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A state science and technology indicator: use of intellectual property as a proxy for technological innovation

Indicador estadual de ciência e tecnologia: uso da propriedade intelectual como uma proxy para inovação tecnológica

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Resumo

O objetivo deste artigo é propor a construção de um indicador estadual de Ciência e Tecnologia (C&T), que permita analisar a dinâmica regional da infraestrutura de C&T no período de 2000 a 2017. Foram utilizadas 10 variáveis para cada um dos 27 estados, buscando captar o esforço dos setores público e privado em construir uma infraestrutura científica e tecnológica capaz de gerar inovação. Metodologicamente, foi utilizada a Análise dos Componentes Principais (ACP), técnica usada na redução da dimensão de dados permitindo identificar padrões e expressá-los de maneira que suas semelhanças e diferenças sejam destacadas. Foram identificados dois estágios de desenvolvimento quanto à capacidade dos estados gerarem e assimilarem inovação, um primeiro com infraestrutura científica e tecnológica madura e um segundo com baixo nível de desenvolvimento científico e tecnológico. Demostrando uma assimetria regional ainda muito acentuada, entre os estados e regiões.
Palavras-chave: Indicador. Ciência e Tecnologia. Espaço econômico. Região tecnológica.

Abstract

This article proposes the construction of a state indicator for science and technology (S&T), which allows analysis of regional dynamics in S&T infrastructure during the period 2000-2017. Ten variables were used for each of the 27 states to capture the efforts of the public and private sectors to build an S&T infrastructure capable of generating innovation. Principal component analysis (PCA) was used to reduce the dimensions of the data and allow the identification of patterns and their expression such that their similarities and differences are highlighted. Two stages of development were identified to capture states' ability to generate and assimilate innovation: one with a mature scientific and technological infrastructure and the second with a low level of scientific and technological development. This demonstrates the strong continued regional asymmetry between states and regions.
Keywords: Indicator. Science and Technology. Economic space. Technological region

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INTRODUCTION

In the 1970s, the scientific policy model underwent a significant change and abandoned an often linear logic, which marked the previous period, to assume a logic based on the identification of priorities proper to modern public planning. Since then, more quantitative information about these activities has been demanded by policy makers, and the need appeared for the development of new scientific-technological indicators (Velho, 2001).

When analyzing technological innovation policies, one indicator commonly used is the number of patents. However, the procedure is not consensual, because it is not possible to clearly determine which aspects of economic activity this variable can capture. Not all inventions are protected by patents, and not all patent registrations go through the process of technological transfer to the productive sector (Bahia and Sampaio, 2015). The relationship between patent applications and productivity has been questioned in developing economies. In these economies, the import of technology goods, stimulated by the low level of intellectual protection, is a greater influence on productivity. In developed economies, on the other hand, companies operate at the frontier of the state of the art, and innovations tend to feel a greater effect from internal technological development processes (Rocha and Dufloth, 2009; Bahia and Sampaio, 2015).

The fragility of using only the number of patents to measure the process of technological innovation is thus evident, so it is necessary to use other constructs to capture the aspects necessary for assessing innovative economic activity. The following question therefore arises as a research problem: because innovation is a categorical element for obtaining competitiveness and growth, how has the Brazilian State managed to foster local scientific and technological knowledge bases and increase innovation processes? The present research starts from the hypothesis that the capacity to generate and assimilate innovations in Brazil is quite heterogeneous. In search of answers for the problem raised, this article proposes the construction of a state science and technology (S&T) indicator, which would allow analysis of the regional dynamics of S&T infrastructure in the period 2000-2017. This article makes use of principal component analysis (PCA), a multivariate statistical technique whose purpose is to replace a large number of original variables with a smaller number of variables.

For structuring purposes, in addition to this introductory section, this article is organized into four sections. The second section addresses a theoretical framework for the concept of technological innovation and its role in regional development, in addition to the importance of indicators in measuring S&T activity. The third section presents the database and methodology. In the fourth section, the observed results are analyzed and the final considerations are presented.

REGIONAL INNOVATION: DYNAMICS AND COMPLEXITY

According to Ketels (2013), a region is a geographical area that constitutes an integrated economic space and is subject to the same spillovers of knowledge and other technological chains. For Ohmae (1995); apud Koschatzky, (2009), a region can be a state within a federation. Although there is no common definition of a region, in recent decades an extensive economic and geographical literature has sought to explain the role of the region in the development process (Cooke, 2004; McCann et al., 2015).

In the process of formulating empirical responses to regional issues, Flanagan and Uyarra (2016); apud Uyarra et al., (2017) have assumed the importance of studying the different actors and levels of governance within economic and technological regions to outline the best regional innovation policies. According to Garretsen et al. (2013), analyses of regional and national governance relationships have an analytical and political importance (realpolitik). All levels of analysis of innovation within geographic and productive regions have tended to capture various dualities or externalities (negative and positive). In Koschatzky's (2009, p. 6) analytical view, "the openness for learning from own and other experiences both in positive and negative ways is essential for regional innovation policy."

Boschma (2012) notes that, since the mid-1980s, neoclassical theory has recognized technology as a key determinant of regional growth. McCann et al. (2015) recognize that the idea of innovation, as a latent phenomenon operating through feedback within firms, had already been well established in the article by Arrow (1962). However, the authors recognize that it was the works of Nelson and Winter (1982), Lundvall (2001), and Nelson (1982) that broadened the theoretical scope, by considering innovation as a systemic phenomenon that not only operates at the micro-level but also at the meso-level, with interactions between firms, institutions, and other actors.

