Spatial distribution of the Brazilian national system of innovation: an analysis for the 2000s

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Abstract

Regional inequality is an intrinsic characteristic of economic underdevelopment. Some structuralists have attributed this feature to the unequal distribution of the benefits of technical progress among subnational regions. This process is thought to be related to the spatial distribution of the components of the national innovation system, which is such that the available opportunities for taking advantage of the benefits of technical progress differ from one region in Brazil to the next. This study examines the distribution of science, technology and innovation assets among different Brazilian microregions in the years from 2000 to 2010. Its findings indicate that the territorial scope of the national innovation system expanded during the period under study to encompass a larger number of microregions and thus has come to exhibit a greater degree of spatial continuity. This process occurred in parallel with a trend towards a greater regional deconcentration of income in the country.

Keywords

Economic development, regional development, innovations, science and technology, regional disparities, science and technology indicators, Brazil

JEL classification

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I. Introduction

The regional concentration of income is an inherent characteristic of economic underdevelopment. In the course of the debate on development and underdevelopment, a number of renowned authors —such as Furtado (1967a and 1967b), Pinto (2000), Hirshman (1977) and Perroux (1967)— drew attention to the concentration or centralization of income in given locations within different countries. Explicitly or implicitly, these authors saw the regional concentration of income as being linked to the unequal regional distribution of the benefits of technical progress. They therefore thought that a greater incorporation of the benefits of technical progress in some subnational regions than in others would give rise to an unbalanced regional growth process.

Viewed from this perspective, regional income concentration —especially in underdeveloped countries— would appear to be related to the unequal geographic distribution of the components of the national innovation system (NIS). The assumption is that the regional concentration of NIS components leads to a regional concentration of the benefits of technical progress and, consequently, of income. It follows that the spatial concentration of NIS assets within a country would therefore also be linked with economic underdevelopment. By contrast, in developed economies, where the regional concentration of income is less marked, NIS assets are distributed more equally among subnational regions and the division of the benefits of technical progress is therefore more balanced.

In the light of these factors, the objective of this study is to analyse the changes that occurred in the geographic distribution of assets in the fields of science, technology and innovation among Brazilian microregions during the 2000s in order to gauge the extent of the system's regional expansion. The starting point for this analysis is the observation that the regional concentration of income has in fact been reduced in Brazil in recent years (Silveira Netto and Azzoni, 2013), as attested to by the fact that the richest microregions' share of the country's gross domestic product (GDP) shrank during that decade while the share of the poorest 50% of its regions expanded.

This shift reflects the presence of broader regional participation in the national innovation system as a result of the regional redistribution of NIS institutions that occurred during the 2000s. This greater continuity of the system within Brazil is presumably enabling various regions to play a greater role in the national economic circuit, thereby reducing income inequality at the regional level. This, in turn, can be expected to pave the way for the consolidation of the national innovation system and to spur the country's economic development. Within this framework, data on the different microregions' scientific and technological activities and on institutions of postgraduate instruction are assessed in order to track the regional performance of the innovation system in 2000-2010. An index that provides a means of gauging the development of local scientific, technological and innovation institutions is therefore proposed for use in measuring each microregion's involvement in that system.

This article is divided into five sections, the first one of which is this introduction. The second section reviews the literature on regional development and innovation systems, while the third traces the trends in science, technology and innovation indicators in Brazil in 2000-2010. The fourth section outlines the design of an NIS regional development index for use in evaluating the geographic distribution or scope of Brazil's national innovation system. The fifth and final section presents a number of concluding observations and considerations.

II. Regional development and innovation systems

Geography has major implications for the technological innovation process. The exchange of information among the various agents in a geographically defined economic system is heightened by physical proximity and the shared social and cultural features of any given locality (Asheim and Gertler, 2005; Cooke, 1998; Jaffe, 1989). Starting with the very first theoretical explorations of the workings of national innovation systems, there was an awareness of the important role played in these systems by institutions and organizations, businesses and learning processes and interactions, but their regional aspects were overlooked (Freeman, 1987 and 1995; Lundvall, 1992; Nelson and Rosenberg, 1993). Thus, the regions' role in the development of these innovation systems was virtually ignored during the development and consolidation of this concept.

