



SPATIAL CONFIGURATIONS AND THE TRANSFORMATION OF REGIONAL INNOVATION SYSTEMS IN MINAS GERAIS: A MUNICIPAL PATTERN-BASED APPROACH (2010–2022)

**CONFIGURAÇÕES ESPACIAIS E TRANSFORMAÇÃO DOS SISTEMAS
REGIONAIS DE INOVAÇÃO EM MINAS GERAIS: UMA ABORDAGEM
BASEADA EM PADRÕES MUNICIPAIS (2010–2022)**

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CONFIGURAÇÕES ESPACIAIS E TRANSFORMAÇÃO DOS SISTEMAS REGIONAIS DE INOVAÇÃO EM MINAS GERAIS: UMA ABORDAGEM BASEADA EM PADRÕES MUNICIPAIS (2010–2022)

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ABSTRACT

This paper aims to analyze the structure and spatial dynamics of regional innovation systems (RIS) in the state of Minas Gerais, Brazil, through the identification of municipal patterns for the years 2010 and 2022. Using multivariate analysis techniques, municipalities were grouped according to scientific, technological, and urban characteristics, allowing the identification of different stages of innovative maturity. The results reveal the persistence of a concentrated pattern, with only a few municipalities exhibiting greater innovative capacity, particularly in the southern portion of the state, while most municipalities remain at incipient levels. Although all RIS groups showed improvements in their indicators over the period analyzed, no significant reconfiguration in the spatial distribution of innovation across the state was observed.

Keywords: Regional Innovation Systems. Regional Development. Minas Gerais. Science and Technology Assets.

RESUMO

Este trabalho tem por objetivo analisar a estrutura e a dinâmica espacial dos sistemas regionais de inovação (SRI) em Minas Gerais, a partir da identificação de padrões municipais nos anos de 2010 e 2022. Utilizando técnicas de análise multivariada, os municípios foram agrupados segundo características científicas, tecnológicas e urbanas, o que permitiu identificar diferentes estágios de maturidade inovativa. Os resultados evidenciam a persistência de um padrão concentrado, com poucos municípios reunindo maior capacidade de inovação, sobretudo na porção sul do estado, enquanto os demais permanecem em níveis incipientes. Apesar dos avanços nos indicadores de todos os SRIs, não se observa reconfiguração significativa na distribuição espacial da inovação no estado, no período analisado.

Palavras-chave: Sistemas Regionais de Inovação. Desenvolvimento Regional. Minas Gerais. Ativos de Ciência e Tecnologia.

1 INTRODUCTION

Strengthening competitiveness and expanding economic growth constitute fundamental pillars for local development and are, therefore, central objectives of economic policies. From this perspective, the Neo-Schumpeterian approach extensively explores the role of innovation as a key determinant in this process, such that economies endowed with local capabilities for learning and innovation tend to occupy a vanguard position in the long-term growth trajectory (Freeman; Soete, 2008). The development of these capabilities, in turn, relies on the presence and interaction of agents involved in the diffusion of knowledge, which imparts a systemic nature to innovation, reinforced primarily by geographic proximity. This conception forms the bedrock of the regional innovation systems (RIS) approach, under which the innovative process is geographically conditioned. Thus, the development of new technologies is tied to the transmission of knowledge associated with spatial proximity, making the regional context a decisive factor in its success (Asheim; Gertler, 2005).

Both the presence of actors associated with innovative activity and the integrity of their interactions are fundamental conditions for the dynamism of RISs, allowing regions to develop technologically. In the Brazilian context, these relationships are generally not fully established, given that the specialized literature points to low system development linked to a pattern of latent regional inequality (Albuquerque, 1996; Barros, 2000; Santos, 2017; Santos; Mendes, 2018). Therefore, considering the findings of these studies regarding the Brazilian case, a scenario of immaturity and lag in innovative activity becomes evident.

However, these characteristics are not limited to the national level as a whole; they are also reflected in the intra-state sphere. According to Santos (2008), the innovation system of Minas Gerais can be considered a reflection of the Brazilian National Innovation System (NIS), which was built during the import substitution process in the second half of the 20th century. Due to this condition, although this innovation system is one of the most developed in the country, it remains immature. Considering this, this study aims to analyze the structure and spatial dynamics of regional innovation systems in Minas Gerais by identifying municipal patterns for the years 2010 and 2022. By applying multivariate analysis techniques, this paper seeks to group municipalities according to their



scientific, technological, and urban characteristics, allowing for the identification of different stages of maturity in promoting innovative activities. Furthermore, a comparative approach between the two periods enables the analysis of shifts in municipal classification within these groups, highlighting trajectories of advancement, stagnation, or reconfiguration in RISs over time.

By offering a dynamic reading of the spatial organization of innovation in Minas Gerais, this study contributes to advancing the debate on the evolution of regional innovation systems in peripheral economies, as well as providing relevant inputs for designing public policies aimed at promoting regional development and reducing inequalities. Accordingly, the article is organized into four additional sections. The following section presents the main theoretical foundations of RIS literature and the context of Minas Gerais regarding this subject; Section 3 describes the variables and methodological procedures adopted; Section 4 discusses the empirical results; and finally, Section 5 synthesizes the main contributions of the study.

2 REGIONAL INNOVATION SYSTEMS AND THE TERRITORIAL DYNAMICS OF INNOVATION

Neo-Schumpeterian literature has consolidated the perception that knowledge and innovation constitute central elements for competitiveness, economic growth, and regional development. From this perspective, innovation is no longer understood as a linear process, but rather as the result of interactions among various economic and institutional agents, involving continuous learning, knowledge production, and technological diffusion (Freeman; Soete, 2008). Concurrently, the understanding that these processes do not occur homogeneously across space has gained prominence, as they are conditioned by the territorial characteristics in which agents are embedded.

When discussing the territorial dynamics of innovation, it becomes imperative to distinguish between the concepts of economic growth and regional development. As elucidated by Oliveira and Quintairos (2011) and Vieira and Santos (2012), while economic growth focuses strictly on the expansion of productive capacity and the evolution of aggregated macroeconomic indicators, development presupposes structural changes that result in the improvement of the population's



standard of living and a more equitable distribution of the regional wealth produced. Under this prism, innovation ceases to be a mere tool for corporate competition and assumes the role of the main driver of socio-spatial cohesion. According to Almeida, Silva, and Oliveira (2014), stimulating localized innovative activities acts as a mitigating mechanism for the “inconsistencies of growth,” generating endogenous competitive advantages capable of promoting a more uniform and sustainable regional development. Thus, the consolidation of structured Regional Innovation Systems (RISs) and the consequent spatial deconcentrating of S&T assets are fundamental conditions for peripheral regions to overcome their historical vulnerabilities and actively participate in the development trajectory.

