***	0.02142	0.02315	0.01379
	(0.114)	(0.142)	(0.172)	(0.209)
Non-government services	0.02213	-0.03505	-0.03526	-0.02134
	(0.152)	(0.179)	(0.181)	(0.175)
Industry	0.10707***	-0.03938*	-0.03922*	-0.02482
	(0.195)	(0.156)	(0.155)	(0.236)
Government services	-0.02882	0.00065	0.00006	-0.00657
	(0.156)	(0.166)	(0.166)	(0.109)
Observation	5973	5973	5973	5618
F-statistic	9.1875	4.6137	4.1100	13.9784
P-value	0.0000	0.0000	0.0000	0.0000
Municipal FE	No	Yes	Yes	Yes
Time trend	No	No	Yes	Yes

Note: OLS is Ordinary Least Squares and 2SLS is Two Stages Least Squares. Standardized beta coefficients; standard errors in parentheses and clustered at the municipal level; $^{*}\ p < .1$, $^{**}\ p < .05$, $^{***}\ p < .01$.

Source: Elaborated by author.

were dispersed. Another reason for that result is that human capital and trade openness affect economic structure via research and development as in Table X.

The coefficients are in standard-deviation terms. Hence, a one-standard-deviation increase in research and development is associated with a 0.43 standard-deviation expansion in economic structure. In order to depict what a one-standard-deviation increase means, few examples are given.

From 2003 to 2014, a one-standard-deviation increase in research and development happened in a period of one year in 44 municipalities. Yet considering a period of one year, a two-standard-deviation and a three-standard-deviation increases in research and development occurred in 16 municipalities and 11 municipalities, respectively. The municipalities that presented the larger increases in research and development in a period of one year were Rio de Janeiro-RJ, Belo Horizonte-MG, São Paulo-SP, Campinas-SP, Belém-PA, Salvador-BA and Santa Luzia-MG.

Taking into consideration a period of two years, a one-standard-deviation rise oc-

curred in research and development in 47 municipalities. Yet in a period of two years, a two-standard-deviation increase happened in research and development in 16 municipalities, while a three-standard-deviation rise took place in 11 municipalities. The municipalities that showed the larger rises in research and development in a period of two years were all the ones that presented larger increases in a period of one year as well as Brasília-DF, Maceió-AL, Manaus-AM, Porto Alegre-RS and Curitiba-PR.

These outcomes indicate that only few municipalities could have larger increases in the labor force working on research and development in a period of one or two years. Furthermore, an expansion of one or two standard deviations tend to occur in big cities, especially in state capitals. However, Campinas-SP and Santa Luzia-MG are not state capitals but presented larger increases in investment in technology. It may come from the size of those municipalities or from their connections with their state capitals.

In order to check the robustness of the results, I tested alternative proxies for the right-hand variables of Equation 15. The first alternative measure is total labor force in the municipality as a proxy for human capital instead of the estimated total labor force in the municipality. Even though the alternative measure is related to the one used in this investigation, the results were not similar. I believe using the estimated total labor force tackles the issue of the non-formal labor market so that the direct effect of human capital on economic structure is captured.

Regarding physical capital, I used two alternative measures for this variable. The first measure was gross fixed capital formation adjusted by municipality's total establishments but municipal output was not considered. The second measure was the quantity of establishments in the municipality. Both alternative proxies for physical capital turned the relation between research and development and economic structure insignificant.

Drawing attention to trade openness, two alternative proxies might be used instead of the measure employed. The first alternative proxy was the sum of imports and exports as the output share. The second alternative proxy was the effective diversity of exports destinations, which depends on the quantity of locations importing the municipality's products as well as on the share of each importing location. Although the differences in calculations, using each of the alternative proxies for trade openness produced similar results when compared to the constructed measure based on imports, exports, output, population and trade terms.

3.5 Concluding Remarks

This investigation contributes to the debate on the importance of private investment in technology in municipal economic structure. Assuming the sophistication of exports reveals economic structure and suggests future income growth, this study focuses on the relationship between private investment in technology and export sophistication.

The proxy for export sophistication was the economic complexity index. This measure is based on the diversity and ubiquity levels of exports, the share of international trade, the connections between products, the relevance of the municipality in the nation's total exports and the importance of the product in the municipal export basket. The estimate is from 2002 to 2016 averaged over three-year periods with a sample of 1459 municipalities.

Results indicate private investment in technology influences economic structure. The measure of private investment in technology is total labor force working on re-

search and development area. The Good Law presented an effect on private investment in technology, which means the instrument is effective. Thus, private investment in research and development is a fundamental key in explaining municipal economic structure. Moreover, the Good Law was an appropriate instrument for municipal private investment in technology. That is, the approval of the Good Law presented a significant effect on private investment in technology, which in turn influences the economic structure.