In the first decades of the 21st century, questions have arisen about the role of the state in the efficient direction of innovation policy (Dijkstra, 2013). In this field, there is an understanding that the analytical understanding of innovation has changed over time. These changes, particularly in the development of innovation policies and strategies, are the greatest support for innovation at the regional level. According to Lesáková (2011), the vision of the region as an economic space has broadened the understanding of the proximity factor between regional actors and the competitive advantages in terms of interactions in the process of absorbing knowledge, which has led to the understanding of the region as a space for collective technological learning.

Definition of Technological Innovation and its Taxonomy

Innovation was the term used by Joseph Schumpeter to define a set of novelties that can be introduced into an economy and that transform the relationships between suppliers and demanders. This phenomenon is the fundamental element for economic development. For the economist, the firm and the network of relationships in which it exists are the protagonists of the process of innovation and technological advancement (Schumpeter, 1934; Rocha and Dufloth, 2009). Extending the discussion, it is possible to conceptualize technological innovation as a set of systematic and coordinated actions, aimed at the production and application of technological knowledge, in the creation and implementation of new products and processes by the industry (Schmitz, Teza, Dandolini, and Souza, 2014). The concept of technological innovation can be categorized based on the different innovation processes existing in the economy, as described in Table 1.

Table 1 - Taxonomy of innovation processes

Innovation Processes	**Description**	**Institutional Modifications**
Radical	This represents a break with the technological standard hitherto in force, gives rise to new products, processes, and markets, and generally originates from discontinuous and intensive RD&I events.	Possible changes in institutional design
Incremental	This refers to the introduction of improvements in products, processes, or in the organization of production. It is characterized by continuous improvements in various	Do not require structural or institutional adjustments

	economic activities and by the processes of learning by using and by doing.	

Source: Felipe and Filho (2017); Schumpeter (1934).

It is important to distinguish the cumulative result of the technological innovation process—the result of activities associated with R&D and those that yield a new product or process that can be introduced in the market. The latter deals with the generation of new technological knowledge, the result of the individual activities of a researcher (or research team) and materialized in a technical solution. Diffusion, on the other hand, corresponds to the dissemination of innovation, originally placed on the market as a precursor by a company, from the moment it is adopted by a large number of competitors or competing companies (Schumpeter, 1934; OECD, 2007).

Intellectual Property and S&T Indicators

The use of indicators seems to be adequate to measure the degree of the relationship between S&T and the innovation process. Velho (2001) has pointed out that, in most countries, attention has gone in two directions concerning the formation of an information system capable of measuring S&T activities. The first seeks to define the dimensions of the scientific infrastructure and develop appropriate measures for these dimensions. The second seeks existing measures in by-products of the management process that have some kind of link with the scientific infrastructure.

In the Brazilian case, it is possible to identify three paths for the formation of a system of scientific indicators, so the information necessary for planning, monitoring, and evaluating the activities developed in S&T is now available. The first path starts from the collection of quantitative data produced as a by-product of another work by gathering all possible and available statistics that have already been generated in the planning and management of scientific policy, and using them as a set of indicators with the necessary adjustments. The second path is very close to the methodology adopted by the Ministry of Science and Technology: articulating a series of adaptations in the system of traditional scientific indicators to reveal the specificities of the national S&T base, while producing internationally comparable data. Table 2 shows the possible adaptations that could be included in the indicator system. The objective here is to produce information with a degree of uniformity that is capable of allowing comparisons between countries, regions, states, and institutions within the same country in a given period of time.

Table 2 - Proposed adaptations to the S&T indicator system

A)	Correcting the figures on scientific potential—that is, establishing a definition of “equivalent researcher” that is more appropriate to the country’s conditions, but that incorporates the basic characteristics used by advanced countries.
B)	The adaptation of the concept of scientific productivity to take into account the comparative disadvantages of Brazilian researchers in relation to their international counterparts, such as insufficient resources, barriers in scientific communication, difficulty in forming teams, and lack of support staff.
C)	The observation of specific precautions in the construction of historical series at constant prices on public and private spending on S&T to provide a real idea of the advances and setbacks of investments in the sector.

Source: Extracted from Velho, (2001, p. 116).

The third path derives precisely from the questioning of the theoretical-conceptual premises underlying the traditional indicators, which have been hegemonic in the social studies of S&T.

With the purpose of distinguishing and measuring S&T activities, the literature points out four important constructs for proposing indicators: (1) scientific production, (2) human capital in S&T, (3) patents, and (4) expenditures applied to the technological innovation process. What is expected, above all, of this methodological proposal is that it will be able to encourage decision-making by public administrators in the formulation of S&T policies (Montenegro, Diniz, and Simões, 2016).

METHODOLOGICAL PROCEDURES AND DATABASE

The methods and techniques used to build an S&T indicator capable of measuring state scientific and technological development are discussed here. For that, 10 variables were used for each of the 27 states of the federation for the period 2000–2017, which represents a database containing 4,860 entries. The variables used seek to capture the effort capacity of the public and private sectors to build a state S&T infrastructure capable of generating innovation. For the construction of the indicator, the 10 variables originally selected were used and then condensed into a smaller number of variables. They were thus transformed into a new set of uncorrelated variables, obtained in decreasing order of importance, so that a proxy for technological innovation could be created based on a set of variables commonly used and recognized by the state of the art. This procedure was carried out through principal component analysis (PCA), which is described in greater detail below.

