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GEOGRAPHY OF INNOVATION: SPATIAL DISTRIBUTION OF PATENT FILINGS IN BRAZIL BETWEEN 1997 AND 2021

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ABSTRACT

Innovation is one of the main characteristics of economic and social development. However, it is a phenomenon that is difficult to measure directly, and may require the use of proxy indicators. This study aimed to map the geographical distribution of innovation in Brazil between 1997 and 2021, using the number of patent filings as a proxy variable. Spatial analysis techniques were applied to identify possible innovation *clusters* and investigate the presence of the *spillover effect*. Two approaches were employed: choropleth maps to describe the distribution of patents by state and heat maps based on the *Kernel Density Estimation* (KDE) technique, to represent the spatial density of the innovation. The results revealed a strong concentration of innovative activity in the South and Southeast regions, with indications of the effect of the spillover of innovation to the Northeast region from 2012 onwards. The analysis highlighted the relevance of the territorial component in the dynamics of innovation and reinforced the importance of public policies that stimulate the internalization of Scientific and Technological Institutions and the strengthening of Research and Development activities.

Keywords: Technological Innovation. Innovation Indicators. Geography of Innovation. Innovation Cluster. Overflow Effect.

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INTRODUCTION

In a world marked by the constant search for solutions, innovation emerges as one of the main characteristics to be pursued. However, it is a concept that is difficult to characterize, multifaceted and marked by complexity. How to measure it correctly is a great challenge, and there is no single indicator capable of capturing such an event (GAULT, 2018; HAAR, 2018; OECD, 2018; NANDAL and DHINGRA, 2020).

As a result, innovative activity can be measured through proxy indicators . Because they are an approximation, they are not able to capture the measured fact in its full extent, but they are able to capture part of the object of study (JALLES, 2010). One variable that can be used to represent research and development (R&D) activity in the context of innovation is the number of patents granted (ACS; ANSELIN; VARGA, 2002; GRILICHES, 1998).

The objective of the present study is to map the geographic distribution of patent filings in Brazil from 1997 to 2021, using spatial analysis techniques, in order to identify *innovation clusters* and the existence of the *spillover effect*.

Innovation clusters refer to the geographical concentration of companies, educational institutions, Scientific, Technological and Innovation Institutions (ICTs), among other actors, with the purpose of fostering innovation and promoting the development of pioneering solutions. These actors act in a joint and interconnected way. As a consequence, there is an increase in productive capacity and creativity. Such geographic clusters emerge as catalysts and attractive force for innovation (MAZUR et al., 2016; YU and JACKSON, 2011).

The *spillover effect* is the phenomenon of the ability of highly innovative regions to disseminate knowledge and technological practices, promoting the spatial spillover of innovation activities and encouraging other regions to adhere to these activities, thus creating regional synergies and articulation between the various actors involved (ALPASLAN and ALI, 2018; CABRER-BORRAS and SERRANO-DOMINGO, 2007; CHEUNG and LIN, 2004). In the Brazilian context, the investigation of such a phenomenon allows us to understand how innovation spreads territorially and which regions can benefit from regional integration policies.

The choice to use spatial analysis techniques in the present study was motivated by the ability of these tools to identify the geographical patterns of concentration of innovation. The use of tools such as choropleth maps and heat maps allows you to observe areas with more or less patent filings. The results generated by these techniques, through visual

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representations, favor the understanding and communication of the findings, allowing, in many cases, a clearer understanding than the simple presentation of compiled statistics.

The identification of spatial patterns allows us to understand how innovation is distributed in Brazil. Such characterization allows the orientation of public policies, regional planning, as well as a correct direction of investments in R&D, favoring technological development in regions with less capacity for innovation. In the specific case of the present study, the spatial approach is the most appropriate to understand regional inequalities and the phenomenon of spillover.

The present study is divided into the following sections, in addition to this introduction. In the Methodology Section, the techniques used, which are based on spatial analysis, will be discussed, with emphasis on the use of choropleth maps and heat *maps.* The Results Section will present the maps and spatial visualizations. In the Discussion Section, the distribution of patents and respective *clusters* will be analyzed throughout the scope of the study, from 1997 to 2021. The results will be interpreted based on the spatial patterns found and their respective implications. Finally, in the Conclusion Section, the limitations of the study and future perspectives will be presented.