My findings suggest the Good Law, which brings up incentives for firms to invest in research and development, conduces to improvements in economic structure. Therefore, policies fostering such incentives, as the Good Law, should be encouraged.

The main limitation of this study is data availability, especially in terms of the economic structure observations. Thus, it is possible that the quantity of observations has certain effects on the estimate efficiency. Additionally, a suggestion for further studies is analyzing the opportunity costs associated with the implementation of the Good Law.

4 GENERAL CONCLUSION

This thesis contributes to the debate on the relevance of both human capital and private investment in technology to economic structure. Considering better economic structure is an indicator of future income growth, I pursued the drivers of economic structure. Given that, two approaches were developed to investigate economic structure at the sub-national level.

The first approach tackled the relation between human capital and economic structure at the micro-regional level. The idea was to bypass the endogeneity of human capital and economic structure by exploiting an exogenous variation in the former. This exogenous variation in human capital was the expansion of the Brazilian federal network of technological and professional education that occurred since 2005.

The main result of the first paper is that human capital has a positive and significant effect on economic structure. Thus, the expansion of the Brazilian federal network of technological and professional education influenced the micro-regions' human capital, which in turn affected economic structure. Hence, policies related to increases in the places in federal institutes of technology should be stimulated.

The second approach deals with the relationship between private investment in technology and economic structure at the municipal level. The idea was to mitigate the endogeneity issues by taking advantage of the implementation of a federal law related to private investment in technology. That law was the Good Law and it was employed as an exogenous variation in private investment in technology. The implementation of the Good Law was in 2005.

The core result of the second paper is that private investment in technology presents a positive and significant effect on economic structure. Thus, the Good Law was effective in fostering investment in research and development in the municipalities, which in turn altered economic structure. Hence, policies associated with incentives for investment in technology should be supported.

Given the outcomes of the two approaches, I state that both human capital and private investment in technology matter for economic structure, being drivers of it. Furthermore, the two public policies analyzed presented satisfactory effects on influencing human capital or investment in technology. Therefore, more efforts should be used in designing effective policies associated with the drivers of economic structure.

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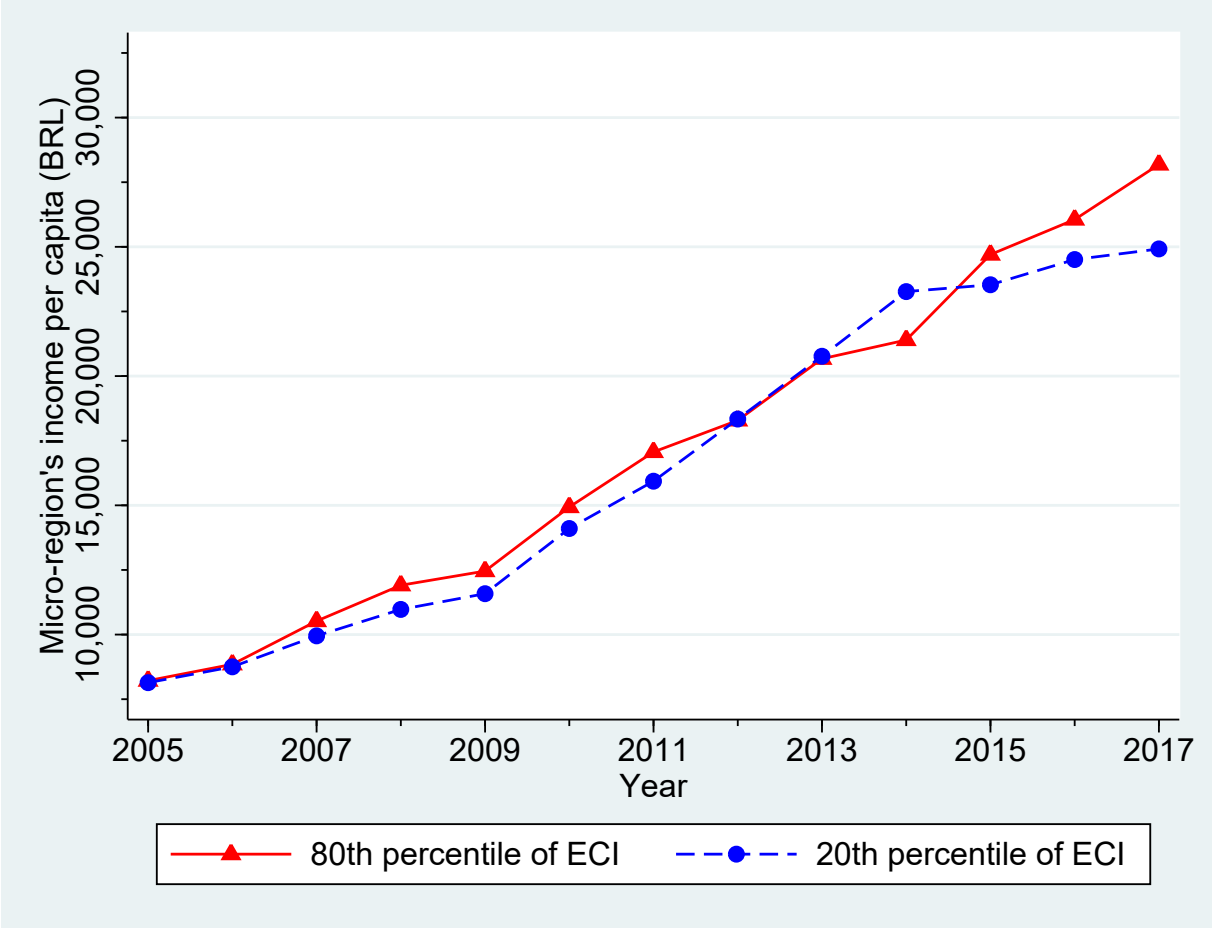
Appendices