Method

PCA is a mathematical formulation used to reduce the dimensions of data. The technique makes it possible to identify patterns in the data and to express them such that their similarities and differences are highlighted. Once patterns have been found in the data, it is possible to compress them—that is, to reduce their dimensions, without much loss of information (Santo, 2012). This method makes it possible to express the information available in a smaller number of variables (components), which are also called variables orthogonal to the main components—not correlated with each other—thus managing to attract all of the variability of the original variables (Betarelli and Simões, 2011). In this way, the reduction in the number of variables makes the analysis and visualization of the data much simpler (Montenegro, Diniz, and Simões, 2014). The main objectives of PCA are: (1) to reduce the number of variables and (2) to analyze which variables or which sets of variables explain most of the total variability, thus revealing the type of relationship that exists between them. The choice of this method here aims to synthesize the variability of information regarding the Brazilian states, which are the unit of observation in this work.

Database and Description of Variables

The choice of variables to represent reality assumes that the model will have limitations by leaving out many potentially important variables to establish patterns of behavior between variables. However, this limitation was mitigated by choosing the variables understood as the most prominent in the state of the art, as shown in Table 3.

Table 3 - Summary matrix of the variables used in the elaboration of the state S&T indicator

Variable	Description	Source	References
PAT	Number of patents deposited with the INPI.	MCTI and INPI	Montenegro, Diniz, and Simões, 2014; Albuquerque, 2010; Albuquerque and Bernades, 2003; Albuquerque, 2002; Simões et al, 2005; Moura and Caregnato, 2011; Bahia and Sampaio, 2015; Oliveira et al., 2015.
PRODT	Technical production of researchers in the form of technological products, without registration or patent in the National Council for Scientific and Technological Development (CNPq) research group (DGP) directory.	CNPq	Albuquerque and Bernades, 2003
PRODS	Technical production of researchers in the form of software, without registration or patent in the DGP directory.	CNPq	Albuquerque, 2002
PUBLN	Scientific production of researchers, disseminated through specialized articles of national circulation in the DGP.	CNPq and MCTI	Montenegro, Diniz, and Simões, 2014; Moura and Caregnato, 2011; Albuquerque, 2010; Albuquerque and Bernades, 2003; Albuquerque, 2002
PUBLI	Scientific production of researchers, disseminated through specialized articles of international circulation in the DGP.	CNPq and MCTI	Montenegro, Diniz, and Simões, 2014; Moura and Caregnato, 2011; Albuquerque, 2010; Albuquerque and Bernades, 2003; Albuquerque, 2002
DOCE	Distribution of non-doctoral professors in Brazil by state.	GEOCAPES	Montenegro, Diniz, and Simões, 2014
DOU	Number of doctoral researchers registered in the directory censuses, without double counting.	CNPq	Montenegro, Diniz, and Simões, 2014
BOLP	Distribution of graduate scholarships in Brazil by state.	GEOCAPES	Montenegro, Diniz, and Simões, 2014
GPESQ	Distribution of research groups according to federation unit.	CNPq	Montenegro, Diniz, and Simões, 2014
PESQ	Distribution of non-doctoral researchers and doctoral researchers by federation unit.	CNPq	Montenegro, Diniz, and Simões, 2014

Source: Elaborated by the author (2019).

The components are influenced by the scale of the variables, precisely because the covariance matrices are sensitive to the scale of each pair of variables. This problem was mitigated by standardizing the original variables before computing the main components, because the covariance matrix of the standardized variables is the correlation matrix of the original variables. Thus, it was decided to normalize the variables to mitigate possible problems of scale, because PCA will tend to give greater explanatory power to the components that present a greater value of scale (Dunteman, 1989; Ho, 2006; Hair et al., 2007). To assign the same weight to all variables, standardization was carried out as follows:

$$Z = \frac{GS - \bar{X}}{S}$$

where *X* is the mean, *S* is the standard deviation, and *GS* is the gross score.

The State S&T Indicator and its Functional Form

Multivariate statistical techniques were adopted as an analytical tool for the construction of an indicator capable of measuring the effort to build an S&T base among Brazilian states. This indicator was used as a proxy for the innovative effort of each local economy. The indicator seeks to identify which state, within the group of each region, has a greater and more solid S&T base capable of inducing and absorbing innovative processes with greater efficiency. The indicator has the following mathematical notation:

$$IECT = \Sigma(\mathrm{Z} \times \mathrm{VC})$$

Where *IECT* is the state science and technology indicator, Z is the original normalized data, and *VC* is the vector of the main component. In this case, it is possible to infer that states with a positive IECT demonstrate a more consolidated innovative effort, because both the input and result indicators are moving in the same direction, with a slight predominance of the result indicators (patents, published articles, technological, and software production). The states for which the indicator has a negative sign may have an S&T base that is undergoing a maturing process, because the input indicators run in the opposite direction to the result indicators—that is, these are states in which there is a strong effort in the allocation of inputs that does not yet have satisfactory results indicators.

ANALYSIS AND DISCUSSION OF THE RESULTS

The efficiency of the method is related to the positive or negative correlation between the original variables. The correlation matrix should display most of the coefficients with a value above 0.30. Other tests for the validation of PCA are the Kaiser–Meyer–Olkin (KMO) test and the Bartlett test. The KMO test varies between 0 and 1, and the closer it is to 1, the better. Palant (2007) suggests 0.6 as a reasonable limit. Field (2005) suggests the following scale to interpret the value of the KMO statistic: (1) between 0.90 and 1.00, excellent; (2) between 0.80 and 0.89, good; (3) between 0.70 and 0.79, median; (4) between 0.60 and 0.69, mediocre; (5) between 0.50 and 0.59, bad; and (6) between 0 and 0.49, inadequate. Hair et al. (2007) suggest 0.50 as an acceptable level. The Bartlett test of sphericity (BTS) statistic was also used, which must be statistically significant ($p < 0.05$). For the data used, KMO and BTS are statistically significant, suggesting that the data are suitable for PCA.