Among all the authors who introduced the concept of national innovation systems, Freeman (1987 and 2002) was the only one to draw attention to the influence exerted by regional policies in helping a country to catch up with more economically developed nations. In his work on the initiatives launched by Japan to promote economic development, he pointed out the patent importance of regional policies in that country and underscored the determined effort that it had put into devising and implementing regional policies in the realms of the sciences, education, communications and infrastructure. He characterized these policies as having played a fundamental part in expanding the coverage of technological training to encompass the entire country and incorporating as many agents as possible into its technological and scientific circles, regardless of their location or economic scale. As noted by Freeman, "regional policies have consistently sought to strengthen technological capability throughout the country, particularly in small and medium-sized firms" (Freeman, 1987, p. 36).

Nonetheless, the regional dimension was virtually ignored in the major studies and research papers on national innovation systems published in the 1990s. Just 15 years later, Freeman (2002) again broke new ground when he introduced the spatial or geographic dimension into this field of study. He thus took the first steps towards identifying the relationship among what he called continental, national and subnational innovation systems based on the assumption that changes in the global economy would trigger changes in those systems. In that study, Freeman highlighted the importance of the subnational scale in research on innovation and asserted that the formation of clusters of industrial activities would have significant development implications. Regional advantages would be influenced, however, by national factors; in other words, they could be leveraged by aspects of the nation's culture, politics, economy and technological institutions. Freeman (2002) thus saw national and subnational innovation systems as being complementary and felt that theorists needed to gain a better understanding of the changes occurring in innovation systems at all levels of analysis (including everything from a global to a regional scale) and of the relationships between these different scales in terms of the promotion of innovation.

Edquist (2005) also looked at the possible geographical and sectoral scales or boundaries of an innovation system. In his view, the importance of the geographic boundaries of innovation systems is determined by national and regional specificities. He contends that in large, regionally diverse countries, regional innovation systems may be more important than national innovation systems. However, since the legal and political factors that will have an influence on those regional systems are often controlled by national governments, even in big countries, a focus on regional systems is necessarily only one dimension of a broader approach. Like Freeman (2002), Edquist concluded that the different geographical scales on which innovation systems exist are complementary rather than exclusionary.

As for a possible relationship between the geographic distribution of a national innovation system and the regional imbalances inherent in economic underdevelopment, it can be assumed that this relationship is the outcome of an unequal distribution of the benefits of technical progress in the national economy (Furtado, 1967b). According to this approach, which is in one way or another present in the work of foundational analysts of regional development such as Perroux (1967) and Hirschman (1977), this relationship is linked to the regional distribution of NIS entities. Thus, a national innovation system, which is the main driver of technological progress in a country, could be linked to the economic imbalances existing among its component regions, since its geographic distribution can exert an influence over the regional distribution of the benefits of technical progress.

The regions in which the main NIS assets interact with one another in ways that enable them to act as drivers of technological innovation would thus tend to develop more quickly than others, since their superior institutional framework for activities in the fields of science, technology and innovation (STI) would give them an advantage over the others in attracting new industries. This, in turn, would fuel the growth of production and boost revenues and tax receipts in those regions. These regions' greater economic capacity would, in turn, enable them to reinvest profits in their learning and knowledge infrastructure, which would tend to strengthen their regional innovation systems and translate into gains in their internal and external competitiveness (Asheim, 1996; Florida, 1995). This process could perpetuate the regional concentration of income in a country via the concentration of the benefits of technical progress. The regions with weak STI structures would have little chance of garnering the benefits of the technological inroads made in the more developed regions because they would not be in a position to absorb those advances or apply them in their own production activities.