According to Garcia et al. (2022), an RIS consists of a system in which agents and subsystems interact with one another to generate, exploit, and apply knowledge to obtain new products and productive processes that transform regional realities. Firms comprising RIS are embedded in the knowledge exploitation and application subsystem, acting as the primary agents driving innovation processes. Simultaneously, these firms interact with the knowledge generation and dissemination subsystem, which consists of universities, public research institutes, technical and technological service centers, and workforce training organizations. These institutions provide support activities and dedicate themselves to generating and diffusing new knowledge among local firms. The structural foundation of a regional innovation system is thus composed of an agglomeration of firms interacting with each other, with higher education and graduate research centers, and with private R&D laboratories, in addition to relating with technology transfer agencies, trade associations, and government departments—all relevant to innovative activity and economic development (Cooke, 1998).

Given that innovation is non-linear but systemic, relying on the interaction of different agents that generate, share, and absorb knowledge, it can be inferred that an uneven process of innovation exists across regions, largely influenced by the degree of maturation of each Regional Innovation System—that is, different types of regions generally face specific systemic challenges (Isaksen, 2001; Tödtling; Trippl, 2005). It is precisely from this understanding that a body of empirical studies aimed at measuring and characterizing regional innovation systems in Brazil has developed. Broadly speaking, these works seek to map the spatial distribution of assets and

capabilities linked to innovation—such as patenting, scientific production, R&D personnel, and the presence of universities and research institutions—to identify the factors that distinguish different regional contexts and the degrees of maturity of their innovation systems (Albuquerque, 1996; Barros, 2000; Santos, 2017; Santos; Mendes, 2018).

Albuquerque (1996), for instance, analyzes the activity of the Brazilian innovation system through the spatial distribution of patents as a performance measure of the productive sector, and scientific publications as a proxy for the performance of the national research infrastructure. The evidence found for Brazil in the 1990s indicates a scenario of weak innovation development, characterized by low corporate engagement in R&D. From the perspective of scientific knowledge production, Barros (2000) highlights the inequality of the Brazilian technical-scientific base across the country's macro-regions. The author argues that the Southeast region, in addition to hosting most centers of research excellence, channels a large share of federal investments allocated to science and technology.

Santos (2017), in turn, draws a parallel between regional economic inequality and the development of the Brazilian innovation system. Based on the analysis of selected data—patents, scientific articles, and faculty in graduate programs in Brazil—for Brazilian micro-regions during the 2000s, signs of regional disparities are revealed. Additionally, Santos and Mendes (2023), utilizing patent data for 2010 and 2015, observe a decentralization of innovative activity in the country. It was demonstrated that in 2010, a total of 1,076 Brazilian municipalities had patent applications—a figure that grew timidly in 2015 to 1,295, representing 23% of municipalities. However, the results still reinforce the trend of regional inequality, given the high concentration of these innovative municipalities in the South and Southeast regions of the country.

Thus, the reported findings reveal that the Brazilian case is marked by an uneven process of innovative development, conditioned by the heterogeneous distribution of scientific, technological, and institutional assets across the territory. This pattern demonstrates that even within a national innovation system, regional dynamics assume distinct configurations, reflecting different stages of RIS development. This heterogeneity manifests not only among the country's major regions, but also within federal units themselves, where areas with high densities of innovative capabilities

coexist with others marked by structural weaknesses. In this sense, subnational analysis becomes crucial for understanding how the assets and interactions underpinning innovation are distributed spatially and how they influence regional development trajectories.

It is within this perspective that the analysis of the state of Minas Gerais is situated. Over the past 20 years, the state has been consolidating its innovation system by strengthening its Research, Development, and Innovation (R&D&I) activities—through the creation of federal universities, technology parks, and research centers; the establishment of additional units of Federal Institutes of Education, Science, and Technology; the emergence of new firms; and the implementation of legislation encouraging innovation and entrepreneurship, such as Law 17,348/08 (governing technological innovation incentives in the state) and Law 23,793/21 (aimed at promoting startups) (Carvalho, 2025).

According to the Secretariat of Economic Development of the State of Minas Gerais – SEDE (2025)¹, 60% of this innovation system consists of Science and Technology Institutions (STIs), both public and private, which develop scientific and technological research activities and are essential for knowledge production in the state. Meanwhile, 24% correspond to National Institutes of Science and Technology of Minas Gerais (INCTs), which carry out research and development programs funded by the Brazilian government. Technological Innovation Nuclei (NITs) account for 11% of R&D&I in Minas Gerais; these are structures within state research institutions and universities designed to facilitate technology transfer from academia to the business sector. The remaining 5% comprises 8 technology parks and 13 units of EMBRAPPI (Brazilian Industrial Research and Innovation Company), which provides technological support to industrial enterprises.

The strengthening of Minas Gerais's innovation system has yielded significant results for knowledge production and capability development in the state. According to SEDE data (2025), the state ranks second in Brazil in terms of Information Technology (IT) companies, with over 800 firms in the software licensing segment alone. Furthermore, according to mapping by the Brazilian Association of Startups (ABSTARTUPS)², Minas Gerais is the third state with the highest concentration of startups, accounting for 9.5% of the country's total, behind São Paulo (32.5%)

1 <https://desenvolvimento.mg.gov.br/inicio/projetos/projeto/1140>

2 <https://centev.ufv.br/minas-gerais-e-o-terceiro-estado-brasileiro-com-a-maior-concentracao-de-startups/>

and Santa Catarina (12.6%). The state also stood out in patent filings between 2000 and 2023 (the period available in the National Institute of Industrial Property - INPI database), ranking second in total patent applications (10.5%), trailing only São Paulo, which accounts for approximately 35% of national production.

Despite these figures, an uneven spatial distribution of the institutions comprising Minas Gerais's innovation system persists. Nearly 60% of Science and Technology Institutions (STIs) are concentrated in the Metropolitan Region of Belo Horizonte, the South/Southwest of Minas, and the Triângulo Mineiro/Alto Paranaíba. Moreover, technology parks and EMBRAPA units exist exclusively within these regions (SEDE, 2025). This implies that innovative activities unfold unevenly across state regions, as scientific and technological knowledge production, university-industry interactions, and industrial support remain concentrated in specific territories.