Table 4 -Synthesis Matrix of Tests for PCA

Tests	Results	Analysis	Sources
Correlation matrix	Coefficients > 0.30	The technique used is appropriate for the data presented.	Statistics/Data Analysis version 14.0.
Bartlett test for sphericity	p-value = 0.000	Statistically significant (p <0.05). Data are suitable for PCA.	Statistics/Data Analysis version 14.0.
Kaiser–Meyer–Olkin Sampling Adequacy Measure	KMO = 0.826	Between 0 and 1 and the closer to 1, the better. The data are suitable for PCA.	Statistics/Data Analysis version 14.0.

Source: Elaborated by the author via *Statistics/Data Analysis* version 14.0 (2020).

As we chose to use the KMO representativeness criterion (eigenvalue>1), the number of components for analysis that reached at least 70% of the total sample variance was selected. Table 5 shows that the first two components, which explain—in the period analyzed (2000 to 2017)—82.8% of the data variance, 60% being explained by the first component and 22.8% by the second component. As the other components have eigenvalues less than one, they did not enter the analysis, thus respecting the adopted criteria. These two components allowed the analysis of two possible scenarios regarding the innovative efforts of the Brazilian states, which facilitates interpretation of state profiles restricted to these components.

Table 5 - Main components

PC	Eigenvalue	% Variance
1	6.0318	60.3190
2	2.2810	22.8100

Source: Elaborated by the author, via *Statistics/Data Analysis* version 14.0 (2019).

The interpretation of the formed components can be done based on the weights of the variables. The loading weights of the variables correspond to the load or importance of each variable for the value of each main component. The most important variables are those with the highest weights—negative or positive (the sign only indicates whether the correlation is positive or negative).

The design of these scenarios begins with the analysis of the coefficients of the selected components; the coefficients in Table 6 indicate the predominance of patents (PAT), international scientific production (PRODI), national scientific production (PRODN), technological production (PRODT), and software production (PRODS) as variables that most characterize the results of the first associated component. The number of researchers (PESQ), the number of research groups (GPESQ), the number of research grants (BOLP), and the number of doctoral researchers (DOU) are those that most characterize the second component associated with inputs.

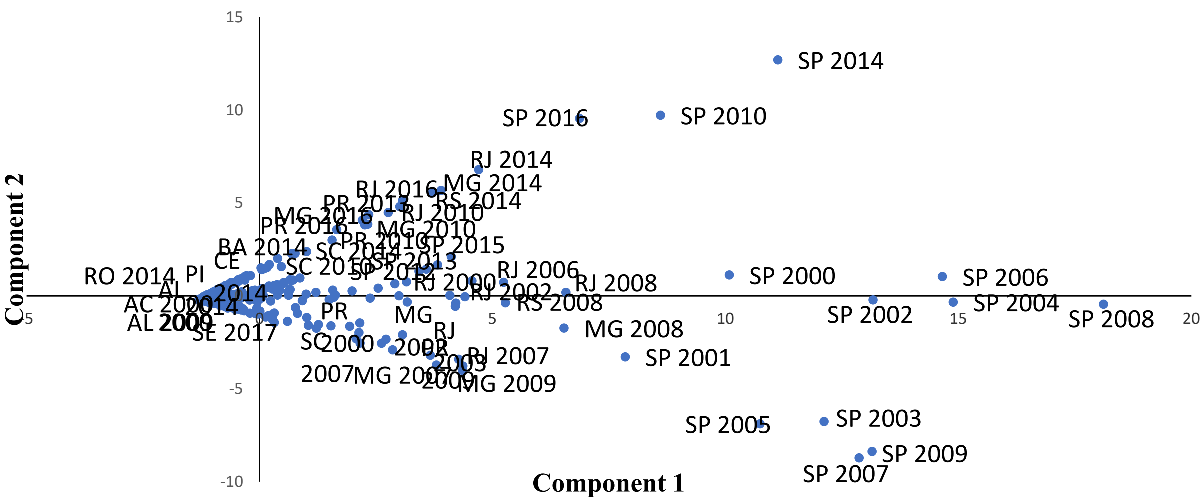
Table 6 - Coefficients of the main components

	PC 1	PC 2	PC 3	PC 4	PC 5	PC 6	PC 7	PC 8	PC 9	PC 10
GPESQ	0.2798	**0.4270**	0.2876	0.2442	-0.1049	-0.0885	-0.2397	-0.0839	0.0526	-0.7148
PESQ	0.2599	**0.4594**	0.2581	0.3527	-0.0091	-0.0855	-0.1821	-0.1133	-0.1394	0.6765
BOLP	0.2793	**0.2689**	-0.5352	0.2055	0.6239	0.0069	0.2104	0.2254	0.1846	-0.0510
DOCE	0.3277	0.09188	-0.4902	0.1181	-0.7070	0.2232	0.2652	-0.0022	-0.0991	0.0064
DOU	0.2723	0.3589	0.3326	-0.6801	0.0271	0.1671	0.4120	0.1390	0.0626	0.0479
PAT	**0.3555**	-0.0329	-0.3571	-0.5133	0.0623	-0.2132	-0.5612	-0.3198	-0.1173	0.0347
PRODN	**0.3471**	-0.311	0.1482	0.0513	-0.1090	0.2402	-0.2959	0.2591	0.7180	0.1352
PRODI	**0.3497**	-0.3052	0.1456	0.0527	0.0914	0.0952	-0.1390	0.5887	-0.6112	-0.0616
PRODT	0.3317	-0.3317	0.1660	0.1518	0.2655	0.4457	0.2248	-0.6243	-0.1296	-0.0554
PRODS	0.3398	-0.3099	0.1224	0.0736	-0.0664	-0.7722	0.3908	-0.0652	0.1015	0.0116

Source: Elaborated by the author via *Statistics/Data Analysis* version 14.0 (2019).