Local STI assets forming part of the same national institutional system may exhibit differing levels of development as a result of the presence of differing technological development trajectories at the regional level and differing local knowledge platforms (Asheim and Gertler, 2005; Oinas and Malecki, 1999). It is therefore assumed that the economic environment influences the actors that exist within it (Cooke, 1998; Isaksen, 2001). In other words, the development and performance of an institutional cluster that is formally linked to a national government and, hence, to the national innovation system, can be determined by the economic and social situation in the region where it is located. This means that similar institutions in a given NIS could start off on an equal footing but could end up moving along differing development paths by virtue of their locations.

It therefore follows that regional development policies should be aligned with national science and technology policies, as was done in Japan (Freeman, 1987). According to this approach, regional development calls for the incorporation of NIS support institutions into the various subnational regions so that they can contribute to the expansion and consolidation of the entire national innovation system. It is important to note, however, that the benefits to be derived from the establishment of a given institution in a specific regional setting will depend on the extent to which that institution is integrated into the social fabric of the region in question (Granovetter, 1985). Such institutions need to be integrated into the social and economic network of the region where they are introduced so that they can help generate and fuel information flows between themselves and local actors involved in the innovation process (Oinas and Malecki, 1999).

In the light of the above, this study will seek to undertake an analysis of national innovation systems from a regional perspective with a view to identifying the determinants and implications of regional systems' distribution within the national system of which they are a part. It is assumed that the spatial distribution of components of a national innovation system may be linked to a country's level of economic development and to the regional imbalances that are an inherent feature of underdevelopment. Viewed from this standpoint, a more balanced distribution of STI institutions within a given country's territory can be expected to be coupled with a spatially broader NIS structure, which would in turn lead to a more equitable distribution of the benefits of technical progress among the various subnational regions. By contrast, the concentration of NIS institutions in just a few regions would be associated with a discontinuous NIS with more limited national coverage, which would in turn be reflected in a regional concentration of the benefits of technical progress and, hence, of income.

III. The spatial distribution of STI assets in Brazil in the 2000s

1. STI indicators

The following analysis of the spatial development of Brazil's innovation system during the 2000s is based on three indicators which will serve as proxy variables for three spheres of activity within the innovation system: technological production, scientific production, and educational and research activities. Technological production will be gauged by looking at the number of patent applications filed by residents of the country's 558 microregions with the National Institute of Industrial Property (INPI). Scientific production will be analysed with reference to the number of articles published in international journals that are indexed in the ISI Web of Science platform. The local education and research network will be quantified in terms of the number of faculty members teaching postgraduate courses in each microregion.

The first of these indicators —the number of patent applications filed by residents of each microregion— was obtained from a special tabulation of the relevant data provided by INPI. The database includes all patent applications filed with INPI between 2000 and 2010, along with detailed information on the applicants (name, National Register of Legal Entities (CNPJ) number or Natural Persons Register (CPF) number, as appropriate, and the state and municipality of residence), as well as the application number and date. The fact that 7,259 patent applications were filed in 2000 and that 8,582 were filed in 2010 points to an increase in the level of technological activity in Brazil during that decade. The data are aggregated at the microregional level for the purposes of the following analysis.

The statistics on scientific articles were drawn from the database maintained by the Institute for Science Information (ISI), which contains references to the articles published in major international journals in all fields of knowledge. Data are available on the fields to which each article is related, its authors, the institutions with which they are associated and their location. For the purposes of this study, the online ISI (Web of Science) database was consulted in the period running from August 2013 to January 2014 in order to obtain read-outs of data on each scientific article published by a resident of Brazil in ISI-indexed journals between the years 2000 and 2010. After checking that the read-outs provided enough information to warrant inclusion in the database used for this study, a total of 10,512 articles published in 2000 and 21,109 articles published in 2010[1] were entered into the database. The data on articles for which insufficient information was available were not included. The locational data made it possible to compute the number of articles for each municipality and then for each microregion. In the cases where an article had been written by authors located in different microregions, it was attributed to each of those locations. The analysis therefore provides for the existence of double counting, since the total number of articles for the different microregions will exceed the total number of articles published by authors residing in the country.