METHODOLOGY

To analyze the concentration of Brazilian innovation, spatial analysis techniques were used, with emphasis on choropleth maps and heat maps. Coropleth maps are a type of thematic map, whose main function is to represent information about a specific variable. In this study, the number of patents registered per year or per period was the variable of interest. The geographic areas, in the present study the Brazilian states, are colored proportionally: the higher the value of the study variable, the more intense the color corresponding to the area. This technique was chosen because it allows the distribution of patents by state to be shown more easily.

In the present study, to ensure that the color scale was comparable in all states, a global maximum value (*global vmax*) of color was defined on the map. The *global vmax* requires that all maps use the same maximum value for the colors, making the maps comparable to each other.

Heat maps, also thematic maps, are used to visualize the spatial density of patents, allowing the identification of areas with the highest concentration of innovation. In this type of map, the areas with the highest concentration of patents will be represented by stronger

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tones. To smooth out the density data and create a more accurate visualization, the *Kernel Density Estimation* (KDE) technique, a nonparametric statistical method, was used to estimate the probability density function in two-dimensional space.

In this way, it was possible to visualize the *innovation clusters* in Brazil. In the context of this study, the term *cluster* or *spatial cluster* refers to areas with a higher density of patent filings, as highlighted by KDE-based heat maps. In addition, the technique also allows you to highlight the presence of the *spillover effect*. This phenomenon occurs when an innovative activity is able to spread and influence neighboring areas. This explores the hypothesis that states with a high concentration of technological innovation act as engines of innovative impulse in adjacent areas.

The database used in the present study was obtained from the Intellectual Property Database (BADEPI) made available by the National Institute of Industrial Property (INPI). The database contains information on patent filings in Brazil from 1997 to 2021. Initially, the database contained 779,332 entries. As the cut-off used in this study was patented by state per year, it was necessary to clean the database. Patent applications made by people or companies residing abroad were discarded, as well as missing amounts in the state fields and filing dates.

To maximize the number of registrations for the study, the available information on the start and end dates of the patent application was combined. The final database, used in the present study, contains 182,342 entries. Although they do not make the study unfeasible, this loss of approximately 77% of the data, especially in the state field (535,256 entries), represents a limitation in the interpretation of the results and should be considered when generalizing conclusions.

As the database used in the study did not contain the specific geographic coordinates for each deposit, the geographic centroid of the states was adopted as the unit of location. The centroids were extracted from the *shapefile* of Brazil, divided by Federation Units (FU), made available by the IBGE. The heat map generated by period used the weights proportional to the number of deposits recorded per state. The density function was estimated using a Gaussian core function, due to the smoothness, symmetry and decay, desirable characteristics for the analysis of continuous spatial phenomena, such as patterns of technological concentration and spillover effects. The density surface was calculated on a two-dimensional grid of 500 by 500 cells, covering the entire national territory and

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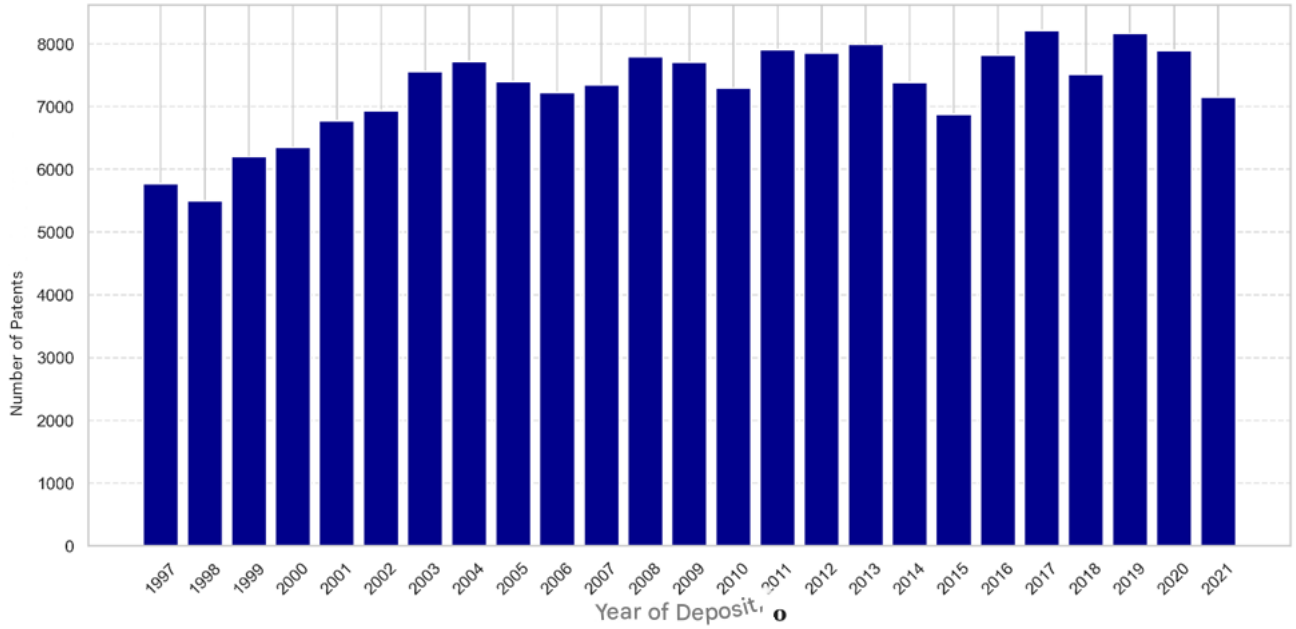
respecting the limits of the *shapefile*. The graphical representations were developed in a Python environment, with the Pandas, GeoPandas, Scipy, Matplotlib and NumPy libraries.