It is possible to infer that states located in the area of influence of the first component have a more consolidated innovative effort, because both input and output indicators are moving in the same direction, with a slight predominance of result indicators (patents, published articles, technological, and software production). The states concentrated in the area of the second component are experiencing an innovative effort that is going through a maturing process, because the input indicators run in the opposite direction to the result indicators. In other words, these are states in which there is a strong effort in the allocation of inputs, but that do not yet have robust result indicators. These results are best verified through the analysis of Figure 1, which shows the distribution of states between the two components, revealing relatively well-defined regional profiles.

Figure 1 - Brazil - Spatial distribution of the main components (2000-2017)



Source: Elaborated by the author, via *Statistics/Data Analysis* version 14.0 (2019).

The Southeast and South regions are significantly and positively related to component 1 and negatively to 2 in certain years of the analyzed series. In turn, the Northeast, North, and Midwest regions are negatively related to component 1, with some exceptions from the Northeast, such as Bahia in 2014 and Ceará in the same year.

Subnational Analysis of Innovative Effort

In this section, an analysis of the innovative efforts of the states for a decade will be made, capturing the different political cycles within the historical framework used. It will thus be possible to capture the evolution in the public policies of the states to foster innovation during the period 2000-2017. Since the end of the 1990s, Brazil has been building a strong system for promoting S&T, which has provided significant improvements in policies to support technological innovation. Special funds were created to finance research, managed by FINEP, such as the Industrial Technological Development Programs (PDTI), the Agricultural Industrial Technological Development Program (PDTA), and the Oil and Gas Sectorial Fund (CT-Petro) in 1999. Between 2000 and 2004, another 15 sectorial S&T funds were created, in addition to the launch of the Industrial, Technological and Foreign Trade Policy (PITCE), which formed the basis for the implementation of an integrated and coherent system for the introduction of technological innovation in national companies (Negri and Morais, 2017).

However, these actions do not seem to have been able to mitigate the regional asymmetry in the innovative capacity of the states. Between 2000 and 2004, it is noteworthy that only four states (São Paulo, Rio de Janeiro, Minas Gerais, and Rio Grande do Sul) present positive values for component 1, which alone accounts for 60% of the data variance throughout the period, as shown in Figure 2. The state of Paraná deserves to be mentioned when composing this group from 2001 through 2004, the year in which three more states (Santa Catarina, Pernambuco, and Bahia) become part of the select group, as can be seen in Figure 3. It is worth mentioning that the data expressed in component 1 indicate a more consolidated innovative effort, because both the input indicators (number of doctoral researchers, distribution of Postgraduate Scholarships, distribution of research groups, distribution of researchers) and the results (patents, published articles, technological and software production) are moving in the same direction. This shows that effort and results are positively correlated.

In contrast to this scenario, all other states during the period show negative data for both component 1 and component 2, demonstrating the low innovative efforts in these states, whether in the capacity to foster inputs or in the generation of results. The scenarios suggested in this section show a high regional asymmetry, with a high concentration of inputs and results of the innovation process in the Southeast and South regions. It is therefore possible that the two failures pointed out in the diagnosis of the late 1990s were not corrected by the proposed actions. These concern the instability of investments for the S&T system, due to the dependence on resource allocation in the federal budget and the fragile interaction between companies and academia, (Negri and Morais, 2017).

The Innovation Law (Law 10,973/2004) was also another important instrument in an attempt to streamline companies' innovation process, according to Negri and Morais (2017). The law provided the necessary conditions to expand and strengthen the triple helix, granting greater flexibility to public Institutes of Science and Technology (ICT) to participate in innovation processes because they were allowed to transfer technologies and the licensing of inventions for the production of products and services by the private sector, without the need for public bidding. However, the results for this period show that only São Paulo, Rio de Janeiro, Minas Gerais, Rio Grande do Sul, Paraná, Santa Catarina, Pernambuco, and Bahia yielded a positive innovative effort. Even so, the last three of these states only presented this positive indicator in the final year (2004) of the analyzed section.

Advancing the analysis between 2005 and 2010, the concentration of the technological innovation effort remains in the South and Southeast regions. However, as of 2006, there is a new and constant presence of states in the Northeast with positive indicators for component 1. This timid regional devolution is not capable of mitigating interregional concentration, because only Bahia, Pernambuco, and Ceará appear as northeastern states that manage to achieve positive indicators in this period.

It is worth noting that, in 2006, the Zero Interest program started, with resources from the Workers' Support Fund (FAT). Aimed at innovative companies with annual revenues of up to R$10.5 million, the program offers financing ranging from R$100 thousand to R$900 thousand, with the objective of promoting special conditions for access and guaranteeing credits, in addition to the adoption simplified processes in the analysis and approval of projects. Although the program is FINEP's initiative, the states are the ones responsible for prequalifying the proposals of small companies that are candidates for loans for projects aimed at obtaining new products, services, or production processes (Negri and Morais, 2017).

Also in 2006, FINEP launched the Economic Subsidy Program, through three calls for projects with three types of support: (1) subsidies to companies, in the total amount of R$300 million; (2) subsidies to micro and small companies (MPE), with the Support Program for Research in Companies (Pappe-Subvenção), with resources of R$150 million; and (3) grants for hiring researchers in companies, with resources of R$60 million (this type of support was created by Law No. 11,196/2005; Negri and Morais, 2017). It is possible that these actions, in addition to previous activities, have contributed to the better performance of northeastern states (Bahia, Pernambuco, and Ceará) in the process of technological innovation.