The literature on Minas Gerais has captured this heterogeneity through distinct approaches. The first group of studies focuses on identifying factors associated with innovative activity. Along these lines, Gonçalves (2006) analyzes the relationship between innovation and urban structure in the state, showing that technological activity is spatially concentrated around the Metropolitan Region of Belo Horizonte, conditioned by factors such as urban scale, economic density, workforce qualification, and local research capacity. Conversely, another strand of literature emphasizes the institutional composition of Minas Gerais's innovation system. In this regard, Pereira et al. (2018) contribute by showing that Minas Gerais possesses a complex and diversified arrangement of scientific and technological institutions, particularly its educational and research base. However, the articulation among its components remains limited, reflecting challenges in bridging knowledge-generation activities with those associated with the exploitation of economically useful knowledge.

A third group of studies seeks to measure innovation systems in the state from a spatial dimension. Santos (2008) represents a major milestone in this effort by proposing a classification of municipalities in Minas Gerais according to the degree of advancement of their local innovation systems, identifying factors related to economic performance, urban structure, and scientific-technological base. Their findings show that urbanization, tertiarization, higher education, labor force qualification, and S&T-related occupations were decisive in distinguishing municipalities

across different development stages of local systems, allowing for the construction of a pioneering typology for Minas Gerais. More recently, Rodrigues et al. (2026) revisit this agenda by sizing the regional innovation system of Minas Gerais through principal component analysis, classifying the state's micro-regions into four distinct profiles.

Nevertheless, relevant gaps remain. On one hand, studies focused on the determinants of innovation help identify key explanatory factors, but do not necessarily advance the characterization of different maturity stages of regional innovation systems within the state. On the other hand, research centered on the institutional composition of the state's system contributes to mapping its agents and organizations yet offers less capacity to capture how these structures translate into uneven territorial configurations. Meanwhile, studies addressing the spatial measurement of innovation systems in Minas Gerais represent decisive advances; however, they either rely on older data from the early 2000s, as in Santos (2008), or operate at higher levels of aggregation, as in the recent study by Rodrigues et al. (2026), which uses micro-regions as territorial units.

It is precisely at this juncture that the contribution of the present study lies. By adopting the municipality as the unit of analysis and comparing two points in time—2010 and 2022—this research aims to update and deepen Santos's (2008) analysis regarding the spatial configuration of regional innovation systems in Minas Gerais, while offering a distinct regional scope compared to Rodrigues et al. (2026). This resolution captures disparities that might be masked at higher levels of aggregation, given that municipalities within the same micro-region can exhibit vastly different scientific, technological, urban, and productive capabilities. Furthermore, by incorporating the temporal dimension, it becomes possible to analyze trajectories of advancement, stagnation, or reconfiguration of municipalities within the dynamic of regional innovation systems in the state.

3 METHODOLOGICAL ASPECTS

The aim of this study is to analyze the structure and spatial dynamics of RISs in Minas Gerais by identifying municipal patterns for the years 2010 and 2022. To capture this patterning and ensure alignment between theoretical foundations and empirical data, a quantitative and exploratory-descriptive approach was adopted, grounded in multivariate statistical techniques (Cluster Analysis and Principal Component Analysis - PCA). The joint application of these techniques is justified by the fact that RISs are comprised of multiple interconnected subsystems (Garcia et al., 2022; Tödtling; Trippel, 2005). As highlighted by literature in regional development (Muller et al., 2008; Pereira et al., 2018; Rodrigues et al., 2026), grouping territorial units via multivariate metrics allows researchers to go beyond simplistic views based solely on isolated economic indicators, thereby revealing the true typology of maturity within local innovation arrangements.

The study area encompasses all 853 municipalities in the state of Minas Gerais. The municipal breakdown is justified as it allows for capturing intra-regional heterogeneities that are typically obscured at higher levels of aggregation, such as micro-regions (Santos; Mendes, 2023).

3.1 CLUSTER ANALYSIS

Cluster analysis is a multivariate statistical method applied here to distinguish patterns among regional innovation systems in Minas Gerais based on the innovation-related characteristics of each municipality in the state. Through this method, the sample can be partitioned into distinct groups composed of elements exhibiting a homogeneous profile among themselves. Thus, the objective is to group municipalities with similar innovation systems and analyze the distribution patterns of these clusters.

Among clustering techniques, the k -means algorithm is used, which can be synthesized in four steps. First, k centroids are chosen to initiate the partitioning process of the dataset elements. Next, each observation is compared to the initial centroids according to a distance metrics specifically, the Euclidean distance, given by:

$$d(X_l, X_k) = \sqrt{\sum_{i=1}^p (X_{il} - X_{ik})^2} \quad (1)$$

Where:

d is the Euclidean distance;

X_l and X_k represent the vector values of any two observations;

p is the number of variables.

According to this dissimilarity measure, the initial clusters are formed so as to minimize the within-cluster variance (or the distance between the centroids and the observations). In the third step, the centroid values are recalculated for each newly formed cluster, after which the second step is repeated using the updated centroids as references. Finally, these last two steps are repeated iteratively until convergence is achieved and all observations are properly assigned to their respective clusters.

3.2 PRINCIPAL COMPONENT ANALYSIS (PCA)

Principal Component Analysis is a multivariate statistical technique that allows for the reduction of data set dimensionality. Through PCA, a set of variables can be condensed via underlying common factors, thereby identifying a smaller set of components that explain the variability of the data without significant loss of information (Hair et al., 2005). A methodological procedure similar to those of Muller (2008) and Rodrigues et al. (2026) is adopted, albeit with a distinct objective. Here, this method is applied in conjunction with cluster analysis to evaluate the influence of each variable in the formation of the clusters. Thus, it is possible to identify which characteristics carry the most weight in differentiating municipalities regarding their innovation systems.

Through PCA, new uncorrelated variables—termed principal components—are obtained, which represent linear combinations of the original variables $X_1, X_2, \dots, X_p$, given by:

$$Y_i = a'_i X = a_{i1}X_1 + a_{i2}X_2 + \dots + a_{ip}X_p \quad (2)$$

Where:

Y_i is the i -th principal component;

a_{ij} represents the component loadings (weights) assigned to each original variable;

X_j corresponds to the j -th standardized original variable.