RESULTS

Figure 1 shows the annual distribution of patents in Brazil in the period from 1997 to 2021.

Figure 1 - Total patents granted in Brazil by year from 1997 to 2021



Source: Elaboration by the authors based on BADEPI data, after treatment and cleaning

Figure 2 presents a choropleth map that illustrates the geographic distribution of patent filings by state, in the period from 1997 to 2021.

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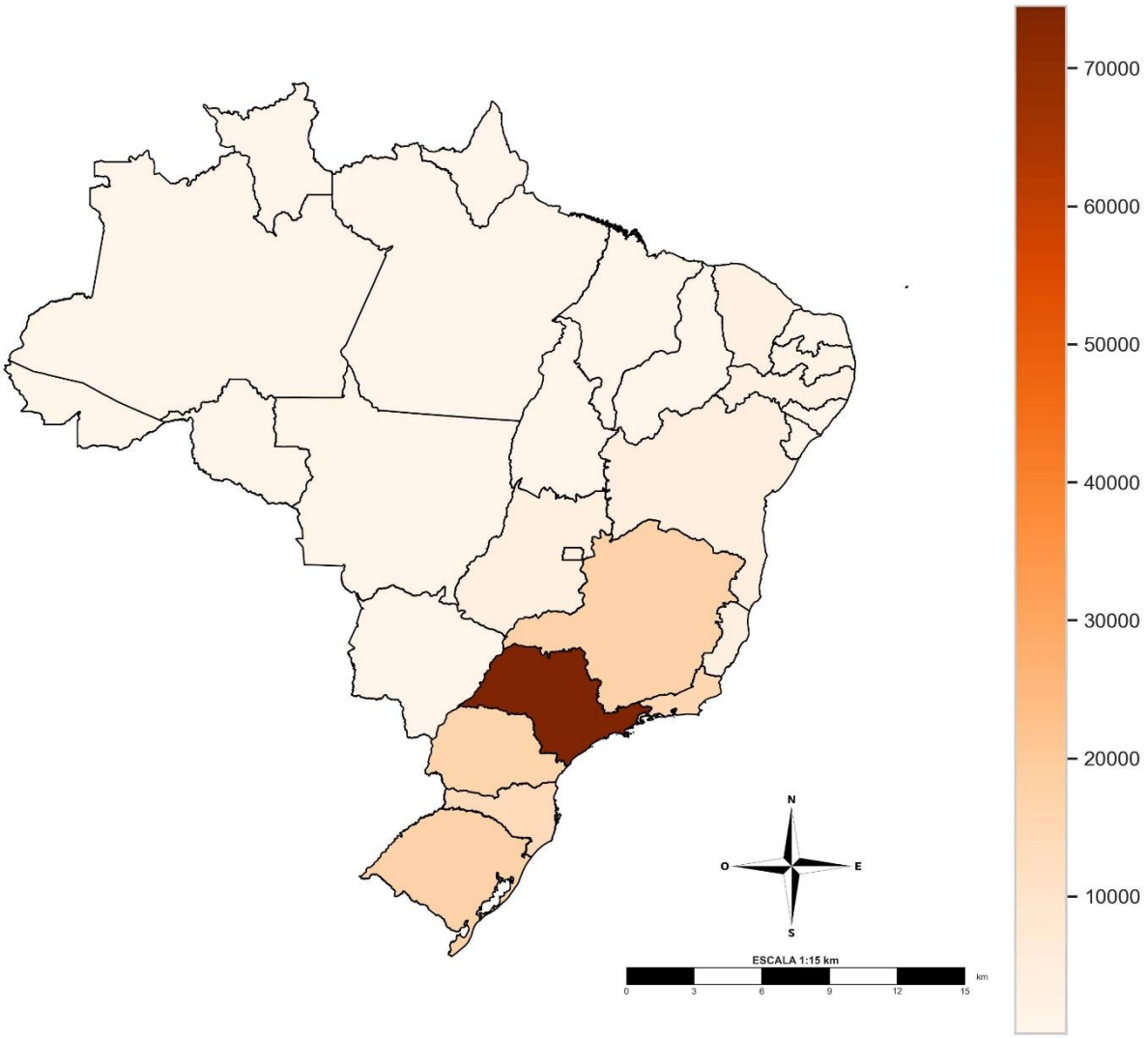
Figure 2 - Coropleth map of patent filings by state (1997–2021)