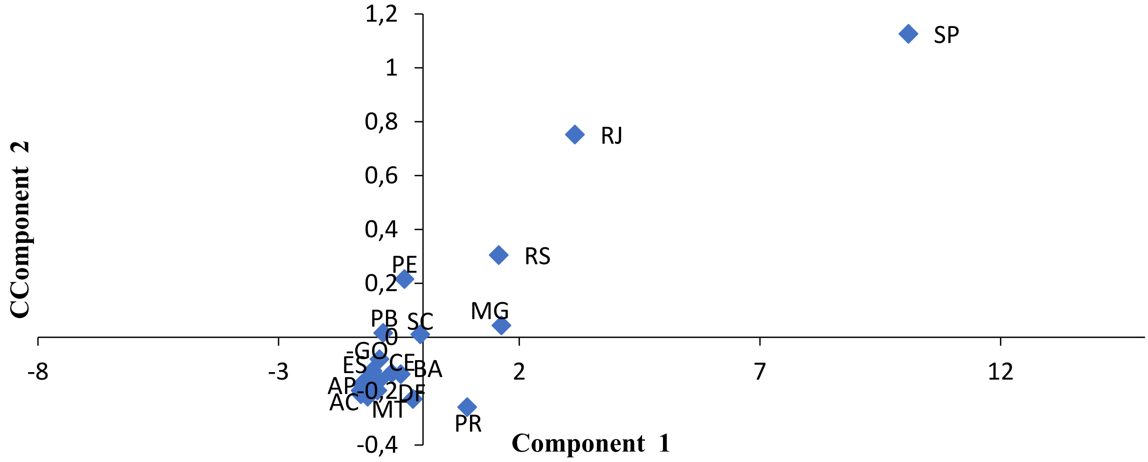
Other important programs were launched during this period. In 2008, programs like Inova Brasil started to grant credit to companies in priority sectors defined in the federal government plan, which sought to encourage increased competitiveness. This was also the case with Pró-Inovação, which financed costs related to civil works and installations; acquisition of equipment; expenses with its own team; hiring of researchers and specialists; acquisition of inputs, materials, software, and the coverage of other costs (Negri and Morais, 2017).

Another important public policy to foster and accelerate the innovation process in less economically dynamic regions—such as the North, Northeast, and Midwest—was the creation of Pappe Integração in 2010. This redirected R$100 million in resources exclusively for these regions through the Research Support Foundations (FAP) in each state. These foundations were responsible for indicating the priority sectors to be supported in RD&I projects that met the development needs of the respective state, in line with the Development Policy (Negri and Morais, 2017).

The result variables PRODN, PRODI, and PRODS used in the construction of the IECT are largely aimed at academic production. The Support Program for Restructuring and Expansion Plans of Federal Universities (Reuni) played an important role in increasing these result indicators, and was responsible for expanding the offer of higher education, especially in the interior of the country, with the campuses of federal universities the number of municipalities served by universities increasing from 114 in 2003 to 237 by the end of 2011. Fourteen new universities were created, from 45 in 2003 to 59 in 2010, with more than 100 new campuses that enabled the expansion of vacancies and the creation of new undergraduate courses (MEC, 2020).

Figure 2 expresses the spatial distribution of the main components of the states for the year 2000 and clarifies how states in the North, Northeast, and Midwest regions have bad indicators for inputs and products related to technological innovation. With the exception of the states of Pernambuco and Paraíba, which have positive values for component 2 (but negative for component 1), all other states in the three regions mentioned have negative values for the two main components.

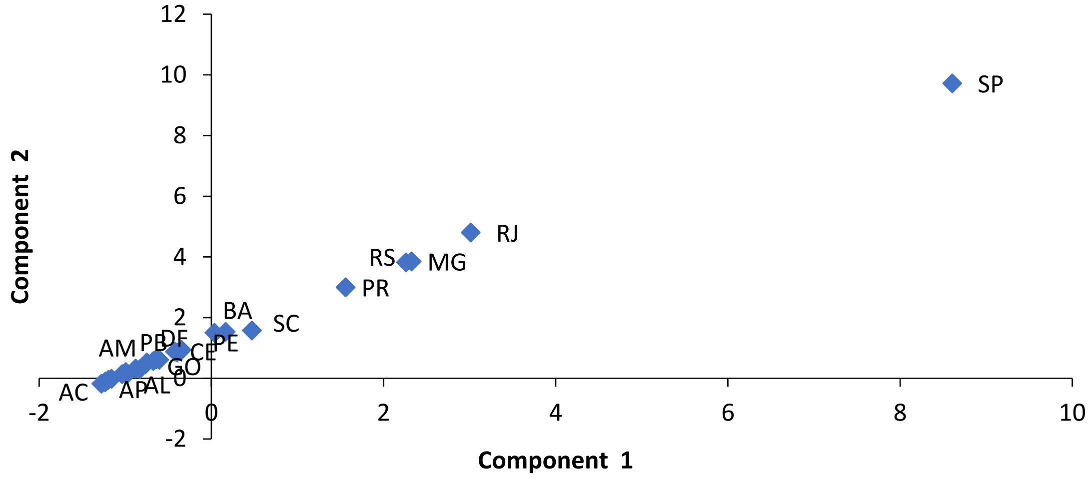
Figure 2 - Brazil - Spatial distribution of the main components (2000)



Source: Prepared by the author, via Statistics/Data Analysis version 14.0 (2019).