The principal components obtained are ordered in descending order of their variance. Thus, the first principal component maximizes $\text{Var}(Y_1) = a_1' \Sigma a_1$ subject to $a_1' a_1 = 1$, while the second principal component maximizes $\text{Var}(a_2' X)$ subject to $a_2' a_2 = 1$ and $\text{Cov}(a_1' X, a_2' X) = 0$. Broadly speaking, variance measures the amount of information carried by each component, such that the higher the variance, the greater the component's capacity to explain the underlying structure of the data. Consequently, the first few principal components account for most of the data variability. Furthermore, the factors loading —represented by the coefficients a_i —allow for identifying the extent to which each variable contributes to the construction of a principal component, where higher absolute values indicate greater influence on that component (Johnson; Wichern, 2007).

3.3 VARIABLES

In strict alignment with the RIS taxonomy proposed by Cooke (1998) and Tödtling and Trippl (2005), the variables selected for the years 2010 and 2022 were operationalized to represent three fundamental theoretical dimensions of regional innovation systems: **i) Knowledge Generation and Dissemination Subsystem:** Measures scientific infrastructure and the capacity to train qualified human resources. In regional literature (Barros, 2000; Catalán et al., 2020; Pereira et al., 2018), universities and research institutes function as the “hard core” of scientific support essential for knowledge spillovers. **ii) Technological Exploitation and Application Subsystem:** Reflects the capacity of the private and enterprise productive sectors to absorb, transform, and codify knowledge into market innovations. The presence of employed technical-scientific personnel (Araújo; Cavalcante; Alves, 2009) and the flow of patent filings (Albuquerque et al., 2002; Santos; Mendes, 2018) represent the dynamism of the business sector in the economic appropriation of innovation. **iii) Economic and Urban Structure:** Represents the structural conditions of the territory required to sustain systemic interactions. As demonstrated by Gonçalves (2006), Santos (2008), and Stojkoski et al. (2016), urban density and the sophistication of the productive structure define the local absorptive capacity of the generated knowledge.



Chart 1 details the methodological framework, summarizing the alignment between the theoretical concepts, operational variables, and supporting literature:

Chart 1 | Variables Used in the Cluster Analysis

Variable	Description	References	Data Source
Faculty	Total number of graduate faculty members in the municipality as a proxy for R&D human resources	Santos e Mendes (2023); Pereira <i>et al</i> (2018)	GEOCAPES
Graduate Students	Total number of graduate students in the municipality as a proxy for R&D human resources	Santos e Mendes (2023); Albuquerque, <i>et al.</i> (2002)	GEOCAPES
Scholarships	Total number of graduate scholarships awarded in the municipality as a proxy for public R&D funding	Barros (2000) Carvalho (2025)	GEOCAPES
Scientific Articles	Scientific publication records as a proxy for knowledge production.	Catalan <i>et al</i> (2020), Neves e Santos Júnior (2023)	Web of Science
POTEC	Technical-Scientific Employed Personnel variable, representing total professionals engaged in R&D and S&T activities within firms and industries	Araújo, Cavalcante e Alves (2009)	RAIS
Public S&T Expenditure (per capita)	Municipal expenditure related to scientific research, technological development, innovation incentives, laboratories, technical services, and related activities	(Isaksen, 2001; Sanso-Navarro; Vera-Cabello, 2018).	SICONFI
Population Educational Attainment	Percentage of the population aged 25 or older with more than 11 years of schooling. Used to measure municipal capacity for knowledge creation and absorption	Gonçalves (2006)	IBGE
Patent	Total patent applications filed per municipality as a measure of technological creation capability	Albuquerque <i>et al.</i> (2002); Santos e Mendes (2018; 2023)	BADEPI
Degree of Industrialization	Ratio of total workers employed in manufacturing to total employed population in the municipality	Gonçalves (2006) Santos (2008)	RAIS
Population	Total resident population in the municipality, used to capture scale and size	Gonçalves (2006) Santos (2008)	IBGE
GDP per capita	Proxy for municipal economic wealth and dynamism	Gonçalves (2006) Santos (2008)	IBGE
Exports	USD value of municipal exports. Serves as a robust methodological strategy to measure innovation output and regional competitive integration	Rodrigues <i>et al</i> (2026)	Comex Stat
Services Sector	Ratio of total workers employed in knowledge-intensive services (KIBS) to total employed population in the municipality	Rodrigues <i>et al</i> (2026) Stojkoski <i>et al.</i> (2016)	IBGE
Urbanization Rate	Proportion of households located in urban areas relative to total municipal households	Gonçalves (2006) Santos (2008)	IBGE

Source: Authors' elaboration.



4 RESULTS

The statistics presented in the table below (Table 1) evidence the latent inequality across the analyzed data for Minas Gerais. A wide dispersion of data relative to the means is observed, along with a striking difference between medians and means, suggesting positive skewness, particularly in variables linked to R&D&I. Furthermore, maximum values are substantially higher than minimum values, which, in turn, are zero for most of the variables. Thus, the data reveals significant heterogeneity among municipalities in Minas Gerais across both analyzed periods.

Table 1 | Descriptive statistics of the analyzed variables

2010					
Variable	Mean	Median	Standard Deviation	Minimum	Maximum
Scholarships	6.1	0.0	77.6	0.0	1,891.0
Graduate Students	6.0	0.0	80.0	0.0	1,966.0
Faculty	6.7	0.0	94.0	0.0	2,486.0
Degree of Industrialization	0.1	0.1	0.2	0.0	0.8
Population	22,974.6	8,003.0	93,751.5	815.0	2,375,151.0
POTEC	12.5	0.0	105.8	0.0	2,364.0
Population Educational Attainment	0.1	0.1	0.0	0.0	0.2
Scientific Articles	4.0	0.0	54.7	0.0	1,445.0
Patents	0.0	0.0	0.2	0.0	7.0
Services Sector	0.1	0.1	0.0	0.0	0.5
Urbanization Rate	0.6	0.7	0.3	0.0	1.0
GDP per capita (BRL) ³	876,565.7	132,736.9	5,246,138.9	20,502.6	126,071,807.1
Exports (USD)	72,927,150.5	0.0	588,260,333.7	0.0	12,818,726,984.2
Public S&T Expenditure (per capita)	2,314,968.8	0.0	66,315,923.7	0.0	1,936,814,511.5
2022					
Variable	Mean	Median	Standard Deviation	Minimum	Maximum
Scholarships	11.4	0.0	148.2	0.0	3,740.0
Graduate Students	10.0	0.0	121.8	0.0	3,017.0
Faculty	13.2	0.0	149.6	0.0	3,819.0
Degree of Industrialization	0.1	0.1	0.1	0.0	0.7
Population	24,079.7	8,048.0	94,352.8	833.0	2,315,560.0
POTEC	18.0	0.0	104.6	0.0	1,631.0
Population Educational Attainment	0.1	0.1	0.0	0.0	0.3
Scientific Articles	14.8	0.0	165.1	0.0	4,181.0
Patents	1.7	0.0	17.4	0.0	486.0
Services Sector	0.1	0.1	0.0	0.0	0.4
Urbanization Rate	0.7	0.8	0.2	0.3	1.0
GDP per capita (BRL) ⁴	31,641.4	22,460.8	31,201.5	8,049.1	390,990.8
Exports (USD)	42,938,889.4	0.0	209,000,979.5	0.0	2,394,101,697.0
Public S&T Expenditure (per capita)	3.1	0.0	20.0	0.0	457.4

Source: Authors' elaboration.