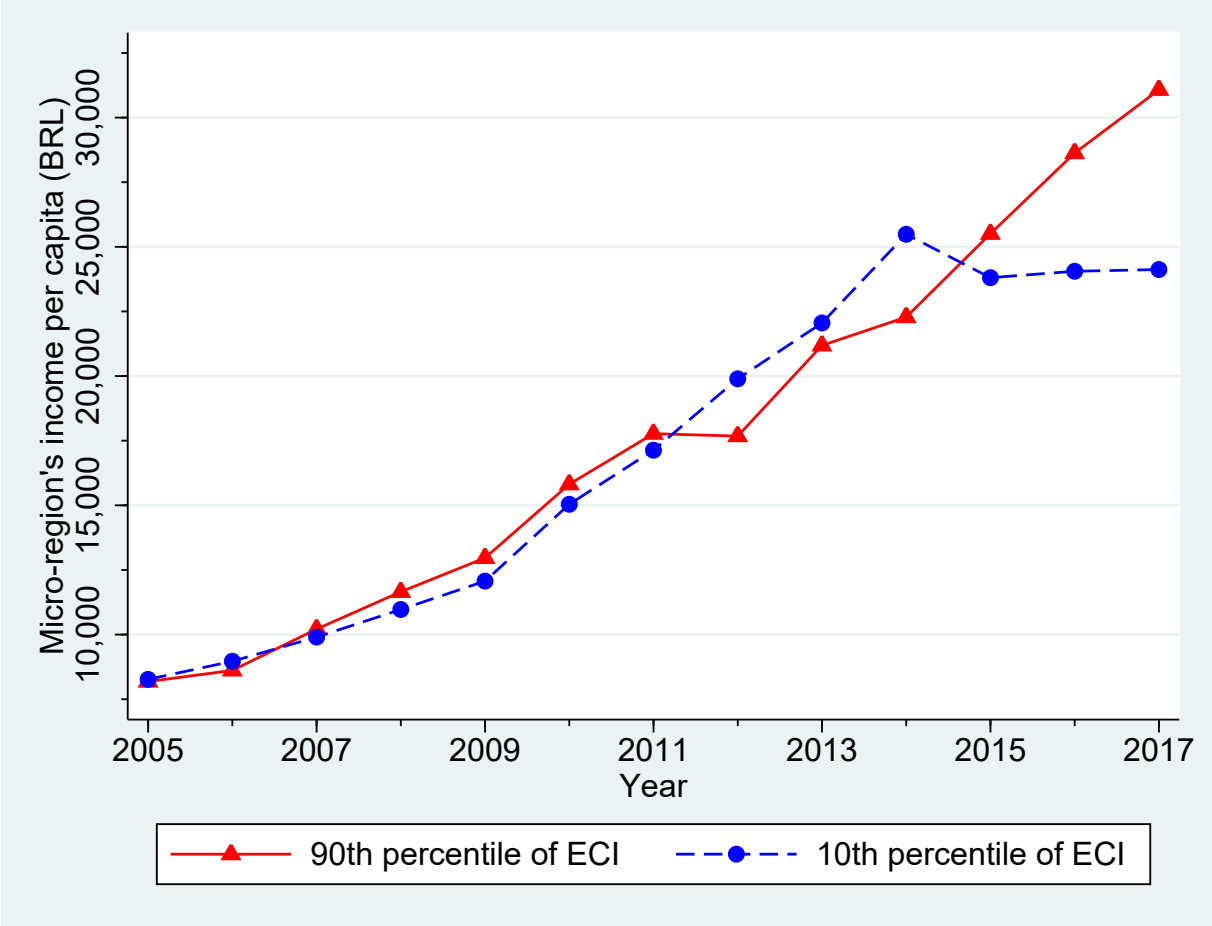
Appendix A

Figure 4: Average income of micro-regions with similar income but different economic complexity in 2005