With the advancement and maturation of public policies for S&T after a decade, the scenario changed for the states in the North, Northeast, and Midwest; this is visible in Figure 3, which shows the spatial distribution of the main components of the states for the year 2010. This is not a radical change, because the regional asymmetry is still strong and concentrated in five states in the Southeast and South regions (São Paulo, Rio de Janeiro, Minas Gerais, Rio Grande do Sul, and Paraná), plus Santa Catarina, which in 2000 did not appear in this select group.

Figure 3 - Brazil - Spatial distribution of the main components (2010)



Source: Prepared by the author, via Statistics/Data Analysis version 14.0 (2019).

It is possible to verify, however, that most of the states in the three mentioned regions presented negative values for the two main components in 2000. In 2010, they showed positive values for component 2, although negative values for component 1. The exceptions are the states of Acre, Amapá, Rondônia, Roraima, and Tocantins, which—even with the action of PAPPE Integração—presented negative values for both components. This indicates that these states were not able to produce enough inputs and results to position themselves in a stage of S&T development capable of generating innovation. Bahia and Pernambuco continued to stand out positively as exceptions, as they presented positive results for both components. Because their input and result indicators are moving in the same direction (positive correlation), this signals that these states had a greater capacity for assimilation and absorption of the policies during the period studied.

Studies by FINEP itself found that the policy adopted until 2010 to support R&D in companies had limited reach in the innovation process of Brazilian companies. despite showing significant advances with notable increases in resources destined to the S&T system. FINEP argued that, to have greater reach, it would be necessary to increase the number of companies served. Between 2005 and 2008, more than 95% of R&D expenditures by Brazilian companies were carried out with their own or private resources, with public funds amounting to less than 5% of these firms' expenditures. In OECD countries, public funding is more significant and reaches around 50% of R&D expenditure (Negri and Morais, 2017). Indeed, according to Negri and Morais (2017), other bottlenecks are relevant to the innovation process of the Brazilian economy in addition to the small volume of investment. They include (1) the low level of integration of the S&T policy; (2) the institutional rigidity of development agencies, such as BNDES and FINEP; and

(3) the limited use of the State's purchasing power to stimulate production.

Analyzing the period from 2011 to 2017, it is possible to verify that there was a modest advance in the national R&D expenditure, which included public expenditures of the union, the states, and companies (private and public). Expenditures from from 1.01% of GDP in 2003 to 1.24% in 2012, and within this variation the participation of the private sector was lower than in the previous period in 2003. The share of private investment in R&D in GDP was 48% in 2013, then dropped to 45%, while the remaining 55% was within the public sector (Negri and Morais, 2017). This increase in R&D expenditure in relation to GDP is largely attributed to the redirection of public policy, because FINEP implemented, as of 2011, a series of new programs to support S&T, a synthesis of which is shown in Table 7.

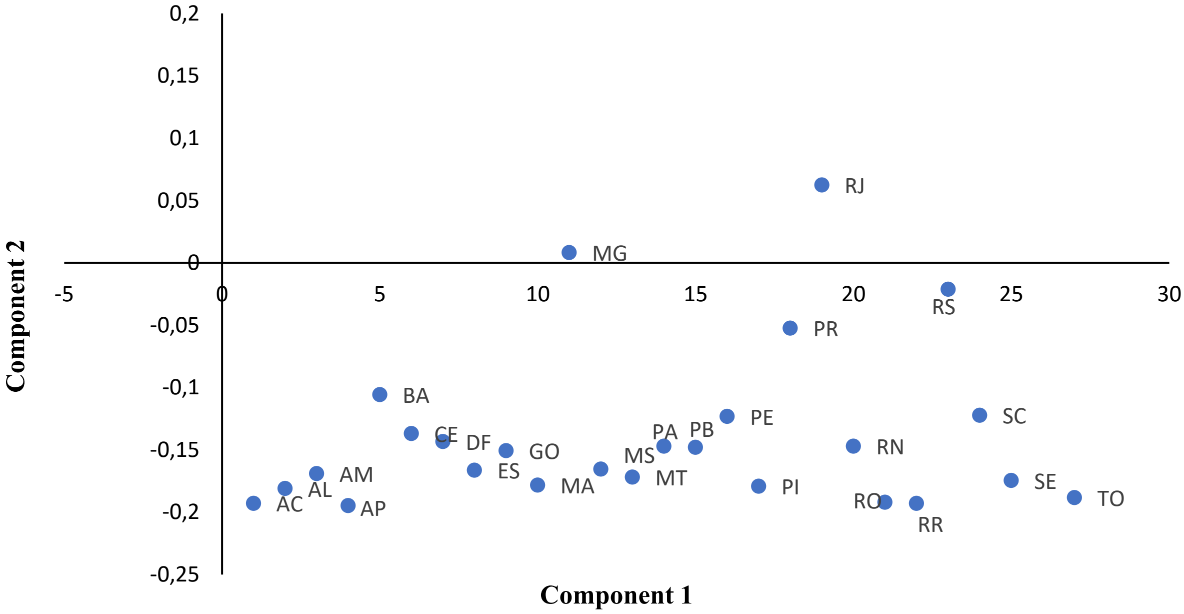
Table 7 - Credit and grant programs at FINEP launched 2011-2014

Support programs	**Financial support modalities**
Inova Empresa Plan (Aero defense, Agro, Energy, Petro, Health, Sustainability, Telecom, Paiss, Agrícola).	Integration: credit (BNDES), subsidy, non-refundable funds and venture capital funds (joint support plan): R$32.9 billion in endowments and partners (1,827 companies and 338 ICT).[1]
Tecnova (grant): R$120 thousand-R$400 thousand per project.	Decentralization of the economic subsidy for MSEs (costing): Research Support Foundations (FAP).
Inovacred Empresa and ICT (innovation for competitiveness).	Decentralization of credit to MPE: state development banks. Companies and ICT with ROB[2] of up to R$90 million.
Inovacred Express	Financing for innovations to companies and ICT with ROB of up to R$16 million.
Inovacred Partners	Financing for innovations to companies and ICT with ROB of up to R$90 million
Repayable financing	Loans to medium and large companies (ROB above R$16 million).
Non-reimbursable financing: ICT-company cooperation	Non-refundable financing: ICT-company cooperation

Source: FINEP. Note: [1]Hired companies and participating ICT, until September 2014 (Negri and Morais, 2017). [2]ROB = gross operating revenue. Note: Venture capital programs are not included.