3 Values deflated using the IPCA (Consumer Price Index), base year 2022.

4 Values deflated using the IPCA (Consumer Price Index), base year 2022.



Through the methods described in the previous section, we sought to characterize the dynamics of innovation activity in the state of Minas Gerais by analyzing the distribution of ST&I (Science, Technology, and Innovation) assets across regional innovation systems. Accordingly, four municipal clusters were constructed based on the dimension of each municipality's innovation system for each of the two years analyzed. The profile of each cluster was evaluated considering the mean values of the assessed variables, as presented in Table 2.

Among the clusters identified for 2010 and 2022, four distinct patterns emerged regarding the average composition of factors representing the nuances of regional innovation systems in Minas Gerais—patterns that persist over the years. Cluster 2 exhibits the lowest means across all groupings, corresponding to municipalities with peripheral innovation systems characterized by low innovative capacity. Conversely, Cluster 1 represents systems in transition: although they still display low dynamism in knowledge production, they possess a relatively dynamic economic and urban structure, being considered intermediate systems with expanded productive capabilities. Cluster 4 comprises municipalities with the state's best innovative infrastructure, configuring themselves as dynamic regional hubs. Finally, the outlier municipality in Cluster 3 constitutes the state's dominant innovation core. This formation highlights the spatial consistency of the clusters and the structural persistence of regional innovation systems in Minas Gerais over time.

Table 2 | Cluster profiles according to the means of selected variables (2010, 2022)

VARIABLE	CLUSTER							
	1		2		3		4	
	2010	2022	2010	2022	2010	2022	2010	2022
Number of Municipalities	317	340	520	491	1	1	15	21
Faculty	1.62	4.48	0.00	0.00	2,486	3,819	183	281
Graduate Students	0.88	1.66	0.00	0.00	1,966	3,017	190	233
Scholarships	1.32	1.72	0.00	0.00	1.89	3,740	194	258
Scientific Articles	1.23	5.35	0.00	0.80	1,445	4,181	104	310
POTEC	11.00	18.00	0.30	0.30	2,364	1,558	311	356
Public S&T Expenditure per capita (BRL)	0.41	4.19	0.15	0.99	81.54	66.75	0.78	32.26
Population Educational Attainment (%)	7	12	5		23	29	14	19



Patents	0.00	1.80	0.00	0.05	7	486	0.00	24
Degree of Industrialization (%)	28	26	6	7	5	4	25	21
Population	29,426	28,314	8,631	8,272	2,375,151	2,315,560	227,027	215,973
GDP per capita (BRL thousands)	35.49	43.72	15.50	20.92	53.07	49.83	73.61	85.84
Exports (USD thousands)	30,072.00	41,450.36	188.25	1,492.09	405,329.	811,702.00	1,278,399	999,496
Services Sector (%)	7	9	6	8	10	12	9	11
Urbanization Rate (%)	83	86	57	64	95	100	100	94

Source: Authors' elaboration.

The comparison between the two periods indicates slightly relevant transformations in the structure of regional innovation systems in Minas Gerais, combining structural shifts with the persistence of strong inequalities. Initially, a reduction was observed in the number of municipalities classified in the most peripheral cluster (Cluster 2), accompanied by an expansion of municipalities in the intermediate group (from 317 to 340) and the dynamic group (from 15 to 21), while the dominant innovation core remains composed of a single municipality. Despite this reduction, Cluster 2 continues to be characterized by extremely low levels of scientific, technological, and productive capacity. Although a marginal improvement is observed in some indicators—such as scientific output, patenting activity, and per capita S&T expenditure, these advances are modest and insufficient to alter their structural position. Thus, the cluster remains marked by persistent limitations, highlighting the difficulty of achieving a broader spatial diffusion of innovative capabilities across the territory.

In turn, the intermediate Cluster 1 expands its share and consolidates itself as a transitional space within the analyzed structure. The growth of this group is accompanied by advances in scientific and technological variables, such as the increase in article publications and the emergence of patenting activity. However, the incorporation of municipalities originating from lower levels contributes to broadening the internal heterogeneity of the cluster, which tends to moderate the growth of its average indicators. Thus, although there is absolute evolution, this grouping maintains an intermediate and unequal profile, reinforcing its role as a transitional stage in the development process of regional innovation systems.



The most dynamic cluster (Cluster 4) displays a clear movement of expansion and strengthening. The increase in the number of municipalities is accompanied by expressive gains in scientific and technological indicators, highlighting significant growth in article publications, the consolidation of patenting activity, and an increase in per capita S&T expenditure. These results indicate the strengthening of innovative intensity in this group, which asserts itself as the main driver of regional dynamism. At the same time, the slight reduction in certain economic variables, particularly exports, suggests the potential incorporation of municipalities with lower economic intensity, contributing to increased internal heterogeneity without compromising its prominent position.

Finally, the dominant innovation core (Cluster 3) maintains its position of extreme centrality, concentrating far superior levels of scientific output, human resources training, and technological activity. Although a slight reduction is observed in indicators such as S&T expenditure and GDP per capita, this cluster exhibits a relevant shift in its composition, evidenced by a significant increase in patenting activity. This dynamic suggests a reconfiguration in how knowledge is generated and appropriated, without, however, altering its status as the main concentrating hub of innovative capabilities.