In order to evaluate microregional education and research networks, data on the number of faculty members teaching postgraduate courses in each microregion were used. These data were obtained from the Georeferenced Information System (GEOCAPES) portal of the Coordinating Office for the Improvement of Higher Education Personnel (CAPES).[2] The portal was consulted during the month of April 2014, so all the data used in the study correspond to the information available in the database at that time. The number of teachers in each municipality in 2000 and 2010 was aggregated at the microregional level for use in the analysis to be undertaken here.

1 The articles for which the data were incomplete were not included in the sample, so that information was lost.

2 The GEOCAPES data are available online at: http://geocapes.capes.gov.br/geocapesds/.

It was decided to conduct this analysis on a microregional scale for a number of reasons. First of all, a smaller scale than the state level had to be used because there is a certain degree of economic concentration within a limited number of locations within states as well. The municipal scale was not deemed to be the most appropriate one for this analysis either because the technological and economic structure of a municipality serves residents in neighbouring municipalities as well. In other words, for example, the university system of a given municipality does not serve only that municipality's residents, and the research work done there is not disseminated only to residents in the city where it is conducted. By the same token, a given city's economic activities serve and employ residents of nearby towns as well as residents of the city in question. In addition, in regions in which there are a number of cities, some activities will tend to be clustered in just one of them, which thus functions as a regional hub.[3] Although these institutions (universities, research centres and companies, among others) tend to be located at more central points in a region at a less aggregated level than states but a more aggregated level than municipalities, they nonetheless establish ties with their surroundings. The microregional scale has therefore been deemed to be the most suitable one for this analysis because it encompasses neighbouring municipalities that tend to exhibit a certain degree of complementarity. The observations reported in the following analysis therefore refer to the 558 microregions of Brazil.

The following discussion will cover trends in the spatial distribution of technological and scientific activities and in the development of higher education and research in Brazil. An index based on the regional distribution of the components of the national innovation system has also been developed as a way of summarizing the information derived from the three above-mentioned indicators and condensing it into a single variable.

2. Regional technological activity in Brazil in 2000-2010

Table 1 provides information on Brazil's microregions, broken down by level of technological activity in 2000. It shows, first of all, that no technological activity was recorded in a majority of microregions during that year, which is a clear sign of the spatial concentration of technological activity in the country. Thus, more than half of all the microregions in the country accounted for less than 10% of Brazil's GDP even though they contained 24% of its population. The most technologically dynamic microregions, in which more than 100 patent applications per million inhabitants were filed, represented just 2% of all of Brazil's microregions in 2000. These 11 microregions accounted for nearly 24% of national GDP and for slightly over 12% of the population during that year. These two groups illustrate the extremes of the microregional income spectrum during the period under study. The first group, made up of a majority of Brazil's microregions, accounted for no more than a fraction of Brazil's national income, whereas the second, composed of just a few microregions, generated a much larger share of the country's income. This situation cannot be dissociated from the technological activity observed in these two groups of microregions.

Table 2 reflects the levels of technological activity in Brazil's microregions in 2010. A comparison of table 2 and table 1 makes it possible to trace the changes in that type of activity in the country between 2000 and 2010. Table 2 shows that a larger number of microregions registered technological activity in 2010 and that more microregions had higher levels of innovation activity, as measured by the number of microregions that had more patent applications per million inhabitants than before.

[3] This is the city in which the most activities of a given region are centralized as described in Christaller's central place theory (Christaller, 1966).

