The effect of private investment in technology on economic structure

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Abstract

We investigate the effect of private investment in technology on economic structure. An export sophistication index - the Economic Complexity Index - is used as a proxy for economic structure. The use of economic complexity is due to it is an adequate measure of per capita income growth. 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 effect on economic structure. We concluded investment in technology should be promoted, especially by laws that incentives this kind of investment and aiming economic structure improvements. (JEL: O11; O32; F43)
Keywords: Economic structure, investment in technology, economic complexity.

Resumo

O artigo investiga o efeito do investimento privado em tecnologia na estrutura econômica. Um índice de sofisticação das exportações - o Índice de Complexidade Econômica - é usado como proxy para a estrutura econômica. O uso da complexidade econômica se deve ao fato de ser uma medida adequada do crescimento da renda per capita. Uma lei federal de fomento ao investimento privado em pesquisa e desenvolvimento é utilizada como instrumento para o investimento em tecnologia. A base de dados é sobre investimento em tecnologia no nível municipal para o Brasil de 2002 a 2016. Os resultados mostraram que a lei federal foi eficaz e que o investimento privado em tecnologia tem um efeito positivo e significativo na estrutura econômica. Concluímos que o investimento em tecnologia deve ser incentivado, principalmente por meio de leis que incentivem esse tipo de investimento e visando melhorias na estrutura econômica. (JEL: O11; O32; F43)
Palavras-chaves: Estrutura produtiva, investimento em tecnologia, complexidade econômica.

1 Introduction

Investment in research and development (R&D) aims to expand the labor force's absorption and creation of technology, which is strongly linked to economic performance. Technological progress is an important way to achieve economic growth (Aghion and Howitt, 1992). However, economic results of such investment may differ given the investment funding sources. That is, private spending on R&D may diverge from public investment in R&D in goals, acting and timing.

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 (Zhang et al., 2003). Hence, the 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).

Justman and Teubal (1991) stated there is a link between technological progress and structural change and this relation holds for industrialized and developing nations. According to them, structural change is a precondition for economic growth. Moreover, Pan (2006) affirmed investment in R&D drives technological development, shaping economic structure. And Ngoc and Hai (2019) stressed 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. And, 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 similarity in them. By similarity, we mean economies with more private R&D have better economic structures, whilst economies with less private R&D 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 considered. Moreover, if there is not a third factor but a bi-causality between private R&D and economic structure, a variation exogenous to private R&D and not related to other factors influencing the economic structure would be used. Hence, an exogenous variation in private R&D would change economic structure, displaying the effect of the former on the latter.

In this strand, we 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. This law provides a few incentives for firms to invest in R&D, consolidating the relationship between private R&D and economic structure. Thus, we believe the implementation of that law causes an alteration in the private R&D, which afterwards improves economic structure.

Although it is satisfactory to investigate the effect of private R&D on economic structure at the national level, we 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. This study proposes to increase the knowledge of economic structure and 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.

Our hypothesis is that private investment in technology determines economic structure. Moreover, the Law No. 11.196/2005 increases 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. 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.

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.

2 Theoretical Background

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 workforce uses at production. 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 future growth. Hence, if an economy presents more per capita income than its economic complexity predicts, it would have slower or negative income growth. And, 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 produces 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). Focusing on investment in technology and it effect on economic structure brings up relevant 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.

2.2 Investment in technology

Technology has been underlined as an important factor in expanding output (Romer, 1990). Further, it is expected an economy with a high level of investment in technology could have faster access to new ideas of manufacturing goods. New ideas are related to better machines, different designs or new products (Grossman and Helpman, 1991).

Using the endogenous economic growth model Jones (1995) proposed and leaving out physical capital for simplicity, we relate production, human capital and technology:

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

$$\frac{\dot{A}_t}{A_t} = \theta L_{A_t} A_t^{-\beta} \quad , \qquad \beta > 0 \tag{2}$$

$$L_{Y_t} + L_{A_t} = L_t = L_0 e^{nt} \tag{3}$$

$$L_{A_t} = \overline{s} L_t \tag{4}$$

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

Equation (1) 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. According to Romer (1989), investments in technology present increasing returns to scale. It happens because technology is non-rival, which makes it have a convex relation to output. Given convexity, as more new ideas are developed, larger will be the effect on output.