Source: Elaboration by the authors based on BADEPI data, after treatment and cleaning

Figure 3 allows us to compare the performance of each state in the period.

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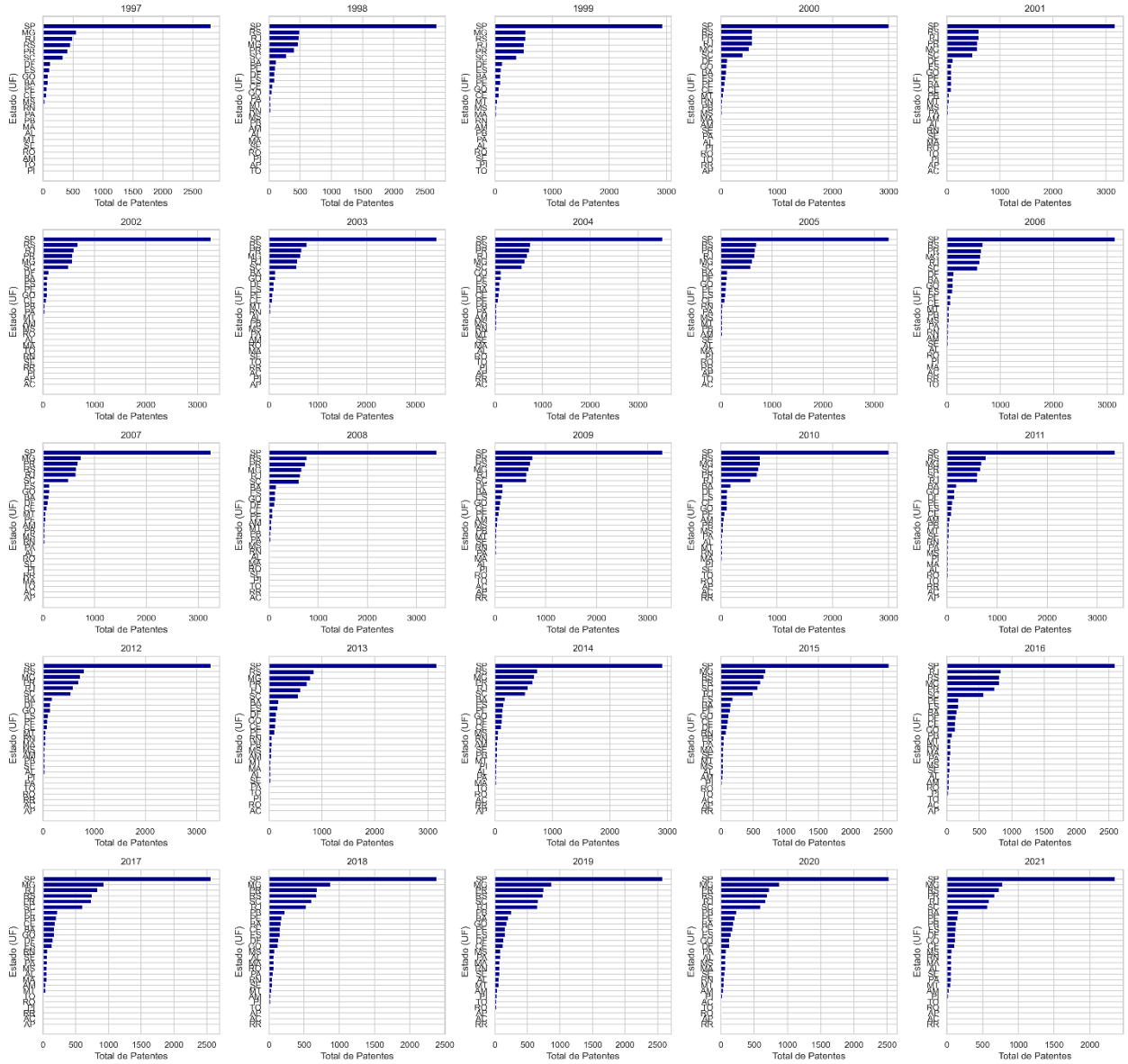
Figure 3 - Distribution of patent filings in Brazil by state and year (1997–2021)