In summary, the results indicate that although there are signs of mobility and relative diffusion of innovative capabilities, the overall structure of the system remains strongly hierarchical, marked by deep disparities across its different levels. Given this, it becomes relevant to advance the analysis, seeking to understand not only the differences between clusters, but also the underlying structures that organize these disparities. In this sense, Principal Component Analysis (PCA) allows for summarizing the information contained within the variables and identifying the main axes structuring the analyzed regional innovation systems. As shown in Table 3, the PCA identified that the first two components (PC1 and PC2) explain more than 60% of the total data variability in both years:

Table 3 | Variance explained by principal component

Component	Explained Variance (%)		Cumulative Variance (%)	
	2010	2022	2010	2022
PC1	49.91	45.98	49.91	45.98
PC2	14.82	16.05	64.74	62.03
PC3	8.32	8.98	73.06	71.01
PC4	7.06	7.67	80.12	78.68
PC5	4.98	6.49	85.1	85.18
PC6	4.55	4.25	89.64	89.43
PC7	3.58	3.84	93.22	93.27
PC8	2.74	2.67	95.96	95.94

Source: Authors' elaboration.

This result demonstrates that the evaluated municipalities are primarily differentiated based on the variables that carry greater weight in these two components. The factor loadings for each variable, presented in the following table (Table 4), indicate the contribution of each variable to each component. The analysis reveals that, for both years under study, the variables corresponding to graduate faculty and students, research scholarships, scientific articles, and POTECE exert greater weight in determining the first component (PC1). Meanwhile, the second component (PC2) is more heavily influenced by variables related to economic structure, such as population educational attainment, municipal degree of industrialization, urbanization rate, and GDP per capita.

Table 4 | Factor loadings by variable

Variable	PRINCIPAL COMPONENT			
	2010	2022	2010	2022
	PC1	PC2	PC1	PC2
Faculty	0.37	-0.09	0.38	0.15
Graduate Students	0.36	-0.08	0.37	0.16
Scholarships	0.36	-0.08	0.37	0.17
Scientific Articles	0.37	-0.09	0.38	0.15
POTECE	0.31	0.05	0.27	-0.22
Public S&T Expenditure per capita	0.29	-0.1	0.07	-0.16
Population Educational Attainment	0.17	0.46	0.2	-0.38
Patents	0.35	-0.14	0.38	0.11
Degree of Industrialization	0.02	0.43	0.02	-0.39
Population	0.35	0.02	0.37	0.02
GDP per capita	0.05	0.42	0.07	-0.44
Exports	0.07	0.3	0.15	-0.38
Services Sector	0.03	0.07	0.06	-0.03
Urbanization Rate	0.08	0.53	0.1	-0.43

Source: Authors' elaboration.



It is worth noting that the first principal component accounts for approximately 50% of the total explained variance in both periods, indicating that disparities among clusters are predominantly captured by the dimension associated with the municipalities' scientific capabilities. Thus, although certain localities exhibit high levels of GDP per capita and a greater degree of industrialization, these characteristics exert a relatively minor influence on differentiating the analyzed cases and, consequently, have a reduced impact on the projection.

Rather than being merely a structural feature, this result can be interpreted as a reflection of the institutional strengthening of the higher education and research system in Minas Gerais over recent decades. As demonstrated by Carvalho (2025), the state underwent a significant expansion of its academic and scientific base, highlighted by the growth in the number of graduate programs and enrolled students—which surged from nearly 9,000 in the early 2000s to almost 40,000 in 2022—alongside the expansion of the network of federal universities and research institutes. This movement contributed to densifying the knowledge-generation infrastructure across the territory, increasing the availability of qualified human resources and scientific output.

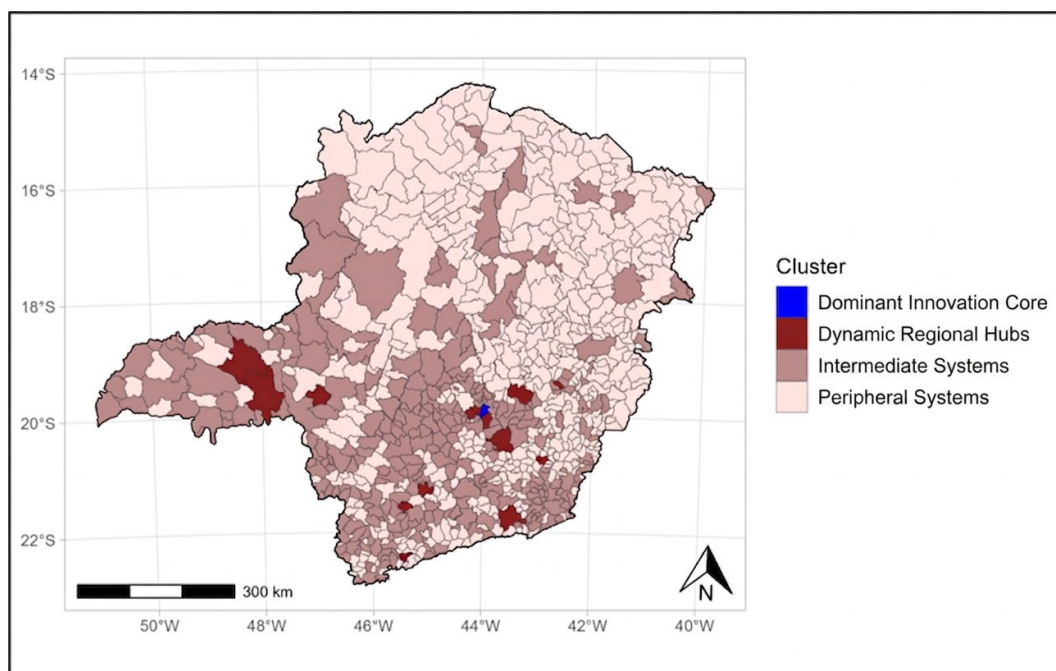
In this regard, the results reveal that the structure of regional innovation systems in Minas Gerais not only remains highly hierarchical but has also become increasingly organized around the scientific and technological dimension. This pattern reinforces the notion that territorial disparities are not explained solely by productive bases or income levels, but primarily by the capacity to generate, absorb, and diffuse knowledge. reorganize the consolidation of this dimension as a structural axis suggests that municipal development trajectories tend to reorganize around these capabilities, making it particularly relevant to analyze how these territories are redistributed over time across the different stages of regional innovation systems.