Equation (2) is the production function of ideas. Accordingly, the technology growth rate 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 technology growth rate and the level of technology (Jones, 2019).

Equation (3) 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 (4) 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 $y \equiv Y/L$, we rewrite Equation (1) as:

$$y_t = A_t^{\alpha}(1 - \overline{s}) \tag{5}$$

Where output per capita is a function of the total stock of technology and the proportion of labor working on output. The main difference from a basic Solow model is that a new idea will increase the overall productivity by being used everywhere. On the other hand, an additional unit of a productive factor that are rival 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 achieved by a new idea spread everywhere.

Rearranging Equation (2) and taking logs and derivatives in relation to time of Equation (5):

$$g_A = \theta \frac{L_{A_t}}{A_t^{\beta}} \tag{6}$$

$$g_y = \alpha g_A \tag{7}$$

Where g stands for the growth rate. To have a g_A constant in the long run, the right side of Equation (6) has to be constant too. So, equaling the numerator and the denominator of the right side of Equation (6) and taking logs and derivatives in relation to time:

$$g_A = \frac{g_{L_A}}{\beta} = \frac{n}{\beta} \tag{8}$$

Combining the Equations (7) and (8), we have:

$$g_y = \frac{\alpha n}{\beta} \tag{9}$$

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. First, the interaction between the non-rivalry of new ideas (α) and the increasing difficulty to expand technology (β) determines 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_A). It happens due to a larger population growth rate means more labor allocated in finding new ideas, rising output per person.

2.3 Economic structure and private investment in technology

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 way 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 R&D. 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.

Studying the relation between private investment in technology and economic structure lead us to relevant issues, especially on the diffusion of new ideas. Breschi and Lissoni (2009) stated knowledge is locally tied, so taking a sub-national measure of investment in technology would yield oriented public policies. Further, Almeida and Kogut (1999) affirmed ideas are created and transferred within a spatially market, which is the core notion of tacit knowledge. Tacit knowledge is one of the supporting concept of economic complexity, the proxy for economic structure.

In this context, we suppose certain factors influence municipal economic structure, such as: physical capital; human capital; and investment in technology. Focusing 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.

Considering the differences in municipalities, it is worth noting that 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, this investigation concentrates on the relation between private investment in technology and economic structure at the municipal level.

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 accepted.

Guellec and van Pottelsberghe de la Potterie (2003) argued 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 ones.

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, discouraging public R&D.

David et al. (2000) explained firms use an analysis of expected cost and benefit when deciding whether invest in R&D or not, and if so, how much. According to this approach, there is a downward sloping curve that is related to the benefits of R&D, while the 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 benefit and the 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. Further, they concluded public and higher education R&D may take time for economy to reap the benefits.

As stated by 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 Methodology

A comparison between private R&D and economic structure without considering omitted variables would generate inconsistent estimates. Omitted variables would be institutions, public investment in technology or geographical features. The 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 the former on the latter. 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 the former is used and the latter 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, a manner 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.

3.1 Identification Strategy

The identification strategy takes advantage of a variation in private R&D that is exogenous to its own municipality. We 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 implementation of the Law No. 11.196/2005, 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[1] The Good Law has 17 chapters and each chapter is related to a specific subject. However, we are particularly interested in the first three chapters and the incentives granted for firms in them.

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 7.5% 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. The normal percentage of import-PIS and import-COFINS are the same applied to PIS and COFINS.

[1] 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 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 are given due to the quantity of researchers allocated for R&D activities.