Source: Elaboration by the authors based on BADEPI data, after treatment and cleaning

Figure 4 presents the choropleth map of the evolution, by five-year period, of patent filings by state.

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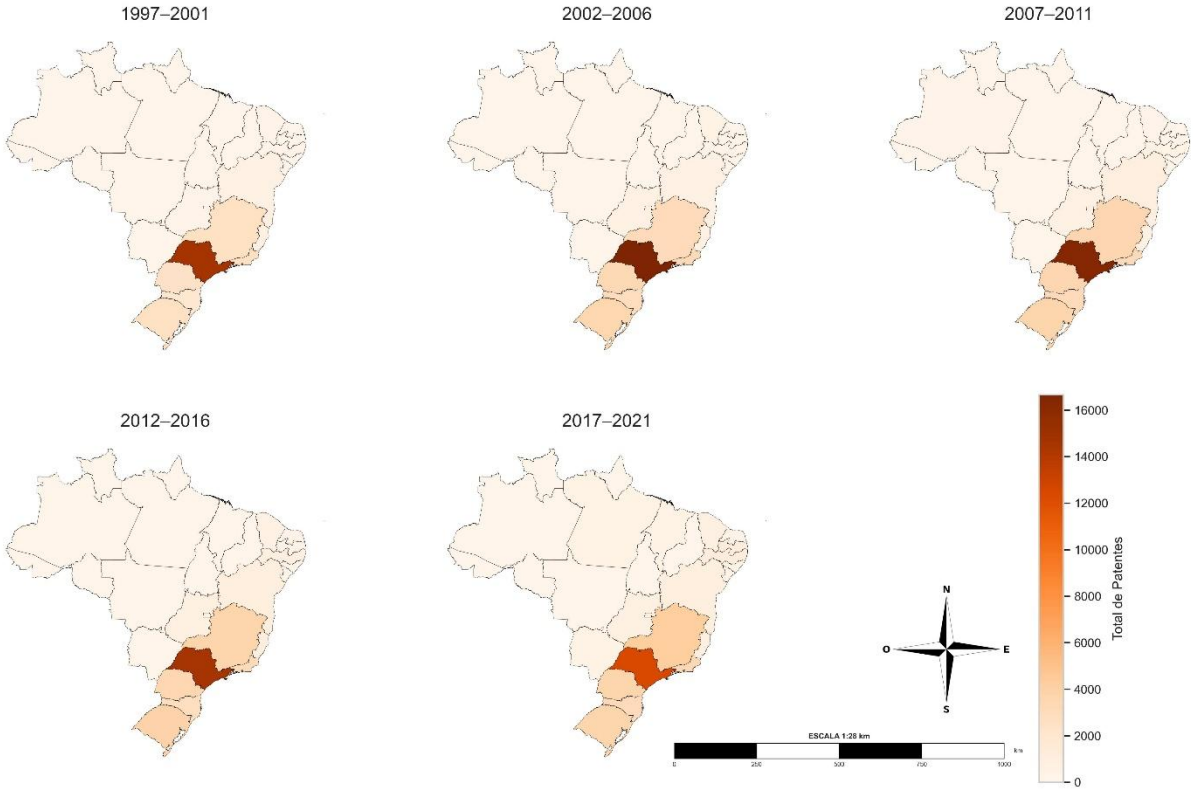
Figure 4 - Coropleth maps of patent distribution by five-year period (1997–2021)



Source: Elaboration by the authors based on BADEPI data, after treatment and cleaning

Figure 5 shows the heat map of innovation in Brazil by state, in the period from 1997 to 2021.