4.1 SPATIAL DISTRIBUTION OF REGIONAL INNOVATION SYSTEMS IN MINAS GERAIS

The analysis of municipal distribution according to the development stage of their regional innovation systems (RIS) reveals the persistence of a heavily concentrated structure. In 2010, 520 municipalities were classified as peripheral with low innovative capacity (Table 2), a figure that decreased only marginally to 491 in 2022. Municipalities categorized as intermediate RIS rose from 317 to 340, while dynamic regional hubs expanded from 15 to 21. Despite this mild expansion in the higher tiers, the overall spatial configuration underwent little change, remaining marked by a sharp contrast: a single, dominant innovation core (Belo Horizonte) accounts for over 40% of the state's total scientific and technological output (Santos, 2023), whereas 57% of municipalities possess virtually no innovative capacity. These findings indicate that while aggregate progress occurred within the state's innovation system, this growth did not translate into meaningful structural transformations in the spatial distribution of innovative capabilities.

Figures 1 and 2 further illustrate the situation described above, providing a visual representation of the spatial distribution for the four clusters derived from the analysis.

Figure 1 | Geographic distribution of clusters (2010)

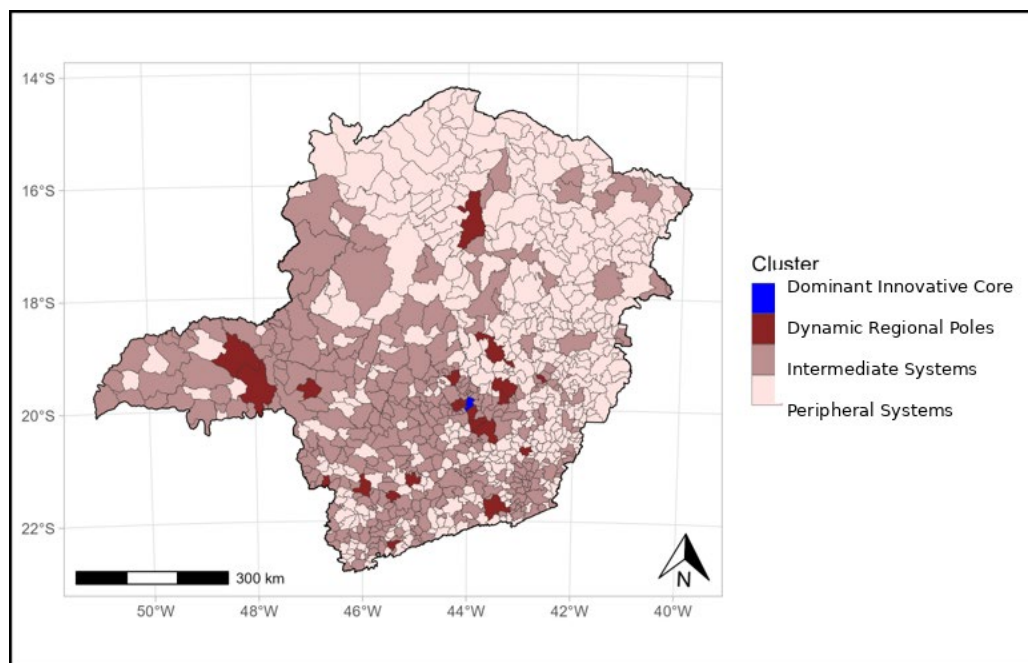


Source: Authors' elaboration.

In line with Santos (2008), who classified the municipalities of Minas Gerais according to the level of development of their local innovation systems in the early 2000s, Figure 1 shows that in 2010 the municipalities with more advanced RIS were still organized as a few isolated clusters of development across the territory of Minas Gerais. In contrast, peripheral systems with low innovative capacity were predominantly concentrated in the Northern region and in the Jequitinhonha and Mucuri Valleys.

As illustrated in Figure 2, between 2010 and 2022, the territorial distribution of regional innovation systems remains remarkably stable, with few changes in the locations of municipalities belonging to the most advanced groups. Dynamic regional hubs continue to function as isolated nodes within the territory, without forming a continuous spatial structure for the diffusion of innovative capabilities. The influence of higher education institutions in shaping this cluster is evident, as all 15 municipalities belonging to this group in 2010 hosted universities, eight of which were home to at least one federal institution of higher education.

Figure 2 | Geographic distribution of clusters (2022)



Source: Authors' elaboration.

Indeed, this group includes the main pillars of higher education in Minas Gerais, such as the municipalities of Juiz de Fora, Ouro Preto, and Viçosa, which house the state's oldest university infrastructure. This explicitly underscores the importance of higher education within the innovation system of Minas Gerais and its potential for a regional development strategy. Furthermore, in 2022, this cluster expanded to include the municipalities of Alfenas and Montes Claros, which also feature major university centers, such as the Federal University of Alfenas (UNIFAL) and the State University of Montes Claros (Unimontes)—the latter constituting the primary knowledge dissemination hub not only for its namesake city but for the entire Northern region of the state.

The strong correlation between academic infrastructure and the maturity of Regional Innovation Systems (RIS) in Minas Gerais, as evidenced by the concentration of dynamic hubs (Cluster 4) in municipalities endowed with established universities, finds direct theoretical support in the role of Higher Education Institutions (HEIs) as drivers of development. As discussed by Steinhorst and Lima (2025), universities act as true hubs of regional socioeconomic development, with their primary functions being the training of qualified human capital, the fostering of research, and the subsequent conversion of this knowledge into intellectual property assets. Furthermore, this group is characterized by a higher proportion of workers employed in science and technology activities and a higher volume of patent applications filed with the INPI (National Institute of Industrial Property)⁵.

Throughout these 12 years of analysis, the municipalities of Conceição do Mato Dentro, São Gonçalo do Rio Abaixo, and Guaxupé also evolved in terms of their innovation system classifications, being currently categorized as dynamic regional hubs. Although these are municipalities with small populations and modest scientific knowledge production, their inclusion in this cluster is understood to stem from their structural and productive dynamics, as the former two are mining-driven municipalities ranking among the state leaders in GDP per capita and export value. Consequently, this reality influences the urbanization rate, industrialization level, and educational attainment of their populations, transforming them into development poles within the state.

In this context, the evolution of the municipality of Itabira is also noticeable, expanding the territorial range of the agglomeration formed by dynamic regional hubs surrounding Belo Horizonte.

5 Compared to other municipalities in the state, excluding the outlier Belo Horizonte, which stands as an isolated core representing the most advanced innovation system in Minas Gerais.

As a result, this spatial cluster now encompasses a belt of Minas Gerais territory stretching from Betim to Ouro Preto, comprising six municipalities. This represents the only spatial agglomeration in the state composed of such a high number of municipalities classified in the most advanced stages of RIS development, illustrating the potential spillover effects originating from Belo Horizonte's innovation system.