In this line, we assume incentives foster firms to rise investment in R&D. Thus, we take the incentives as a source of exogenous variation in private R&D, once it is economically reasonable. Further, we believe the approval of the Good 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. And, the incentives are equal to all companies[2] so there is no association between the other variables and the incentives or the approval of the Good Law. Given that, we 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. We 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 mu-

[2]The first chapter of the the Good Law is dedicated only to exporting firms of the information technology sector (IT). However, the second and especially the third chapter of the law offer incentives to all firms, excepting the ones opting for the "Simples Nacional" regime. The Simples Nacional tax regime is possible only for firms with a revenue of 4,8 million Brazilian reals in the last 12 months.

nicipal level. Given that, we 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. Further, the data availability restricted the number of municipalities and period analyzed. We used three-year intervals in order to mitigate the correlation coming from business cycles effects (Fölster and Henrekson, 2001). By doing that, we 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:

$$PI_{it} = \theta_i + Tr + \beta_1 Inc_t + \beta_2 HC_{it} + \beta_3 PC_{it} + \beta_4 TO_{it} + \sum_{a=1}^{a=4} \beta_{5a} ES_{ait} + \epsilon_{it} \tag{10}$$

$$Eco.Str_{it} = \theta_i + \kappa_t + \lambda_1 \widehat{PI_{it}} + \lambda_2 HC_{it} + \lambda_3 PC_{it} + \lambda_4 TO_{it} + \sum_{a=1}^{a=4} \lambda_{a5} ES_{ait} + \eta_{it} \tag{11}$$

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). $Eco.Str$ is economic structure; Tr is a trend variable; Inc is a dummy variable that is 1 if the Good Law was already implemented in the period and 0 otherwise; PI is private investment in technology; HC is human capital; PC is physical capital; TO is trade openness; ES is a vector of the share of each economic sector; θ is the intercept for each municipality; 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[3].

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[4].

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.

3.2 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*[5] 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 munici-

[3] Carmo et al. (2017) utilized a similar approach for variation in micro-regional physical capital.

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

[5] *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.

pality 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)[6] and is provided by Dataviva.

The measure of human capital is the estimated total labor force in the municipality. The estimated quantity of workers is between 118 and 1,399,537. Data on the estimated total labor force also come from RAIS and is provided by Dataviva. The proxy for 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 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 I shows information on variables, proxies and sources. Table II and III 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 II and III, we 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.

Table I: 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.

[6] 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.

Table II: Summary statistics for municipalities between 2002 and 2005

	Observation	Mean	Std.Dev.	Minimum	Maximum
Economic structure	2085	-0.001734	0.8551	-10.869	12.282
Research and Development	5558	5.5796	91.869	0	4019.7
Good Law	5560	0	0	0	0
Human capital	5558	11287.4	19280.6	6268.0	1103687.9
Physical capital	5558	0.0003	0.0002	0.000004	0.001
Trade Openness	1391	-2109.3	38671.2	-22696.0	701358.6
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.

Source: Dataviva; MTE; MEC; IBGE; MDIC and FUNCEX.

Table III: Summary statistics for municipalities between 2006 and 2016

	Observation	Mean	Std.Dev.	Minimum	Maximum
Economic structure	5772	0.01650	1.0680	-10.074	18.653
Research and Development	22262	8.2561	141.49	0	7585.3
Good Law	22264	1	0	1	1
Human capital	22262	12955.5	22120.1	117.66	1399537.1
Physical capital	22262	0.0002	0.0001	0.000003	0.001
Trade Openness	6433	-1854.5	57867.6	-25366.2	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	0.009600	0.9497

Note: The Good Law stands for the federal Law No. 11.196 passed in 2005.

Source: Dataviva; MTE; MEC; IBGE; MDIC and FUNCEX.

4 Results and Discussion

To try to satisfy the first assumption of a 2SLS estimator, we have run a regression of the first stage. The results of the first stage were that the Good Law has a significant effect on R&D. Then, the first assumption for a good instrument is fulfilled and the instrument is relevant. We also made two statistical tests. The first test was the underidentification test, which uncover whether the first-stage equation is identified. The second test was the weak-identification test, which checks whether the instrument is weak. Moreover, Table IV shows the results of the structural form and three other estimators are presented to be compared with the 2SLS estimator.