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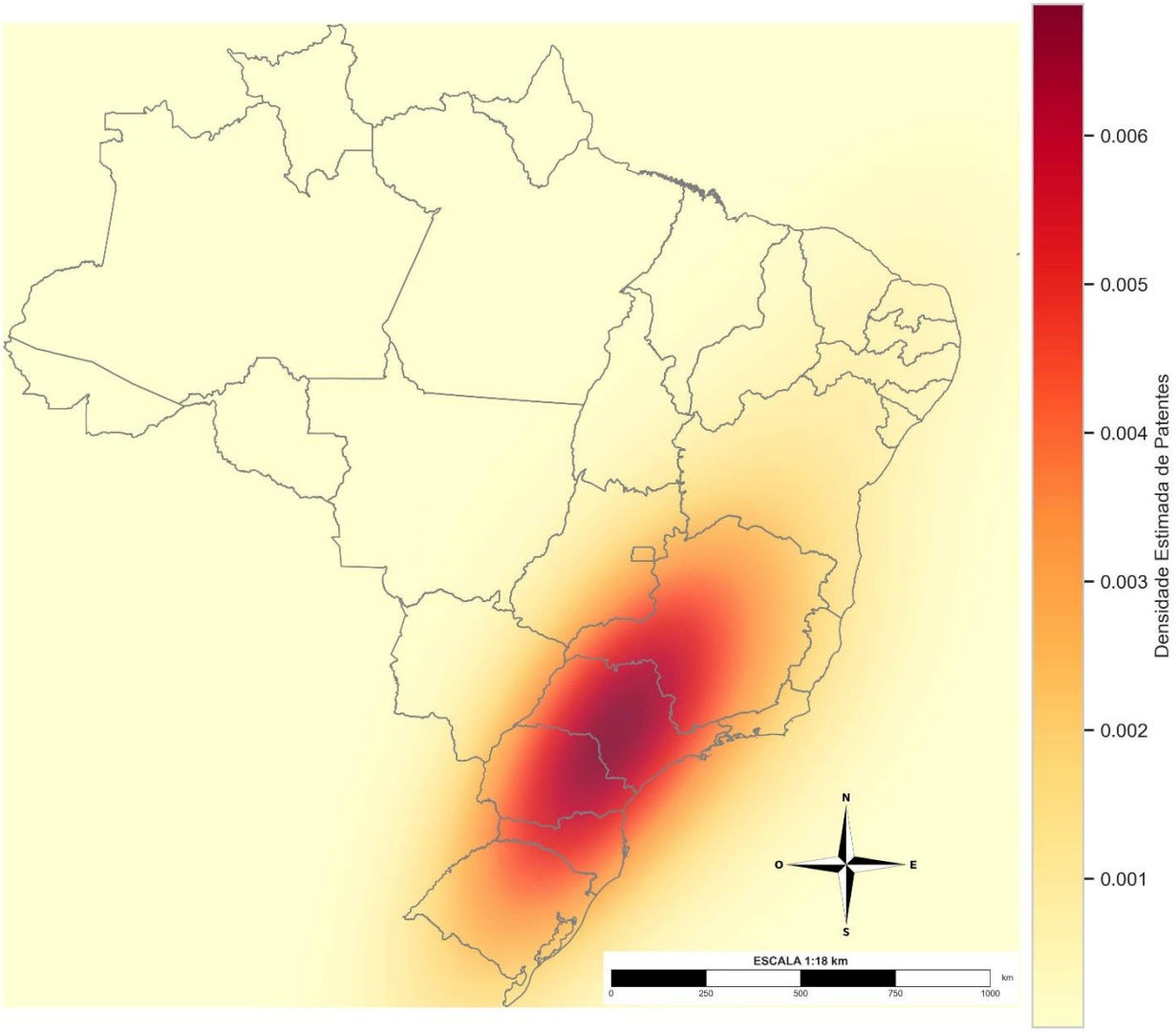
Figure 5 - Heat map of Brazil's patent filings by state (1997–2021)



Source: Elaboration by the authors based on BADEPI data, after treatment and cleaning

Figure 6 explores the evolution of innovation by five-year periods, allowing the temporal analysis of the evolution of the processes of concentration and diffusion of innovative activity in Brazilian territory.