Table 1
Brazil: microregions, by level of technological activity and percentages of the total number of microregions, the total population and the country's gross domestic product, 2000

Patents per million inhabitants	Number of microregions	Percentage of microregions	Percentage of the total population	Percentage of GDP
0	305	54.7	23.7	9.5
1-30	169	30.3	35.5	27.6
31-60	46	8.2	17.2	23.8
60-100	27	4.8	11.2	15.3
>100	11	2.0	12.4	23.8
Total	558	100.0	100.0	100.0

Source: Prepared by the authors, on the basis of data from the National Institute of Industrial Property (INPI) and Ipeadata.

Table 2
Brazil: microregions, by level of technological activity and percentages of the total number of microregions, the total population and the country's gross domestic product, 2010

Patents per million habitants	Number of microregions	Percentage of microregions	Percentage of the total population	Percentage of total GDP
0	273	48.9	21.2	8.9
1-30	186	33.3	36.0	29.7
31-60	57	10.2	20.0	25.6
60-100	26	4.7	9.7	13.0
>100	16	2.9	13.1	22.8
Total	558	100.0	100.0	100.0

Source: Prepared by the authors, on the basis of data from the National Institute of Industrial Property (INPI) and Ipeadata.

Whereas patent applications were filed by persons or institutions in 253 of Brazil's microregions in 2000, by 2010 that figure had climbed to 285. In other words, by the second year of reference, more than half of all the microregions were registering technological activity. This means that significant changes occurred in the groups at the two extremes of the spectrum. Although regions in which technological activity was absent remained the largest of the five categories in 2010, that group accounted for smaller percentages of the population and of GDP than it had in 2000. The fact that, although the number of microregions with over 100 patent applications per million inhabitants rose to nearly 3% of the total, their share of GDP shrank may be attributable to an increase in the incomes of the poorer regions. The shares of total income of the groups with 1-30 and 31-60 patent applications per million inhabitants expanded because the number of microregions in those categories rose, as many of the microregions that had previously been in the category displaying an absence of technological activity had moved into one of those two groups.

3. Regional scientific activity in Brazil in 2000-2010

The data on scientific production in Brazil paint a similar picture. In 2000, scientific activity was primarily concentrated in southern and south-eastern Brazil, and the microregions in which it was most intense were in the State of São Paulo. Table 3 shows that the microregions in which scientific activity was taking place in 2000 accounted for just slightly more than 30% of the total.

Table 3
Brazil: microregions, by level of scientific activity and percentages of the total number of microregions, the total population and the country's gross domestic product, 2000

Articles per million inhabitants	Number of microregions	Percentage of microregions	Percentage of the total population	Percentage of total GDP
0	383	68.6	33.5	16.2
1-30	106	19.0	22.9	22.2
31-100	35	6.3	13.7	12.6
101-500	30	5.4	28.2	46.0
>500	4	0.7	1.7	3.0
Total	558	100.0	100.0	100.0

Source: Prepared by the authors, on the basis of data from the Institute for Science Information (ISI) and Ipeadata.

As may be seen from table 3, 69% of the microregions displayed no scientific activity in the year 2000. These microregions, which were mostly in the northern and north-eastern parts of the country and some areas of the State of Minas Gerais and of the central-western portion of Brazil, represented approximately one third of the country's population and 16% of its GDP. The figures shown here indicate not only that a majority of the microregions were not involved in the country's scientific activities in the year 2000 but that a large portion of the population was far removed from the locations in which people might benefit from that type of activity. By contrast, a large share of the country's income was concentrated in the areas that served as sites for scientific activity, since the 6% of the microregions with more than 100 publications per million inhabitants accounted for 50% of the country's GDP.

By 2010 the situation had changed considerably. As may be seen from table 4, the share of Brazil's microregions engaged in scientific activity had risen, as had the nation's level of scientific production and its degree of regional deconcentration.

Table 4
Brazil: microregions, by level of scientific activity and percentages of the total number of microregions, the total population and the country's gross domestic product, 2010

Articles per million inhabitants	Number of microregions	Percentage of microregions	Percentage of the total population	Percentage of total GDP
0	203	36.4	13.6	5.7
1-30	147	26.3	19.3	15.3
31-100	93	16.7	13.6	12.9
101-500	90	16.1	38.7	42.0
>500	25	4.5	14.8	24.1
Total	558	100.0	100.0	100.0

Source: Prepared by the authors, on the basis of data from the Institute for Science Information (ISI) and Ipeadata.