Hereafter, we consider the significance level at 0.10. According to Table IV, only R&D has a significant effect on economic structure. Further, 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. We 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 were dispersed. Another reason for that result is human capital and trade openness affect economic structure via R&D.

The coefficients are in standard-deviation terms. Hence, a one-standard-deviation rise in R&D is associated with a 0.43 standard-deviation increase in economic structure. To depict what a one-standard-deviation increase means, few examples are given.

From 2003 to 2014, a one-standard-deviation increase in R&D 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 R&D occurred in 16 municipalities and 11 municipalities, respectively. The municipalities that presented the larger increases in R&D 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.

Considering a period of two years, a one-standard-deviation rise occurred in R&D in 47 municipalities. Yet in a period of two years, a two-standard-deviation increase happened in R&D in 16 municipalities, while a three-standard-deviation rise took place in 11 municipalities. The municipalities that showed the larger rises in R&D 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 only few municipalities could have larger increases in the labor force working on R&D in a period of one or two years. Further, 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 mu-

Table IV: 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)	(0.000001)	(0.000001)	(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
	(0.0000006)	(0.0000004)	(0.0000004)	(0.0000006)
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: Standardized beta coefficients; standard errors in parentheses and clustered at the municipal level; $^{*}\ p < .1$, $^{**}\ p < .05$, $^{***}\ p < .01$.

Source: Elaborated by author.

nicipalities or from their connections with their state capitals.

In order to check the robustness of the results, we tested alternative proxies for the right-hand variables of Equation 11. 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. We 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, we used two alternative measures. The first one was gross fixed capital formation adjusted by municipality's total establishments but municipal output was not considered. The second one was the quantity of establishments in the municipality. Both alternative proxies for physical capital turned the relation between R&D 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.

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.

According to results, private investment in R&D is a central key in explaining municipal economic structure. This variable showed a positive effect on economic complexity. Moreover, the Good Law was an appropriate instrument for municipal private investment in technology. That is, the Good Law presented a positive and significant effect on private investment in technology, which in turn influences the economic structure.

Our findings suggests the Good Law, which brings up incentives for firms to invest in R&D, 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.

References

Adak, M. (2015). Technological progress, innovation and economic growth; the case of turkey. *Procedia-Social and Behavioral Sciences*, 195:776–782.

Aghion, P. and Howitt, P. (1992). A model of growth through creative destruction. *Econometrica*, 60(2):323–351.

Almeida, P. and Kogut, B. (1999). Localization of knowledge and the mobility of engineers in regional networks. *Management science*, 45(7):905–917.

Balland, P.-A. and Rigby, D. (2017). The geography of complex knowledge. *Economic Geography*, 93(1):1–23.

Barro, R. J. (2003). Determinants of Economic Growth in a Panel of Countries. *Annals of Economics and Finance*, 4(2):231–274.

Becker, B. (2015). Public R&D policies and private R&D investment: A survey of the empirical evidence. *Journal of economic surveys*, 29(5):917–942.

Bilbao-Osorio, B. and Rodríguez-Pose, A. (2004). From R&D to innovation and economic growth in the EU. *Growth and Change*, 35(4):434–455.

Breschi, S. and Lissoni, F. (2009). Mobility of skilled workers and co-invention networks: an anatomy of localized knowledge flows. *Journal of economic geography*, 9(4):439–468.

Carmo, A. S. S. d., Raiher, A. P., and Stege, A. L. (2017). O efeito das exportações no crescimento econômico das microrregiões brasileiras: uma análise espacial com dados em painel. *Estudos Econômicos (São Paulo)*, 47:153–183.

Chen, B. and Feng, Y. (2000). Determinants of economic growth in China: Private enterprise, education, and openness. *China Economic Review*, 11(1):1–15.

Coccia, M. (2010). Public and private R&D investments as complementary inputs for productivity growth. *International Journal of Technology, Policy and Management*, 10(1-2):73–91.

Cohen, W. M., Nelson, R. R., and Walsh, J. P. (2002). Links and impacts: the influence of public research on industrial R&D. *Management science*, 48(1):1–23.