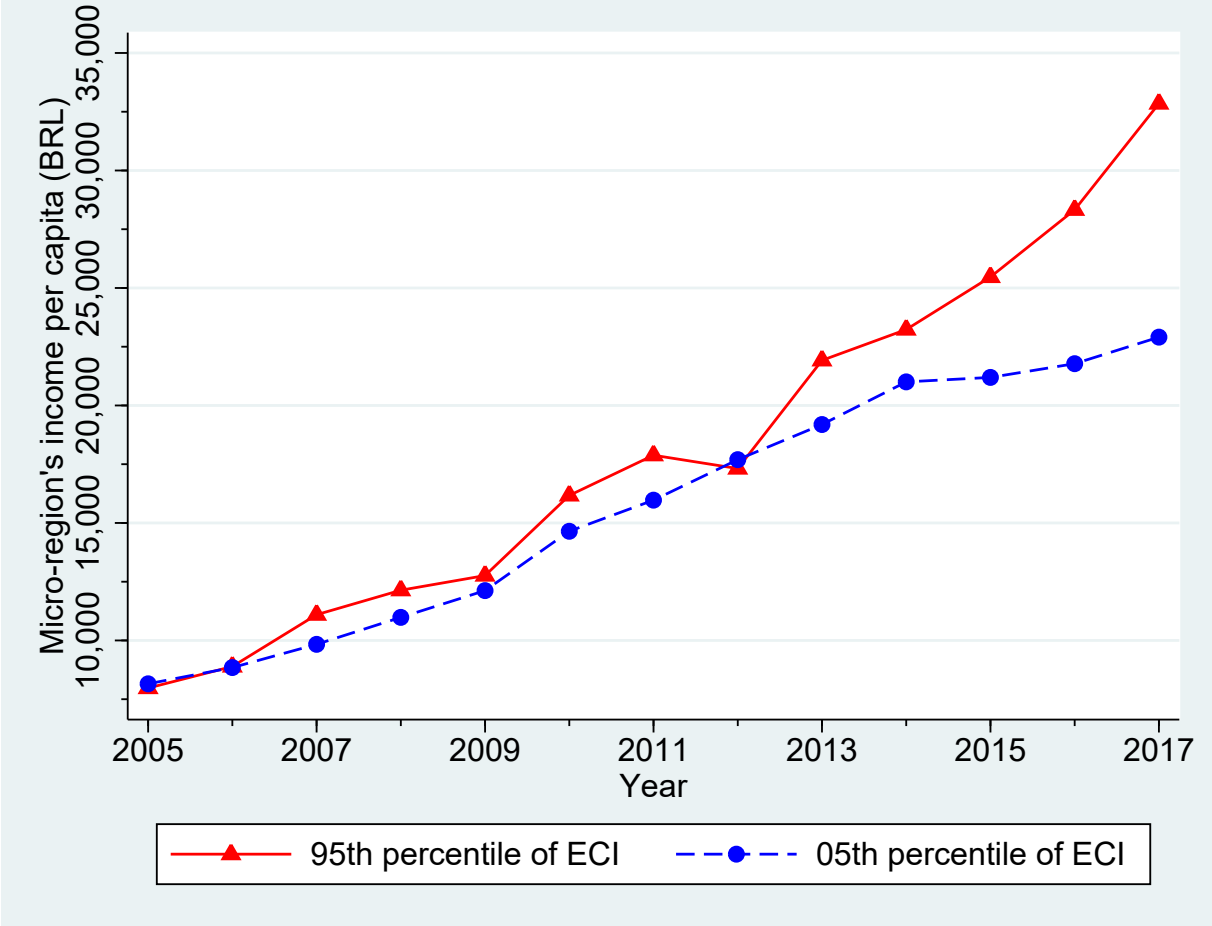
Note: Per capita income is at current Brazilian Reals.
Source: Elaborated by author.

Figure 5: Average income of micro-regions with similar income but different economic complexity in 2005



Note: Per capita income is at current Brazilian Reals.
Source: Elaborated by author.

Figure 6: Average income of micro-regions with similar income but different economic complexity in 2005



Note: Per capita income is at current Brazilian Reals.
Source: Elaborated by author.