In 2010, the number of microregions in which scientific activity was absent was much smaller, amounting to 36% of the total. This category also came to represent smaller shares of the population and GDP, while the share of those aggregates represented by the microregions with a more intense level of scientific activity grew. The number of microregions in which more than 100 articles were published per million inhabitants had climbed from 34 in 2000 to 105 (21% of the total) by 2010. As is to be expected, the bulk of GDP continued to be concentrated in this group.

This indicates that scientific activity increased as it became more evenly distributed across the country. It is also a clear reflection of the expansion of Brazil's system of higher education and particularly of its federal universities, which are the lead institutions for scientific research in the country. The regional redistribution of institutions of higher learning was coupled with the spatial expansion of university-level research, which was reflected in a broader distribution and a regional deconcentration of scientific publications

Mention should be made at this point of the possible relationship between the regional deconcentration of scientific activity and the deconcentration of technological activity. As noted earlier, the two processes occurred in tandem in the 2000s, in line with the observations of Nelson and Rosenberg (1993) concerning the mutual causation of scientific and technological advances. Thus, the greater regional scope of scientific activity can be regarded as an important driver of the regional deconcentration of technological activity in the country. By the same token, the deconcentration of technological activity may have leveraged the regional deconcentration of scientific activity.

4. Educational and research institutions

In order to flesh out the data on regional trends in science and technology in Brazil between 2000 and 2010, trends in higher education and research activity in the country's microregions will be presented in this section. The number of professors teaching postgraduate courses in each microregion —data that can be obtained from the Ministry of Education's GEOCAPES system— will be used as a proxy variable for this purpose.

Here again, a high degree of concentration, especially in the south-eastern part of the country, can be observed. In 2000, postgraduate courses were being taught in 22 of the country's 27 states. This means that some states, such as Acre and Tocantins lacked these kinds of institutions entirely and thus had no means of teaching advanced research skills or engaging in research within the realm of higher education (see table 5).[4]

Table 5
Brazil: microregions with and without postgraduate educational institutions, by number and percentage of microregions and percentages of the total population and the country's gross domestic product, 2000

	Number of microregions	Percentage of microregions	Percentage of the total population	Percentage of total GDP
No teaching institution	490	87.8	52.4	35.3
At least one teaching institution	68	12.2	47.6	64.7
Total	558	100.0	100.0	100.0

Source: Prepared by the authors, on the basis of data from the GEOCAPES database and Ipeadata.

In 2000, postgraduate instruction was being provided in only 68 of Brazil's 558 microregions. While this group represented only slightly more than 12% of the total, it accounted for a majority share of national income. By contrast, the microregions that did not have any postgraduate educational institutions were home to over 50% of the total population at the start of the period under study. These figures attest to the fact that only a small part of the country belonged to the nation's postgraduate education and research system in 2000 and dovetail with the statistics on scientific and technological production in the country for that same year. As will be seen later on in this analysis, that situation had changed a great deal by 2010.

The data compiled for the end year of the period under study provide evidence of a redistribution of university education and research activity in Brazil. As shown in table 6, the number of microregions

[4] The other states in which no postgraduate courses were being taught as of the year 2000 were Amapá, Rondônia and Roraima.

with professors at the postgraduate level had risen to 115 by 2010, for an increase of more than 70% over the figure for 2000. The average number of professors at the postgraduate level per microregion also jumped from 52 per microregion to 104.5. This increase reflects a rapid expansion of higher education in the 2000s, as nearly 60% of the population was living in microregions in which university-level teaching and research activities were being conducted in 2010. In addition to leading to an increase in the number of professors at the postgraduate level and, consequently, in the number of highly advanced courses that were available, this expansion had the effect of integrating a larger part of the country and of the nation's population into this field of activity. Nonetheless, these statistics also show that much remains to be done in this regard.