The resources available for R&D projects have expanded significantly. Credit operations, non-repayable resources, and economic subsidies went from R$9.9 billion in 2007-2010, to R$23.4 billion for 2011-2014. Credit operations reached R$14.5 billion contracted in 2013-2014, or more than four times the credit contracted in the period 2009-2010. The allocation of resources was directed to strategic sectors such as health, energy, oil and gas, and agriculture and food (Negri and Morais, 2017). These changes, which occurred in the period 2011-2014, reflected the state policies about S&T, causing a new spatial configuration of the indicator of state technological innovation effort, as shown in Figure 4.

Figure 4 - Brazil - Spatial Distribution of Main Components (2017)



Source: Elaborated by the author, via Statistics/Data Analysis version 14.0 (2019).

It is noticeable that this increase in public investments in R&D between 2011 and 2014 was reflected (in 2017) in the positioning of the states regarding their S&T policies. States such as São Paulo, Rio de Janeiro, and Minas Gerais continued to have positive indicators for the first and second components, which indicates that their input indicators (PESQ, GPESQ, BOLP, and DOU) were going in the same direction as their result indicators (PAT, PRODI, PRODN, PRODT, and PRODS), thus demonstrating the maturity level of these local innovation systems. The other states are all located in a negative position for the second component and positive for the first, but at different levels. This makes it possible to notice a graduated level of innovative effort. Rio Grande Sul and Paraná, for example, despite being negatively located for the second component, are closer to zero than Alagoas and Acre, in addition to presenting positive values for the first component much higher than those of the North and Northeast in question (with the exception of Sergipe and Tocantins).

What is clear in Figure 4 is that, although most states still have poor input indicators, the greater contribution of federal public resources via FINEP has had a positive impact on the states' product indicators. The states of Sergipe and Tocantins are examples of this: in 2017, they are highly positive for component 1, but remain quite negative for component 2, which demonstrates the great importance that the union has in regional S&T policies.

FINAL CONSIDERATIONS

With regard to the state S&T indicators, which together form an indicator of the technological innovation effort at the subnational level, the trajectory and evolution of this indicator suggests that scientific and technological activity was unevenly distributed regionally in the period under study. The analysis of the data shows that the greatest effort of technological innovation concentrated in the South—and especially the Southeast. The construction of the technological innovation effort indicator for the states through PCA made it possible to identify two distinct stages of development in state capacities to generate and assimilate technological innovation.

In the first stage, there are the federative units that present a mature scientific and technological infrastructure—that is, the input indicators (i.e., the number of researchers, research groups, research grants, doctoral researchers, and non-doctoral research professors) move in the same direction as the result indicators (i.e., patents, published articles, and technological and software production). This occurs for a select group of states concentrated in the South and Southeast, where São Paulo, Rio de Janeiro, Minas Gerais, Paraná, Santa Catarina, and Rio Grande do Sul stand out, with oscillations from states such as Bahia, Pernambuco, Ceará, and the Federal District during the analyzed period. In the second stage, states with a low level of S&T development appear. In this stratum are the other states of the federation, where the selected input and output indicators move in opposite directions. This means that the S&T infrastructure of these states is still unable to assimilate and absorb the scientific knowledge produced, thus confirming the hypothesis that the capacity to assimilate innovations in Brazil is quite heterogeneous.

Despite the significant advances in Brazilian policies toward technological innovation, with the relevant increase in resources allocated to the S&T system, the policies had a limited scope. Admittedly, the S&T infrastructure grew significantly after 2005, and it was possible to achieve much more than was done in previous years, when the Innovation Law and the resources of the sectorial funds were not available. However, it is necessary to expand programs with resources for innovation. The data showed that FINEP financed just over a thousand companies in the 2005-2008 period. That means, in Brazil, more than 95% of companies' R&D expenditures were made with their own or private resources—that is, public funds contributed less than 5% of these companies' expenses. In developed countries, public funding is more relevant and public funds contribute closer to 50% of R&D support. The innovative effort indicator for the Brazilian states shows that, in general, even with small advances, regional and interregional concentration is still uneven, presenting high levels of asymmetry between states and regions. Although Brazilian policies to support innovation strongly favor innovation, from the point of view of fiscal incentives, the indicators are still comparatively poor, while there seems to be no compatible counterpart from the production of innovation to the good performance observed in scientific production.

Concerning the limitations of this research, it should be noted that the theoretical and methodological approach adopted does not capture all of the variables that could affect regional and local innovative effort. There is potential for new research to investigate the potential effects of other variables related to innovation, particularly with the use of a more comprehensive database on the topic. This would allow the presentation of more detailed results that would capture the subsidizing of S&T public policies more accurately and efficiently. In addition, the use of new methodologies, such as smaller geographic unites—such as mesoregions, microregions, and/or municipalities—would allow a more thorough investigation into the strengths and weaknesses of Brazilian regional/local innovative system.

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