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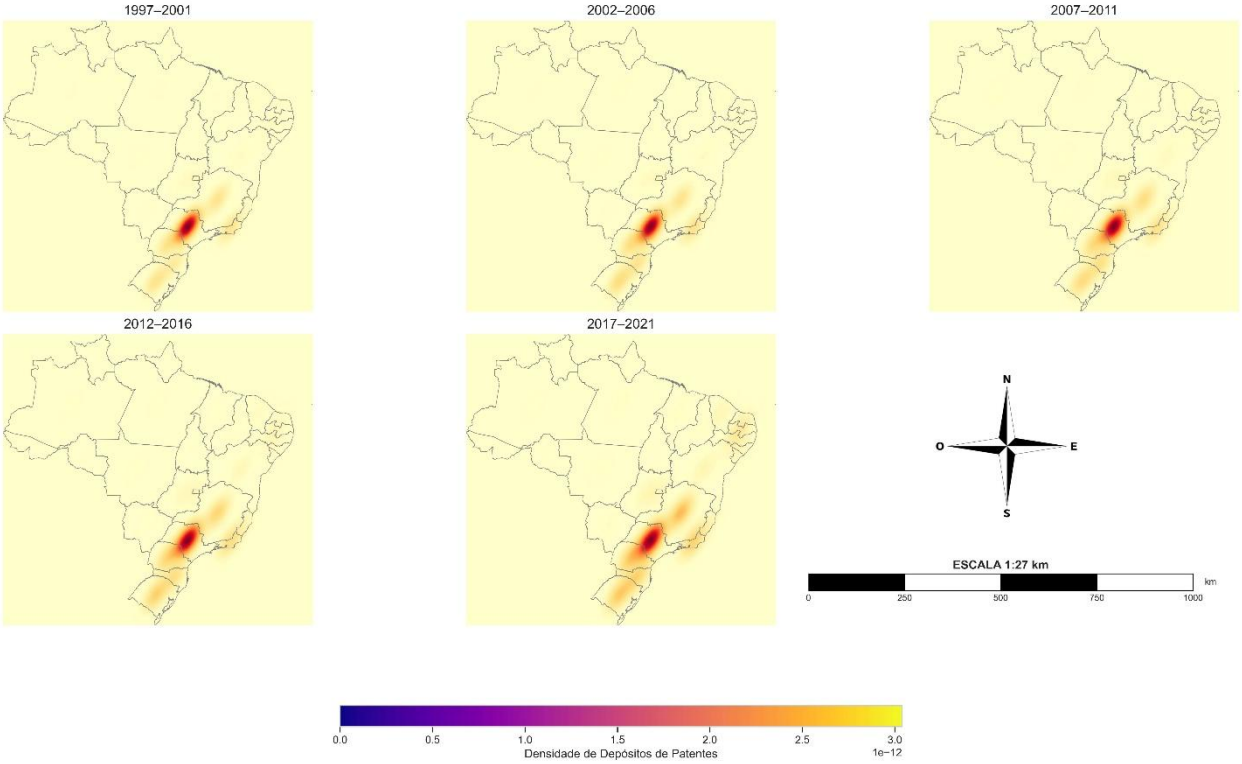
Figure 6 - Heat map of Brazil's patent filings by state by five-year period (1997–2021)



Source: Elaboration by the authors based on BADEPI data, after treatment and cleaning

In the next Section, the results of this Section will be discussed and analyzed.

DISCUSSION

Figure 1 shows the total number of patents granted in Brazil from 1997 to 2021. The year with the lowest number of patents was 1998 and the year with the highest was 2017. The data indicate a gradual growth trend over the period analyzed, suggesting advances in R&D and increased investments in strategic sectors. The implementation of public policies, such as the introduction of the Innovation Law (Law No. 10,973) in 2004, may be possible contributing factors to the promotion of national innovation.

The question that arises is whether there have been significant disparities between regions in terms of the granting of patents. Figure 2 reveals that, at the national level, there were areas with greater and lesser concentration of innovation, measured by the proxy variable patent granting, with emphasis on the states of the South and Southeast regions. In contrast, the North and Northeast regions showed a lower concentration of patents, showing signs of regional disparity in innovative activity.