Figure 2 further reveals that the municipalities that transitioned from peripheral RIS status to the intermediate group are predominantly located in the Northwestern and Southern regions of the state, suggesting that upgrading to higher levels of innovative capability is associated with previously structured regional dynamics. Only two municipalities in the Northern region advanced their innovative status from peripheral to intermediate—namely Januária and Itacarambi—whereas no localities in the Jequitinhonha and Mucuri Valleys underwent any reconfiguration in their RIS.

This territorial rigidity and the persistence of these regions in the innovation periphery of the state are explained by severe local socioeconomic vulnerabilities. As highlighted by Bahiense and Lima (2021), rural predominance, limited infrastructure, low educational attainment, and low wages result in weak employment and income performance. Additionally, these regions are marked by constraints in attracting private investment, heavy reliance on public expenditure, and low municipal HDIs. This scarcity of opportunities fuels the out-migration of youth and talent to larger centers, preventing the consolidation of modern productive activities. Lacking qualified human capital retention and the infrastructure to support innovation, Northern and Northeastern Minas Gerais perpetuate a landscape of innovative emptiness and persistent regional disparity.

In summary, these findings corroborate the empirical evidence provided by Gonçalves (2006) and Santos (2008) for the early 2000s, demonstrating the spatial inertia of innovative inequality in the state. The concentration of dynamic municipalities along the Central-South axis and the systematic marginalization of the North and the Jequitinhonha and Mucuri Valleys reflect the classic “polarization effects” theorized in regional development literature (Hirschman, 1958; Myrdal, 1957). The cumulative advantages of agglomeration and the presence of academic and industrial hubs continue to act as magnetic forces attracting human capital and investments to consolidated regions, suppressing the buildup of absorptive capacities in less dynamic territories.

On the other hand, in terms of empirical advances and distinctions, this research refines the conclusions of Rodrigues et al. (2026). By descending to the municipal scale, this study demonstrates that the progress or dynamism suggested in larger regional aggregations often masks local “innovative voids.” While the microrregional approach of Rodrigues et al. (2026) suggests greater homogeneity within microregions, the municipal mapping conducted here reveals that even in the most dynamic regions, innovative capacity remains extremely localized, restricted primarily to municipalities hosting public universities.

Additionally, the formation of a continuous agglomeration of dynamic hubs surrounding the Metropolitan Region of Belo Horizonte was identified. This phenomenon indicates that knowledge and productive capacity spillovers occur almost exclusively under conditions of strong geographical proximity and pre-existing industrial density, failing to reach the distant hinterland. Therefore, contrary to the hypothesis of regional innovation deconcentration observed by Santos and Mendes (2023) at a national scale for certain Brazilian regions, the intra-state landscape of Minas Gerais demonstrates a pattern of “polarized” or localized deconcentration, incapable of altering the structural asymmetry of regional development across the state.

Given that higher levels of innovation translate into greater economic development, and that innovation capacity is directly connected to the development stage of the regional innovation system, structuring the RIS across Minas Gerais becomes imperative. Therefore, establishing STI (Science, Technology, and Innovation) foundations in municipalities outside the state’s main dynamic axis is essential to increase spatial continuity and optimize the regional innovation architecture. Consequently, public policies aimed at the interiorization of scientific and technological capacity to promote knowledge diffusion are essential, particularly in regions exhibiting low engagement in innovative activities (Sanso-Navarro & Vera-Cabello, 2018).



5 CONCLUSIONS

The empirical findings of this study allow for mapping the regional profile of innovative activity in Minas Gerais while exposing persistent structural vulnerabilities. In 2010, the analysis identified four distinct groupings, in which the systems characterized by greater dynamism and capability were concentrated in just 16 of the state's 853 municipalities, with the dominant cluster comprising exclusively Belo Horizonte. These highly developed systems were distributed across a few isolated nodes, predominantly situated in the southern half of the state, whereas the northern and northeastern regions contained municipalities with incipient or non-existent innovative capacity. Considering the temporal dynamics up to 2022, an increase in indicator averages was observed, reflecting progress in the broader innovation landscape; however, the core structural configuration remained largely unchanged: the vast majority of municipalities remained in the lowest capability clusters, while the number of localities belonging to the most advanced systems reached just 21 municipalities.

The preponderance of the scientific dimension in accounting for total data variance (approximately 50%) and the persistent structural rigidity of the clusters over the 12-year period align directly with the theoretical framework of Tödtling and Trippl (2005) regarding the boundaries of innovation-based regional development in peripheral territories. The authors argue that peripheral regions face structural capacity deficiencies and weak systemic connectivity between knowledge-generation and knowledge-application subsystems. In the case of Minas Gerais, despite the quantitative expansion of scientific and academic assets between 2010 and 2022, the limited spillover capacity of these assets into local productive structures prevented peripheral municipalities (Cluster 2) from transitioning to higher stages of maturity. This demonstrates a divergence from overly optimistic notions of automatic regional catch-up: the mere expansion of academic infrastructure in isolated nodes proved insufficient to trigger homogeneous dynamics of regional development.

Consequently, while there are indications of general progress across STI (Science, Technology, and Innovation) indicators—driven primarily by state investments that fostered innovative activities—no significant spatial reconfiguration of municipalities in terms of regional innovation system capacity occurred during the analyzed 12-year timeframe. This pattern suggests that the

regional innovation system of Minas Gerais maintains a highly concentrated structure, in which very few localities aggregate the necessary conditions to foster innovation, while most municipalities remain stagnant in less advanced stages. In terms of public policy, these results demonstrate that measures focused solely on the quantitative expansion of STI resources are insufficient unless paired with strategies designed to strengthen local absorptive and productive capabilities. It is therefore imperative to craft targeted regional policies that actively promote synergy between universities/ PRIs (Public Research Institutes) and the business sector in peripheral regions, reinforcing systemic connectivity and counteracting the brain drain and asset depletion in the Northern and Northeastern regions of the state.

Finally, a key limitation of this study lies in its reliance on secondary administrative datasets and the absence of direct, municipality-level indicators regarding private business expenditure on R&D. For future research, it is recommended to conduct empirical studies examining university-industry cooperation networks and knowledge flows within the regional dynamic hubs of Minas Gerais, aiming to elucidate how knowledge generated in these centers can be absorbed to revitalize the productive structures of these cities and their surrounding hinterlands.

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