David, P. A., Hall, B. H., and Toole, A. A. (2000). Is public R&D a complement or substitute for private R&D? a review of the econometric evidence. *Research policy*, 29(4-5):497–529.

Fölster, S. and Henrekson, M. (2001). Growth effects of government expenditure and taxation in rich countries. *European Economic Review*, 45(8):1501–1520.

Freitas, E. E. and Paiva, E. A. (2015). Diversificação e sofisticação das exportações: uma aplicação do product space aos dados do brasil. *Revista Econômica do Nordeste*, 46(3):79–98.

Gao, J. and Zhou, T. (2018). Quantifying china's regional economic complexity. *Physica A: Statistical Mechanics and its Applications*, 492:1591–1603.

Geiger, R. L. and Sá, C. (2005). Beyond technology transfer: Us state policies to harness university research for economic development. *Minerva*, 43(1):1–21.

Gould, D. M. and Ruffin, R. J. (1995). Human capital, trade, and economic growth. *Weltwirtschaftliches Archiv*, 131(3):425–445.

Grossman, G. M. and Helpman, E. (1991). Quality ladders in the theory of growth. *The review of economic studies*, 58(1):43–61.

Guellec, D. and van Pottelsberghe de la Potterie, B. (2003). The impact of public R&D expenditure on business r&d. *Economics of innovation and new technology*, 12(3):225–243.

Hausmann, R., Hwang, J., and Rodrik, D. (2007). What you export matters. *Journal of Economic Growth*, 12(1):1–25.

Hidalgo, C. A. (2009). The Dynamics of Economic Complexity and the Product Space over a 42 year period. *CID Working Paper*, 189.

Hidalgo, C. A. and Hausmann, R. (2009). The building blocks of economic complexity. *Proceedings of the National Academy of Sciences of the United States of America*, 106(26):10570–10575.

Hidalgo, C. A., Klinger, B., Barabási, A.-L., and Hausmann, R. (2007). The product space conditions the development of nations. *Science*, 317(5837):482–487.

Ishibashi, I. and Matsumura, T. (2006). R&D competition between public and private sectors. *European Economic Review*, 50(6):1347–1366.

Jones, C. I. (1995). R& D-based models of economic growth. *Journal of political Economy*, 103(4):759–784.

Jones, C. I. (2019). Paul romer: Ideas, nonrivalry, and endogenous growth. *The Scandinavian Journal of Economics*, 121(3):859–883.

Justman, M. and Teubal, M. (1991). A structuralist perspective on the role of technology in economic growth and development. *World Development*, 19(9):1167–1183.

Ngoc, B. H. and Hai, D. B. (2019). The impact of foreign direct investment on structural economic in vietnam. In *Beyond Traditional Probabilistic Methods in Economics 2*, pages 352–362. Springer.

Pan, H. (2006). Dynamic and endogenous change of input–output structure with specific layers of technology. *Structural Change and Economic Dynamics*, 17(2):200–223.

Reynolds, C., Agrawal, M., Lee, I., Zhan, C., Li, J., Taylor, P., Mares, T., Morison, J., Angelakis, N., and Roos, G. (2018). A sub-national economic complexity analysis of Australia's states and territories. *Regional Studies*, 52(5):715–726.

Romer, P. M. (1989). Increasing returns and new developments in the theory of growth. *NBER Working paper*, (w3098).

Romer, P. M. (1990). Endogenous technological change. *Journal of Political Economy*, 98(5):S71–S102.

Salles, F. C., da Rocha, E. M. P., de Bessa Porto, I. V., and Vasconcelos, F. L. V. (2018). A armadilha da baixa complexidade em minas gerais: o desafio da sofisticação econômica em um estado exportador de commodities. *Revista Brasileira de Inovação*, 17(1):33–62.

Zhang, A., Zhang, Y., and Zhao, R. (2003). A study of the R&D efficiency and productivity of Chinese firms. *Journal of Comparative Economics*, 31(3):444–464.