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Figure 3 presents horizontal bar graphs that show the total number of patents granted by state over the years. Each chart represents a specific year, and the bars are arranged in descending order, allowing you to analyze regional fluctuations in the analysis period. The state of São Paulo (SP) led the innovation in all years, while the other states in the Southeast and South took turns in the main positions of this index.

Figure 4 shows the distribution of patents in Brazil over five five-year periods (1997-2001, 2002-2006, 2007-2011, 2012-2016, 2017-2021). The division into such periods allowed us to evaluate how innovation was distributed in the different FUs over time. The maps ratified that the Southeast and South regions have a higher performance in terms of innovation. However, it is verified that, in some periods, there is an increase in patent filings, *a proxy* for innovation, in other parts of the country. This type of analysis allows us to verify how innovation is spatially distributed and how intense it is in some regions, giving indications of the *spillover effect*, where regions that are innovation hubs influence adjacent regions.

Figure 5 shows the heat map of patent filings by State in the period from 1997 to 2021. This type of map allows us to identify the spatial density of innovation in Brazil, with chromatic variations, where lighter tones represent low intensity of innovation and darker tones represent high intensity of innovation.

As evidenced in the previous figures, the highest concentration of innovation is found in the South and Southeast regions. The map suggests the possible presence of the *spillover effect* from the most innovative areas of the Southeast to the adjacent regions. In recent decades, public innovation policies have been implemented in the national territory, highlighting the introduction of the Innovation Law in 2004 and the increase in investments in strategic sectors.

Figure 6 shows the heat map in Brazil over five five-year periods (1997-2001, 2002-2006, 2007-2011, 2012-2016, 2017-2021). Throughout all the periods analyzed, a high innovation density was observed in the South and Southeast regions, indicating a maintenance of consolidated innovation *clusters*. In all five-year periods, it was possible to observe an overflow of innovative density to the neighboring areas of the Southeast region, reinforcing the role of a propagating nucleus of innovation in the national territory.

From the 2012-2016 five-year period, the first signs of an increase in innovative activity in the Northeast region emerged. This phenomenon is accentuated in the following five-year period (2017-2021), with a noticeable growth in the estimated density in the

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region, suggesting a gradual expansion that crosses the borders of the South and Southeast regions. Inferences can be made, pointing to a positive effect of the implementation of policies for the internalization of innovation, through the implementation of technological infrastructure, the introduction of ICTs and public universities, and investments in research and development.

Figure 6 also highlights the importance of analyzing innovation activity by cycles and not as a whole. The use of five-year periods made it possible to observe the gradual trends of innovation expansion, which would be difficult to identify with the use of annual data.

CONCLUSION

The objective of this article was to map the innovation *clusters* in Brazil and to verify the existence of the spillover effect of these regions. Considering that innovation is a phenomenon that is difficult to measure directly, the present study used patent filings between the years 1997 and 2021 as a proxy variable. The study relied on spatial analysis techniques, specifically choropleth maps, to explore patent distribution, and heat maps with KDE estimation, to investigate the presence of the spillover effect.

Through this cut, it was possible to verify the concentration of innovative activity in the South and Southeast regions of the country. The results pointed to the existence of consolidated clusters in these locations. The results indicate that the consolidation of these poles of excellence exert influence on adjacent regions, characterizing the existence of the spillover effect. In addition, this influence has spread to other Brazilian regions, with signs of gradual strengthening of innovation in the Northeast from 2012 onwards.

The use of spatial analysis proved to be a valuable approach to measure and visualize innovation patterns. By combining the correct technique with the appropriate period of analysis, it was possible to highlight both the benefited territories and those that still require specific public policies and investments in R&D. The study also reinforces the importance of internalizing innovation and expanding ICTs outside *the consolidated innovation clusters.*

However, reservations must be made when the possibility of generalization of the results. One of the major problems of conducting research with secondary data is the need to discard data due to the absence of specific fields. For the present study, it was necessary to exclude approximately 77% of the data due to two reasons, the absence of information on FUs or the fact that the applicants were foreigners. In addition, the available base only

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includes the quantitative aspect of the deposits, without detailing the technological areas involved. Future research, depending on the availability of data, can integrate the relationship between innovation and regional development indicators and integrate authorship with innovation networks or technological partnerships, providing other aspects of the dynamics of innovation in Brazil.

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