Table 6

Brazil: microregions with and without postgraduate educational institutions, by number and percentage of microregions and percentages of the total population and the country's gross domestic product, 2010

	Number of microregions	Percentage of microregions	Percentage of the total population	Percentage of total GDP
No teaching institution	443	79.4	40.2	24.5
At least one teaching institution	115	20.6	59.8	75.5
Total 2010	558	100.0	100.0	100.0

Source: Prepared by the authors, on the basis of data from the GEOCAPES database and Ipeadata.

One important change brought about by this expansion is that, as of 2010, postgraduate courses were being taught in every state of the federation. The fact remains, however, that, although the central-western and north-eastern parts of the country did become more involved in the nation's scientific systems, the number of professors at the postgraduate level per million inhabitants did rise more sharply in the southern and south-eastern regions.

Scientific production in the country advanced more rapidly than its postgraduate teaching institutions did. In other words, the number of microregions in which scientific articles were published (352) exceeded the number in which postgraduate courses were being taught (115) in 2010. This may be a reflection of spillovers from the creation of an educational and research structure in a given region, since the impact of the establishment of such an institution will be felt beyond the borders of the microregion in question. This is because students and working people who are residing in other microregions may be able to attend courses in the microregion in which a newly created teaching and research institution is located. It is also the case that information flows and the exchange of knowledge will take place between universities, businesses and a wide range of other actors located in different regions.

The same is true of technological production, which was diffused over a greater portion of the country than higher education and research activities were.[5]

IV. A regional development index for the innovation system in 2000-2010

Indicators of technological activity, scientific activity and higher education and research activity can be used to track the deconcentration of national innovation system assets in Brazil during the 2000s. All the indicators used in this study attest to a quantitative improvement marked by sizeable increases in

[5] As was seen earlier, in 2010 patent applications were received by the National Institute of Industrial Property (INPI) from 285 microregions.

technological and scientific production and in the number of professors at the postgraduate level by microregion. This quantitative expansion enabled a larger number of microregions to enter into Brazil's innovation system. In order to shed more light on this process, the data on the three STI indicators that have been examined thus far will be merged into a single development indicator for the country's microregions that will reflect their progress in terms of technological capacity-building. The aim is to assess the spatial expansion of Brazil's national innovation system between 2000 and 2010 using an index to trace the various microregions' development.

The index used for this purpose was built using a factor analysis approach. This is a multivariate statistical method that is primarily used to describe the variability of a larger dataset in a smaller set of uncorrelated random variables, known as factors, which are linear combinations of the original set of variables. The factor analysis model is given by:

$$\begin{aligned} Z_1 &= l_{11}F_1 + l_{12}F_2 + \dots + l_{1m}F_m + \varepsilon_1 \\ Z_2 &= l_{21}F_1 + l_{22}F_2 + \dots + l_{2m}F_m + \varepsilon_2 \\ Z_p &= l_{p1}F_1 + l_{p2}F_2 + \dots + l_{pm}F_m + \varepsilon_p \end{aligned} \tag{1}$$

The F_j terms are the factors, i.e. the new variables, while the Z_i terms represent the original set of variables. The loading indicator l_{ij} represents the coefficient i to the nth for the standardized variable Z_i in the j to the nth factor F_j, demonstrating the linear correlation between them. The model provides a linear relationship between the standardized variables and the common m-factors, which in theory are unobservable (Mingoti, 2005).[6] This technique makes it possible to reduce the original set of variables to a smaller number of factors that will summarize the original data.

Once the factors have been obtained, their numerical values can be calculated for each element in the sample. Each of these Fi values, which are the scores for the i factor, sum up the dataset reflected by the original variables in the standardized analysis for each observation i, as per the following equation:

$$F_i = c_{1i}Z_i + c_{2i}Z_i + c_{3i}Z_i \tag{2}$$

Thus, the values for the index being proposed here are given by the F scores obtained for each of the microregions. We are therefore dealing with a linear combination of the variables "patents per million inhabitants", "articles per million inhabitants" and "professors at the postgraduate level per million inhabitants" which will represent these variables by means of a combined indicator.[7] This indicator, which will be referred to as the "national innovation system regional development index" (NISRDI), is thus constructed using the scores for the first factor that is obtained when the above-mentioned data for 2000 and 2010 are subjected to a factor analysis. The NISRDI is obtained using the following equation:

$$\begin{aligned} NISRDI_i = {} & c_{1i}(Patents/million\ inhab_i) + c_{2i}(Articles/million\ inhab_i) \\ & + c_{3i}(Postgraduate\ professors/million\ inhab_i) \end{aligned} \tag{3}$$

In order to obtain the values for this index, the cji coefficients, which are the weightings for the variables used to construct the NISRDI, have to be estimated. These coefficients are estimated using the ordinary least squares (OLS) method based on the loading matrix, which represents the correlation between the original variables and the factors. The value for each coefficient is therefore positively influenced by that correlation. Hence, the greater the loading of a given variable (suggesting that it

6 For a more detailed discussion of the factor analysis model, see Mingoti (2005).

7 For more information on the factor analysis method, see Mingoti (2005).

correlates more closely with the factor in question), the greater its weighting will be in the calculation of the corresponding score or rating on the index (Mingoti, 2005).

The NISRDI consists, then, of the weighted sum of the values of the standardized variables “patents per million inhabitants”, “articles per million inhabitants” and “professors at the postgraduate level per million inhabitants” obtained using a factor analysis for each of Brazil’s microregions. By convention, the vector of scores for the n observations is normalized so that the mean is equal to 0 and the standard deviation is equal to 1 (Mingoti, 2005; STATACORP, 2009). As a result of this normalization, observations where the result is below the overall mean will be represented by negative values on the NISRDI.

Table 7 shows the characteristics of the factors used to extract the NISRDI index for the years 2000 and 2010.

Table 7
Properties of the factors used to extract the national innovation system regional development index (NISRDI), 2000 and 2010

	Factor 1 (2000)		Factor 1 (2010)	
	Loadings	Scores	Loadings	Scores
Patents per million inhabitants	0.3659	0.07402	0.3834	0.03181
Articles per million inhabitants	0.8494	0.44418	0.9363	0.43059
Postgraduate professors per million inhabitants	0.8575	0.47607	0.9460	0.53734
Autovalue	1.59057		1.91852	
Explained variance (*percentages*)	112		103	
KMO test	0.57		0.56	

Source: Prepared by the authors, on the basis of data from the National Institute of Industrial Property (INPI), the Institute for Science Information (ISI) and GEOCAPES.

Since the values of the loadings and the coefficients are positive, the NISRDI index exhibits an increasing correlation with technological and scientific activities and with local education and research institutions. Thus, the greater the index values, the greater the level of development of a microregion’s STI structure within the national innovation system. It should be noted that the weighting of the “patents per million inhabitants” variable in the NISRDI is less than those of the other variables. The lower value of its loading, which translates into a lower value for its coefficient, indicates that this variable is less representative in the numerical systematization of the innovation systems being considered here. This may be seen as a reflection of the weak technological performance of the Brazilian innovation system.

Another noteworthy aspect of table 7 is that the only variable whose significance in the make-up of the NISRDI increased between 2000 and 2010 is “postgraduate professors per million inhabitants”, as may be seen from a comparison of the coefficients for those two years. This may be attributable to the government’s policy of focusing on the expansion of the nation’s higher education system in all regions of the country, including the poorest ones. This backs up the evidence discussed in the preceding section.

Table 8 gives descriptive statistics for the NISRDI in 2000 and 2010. In theory, as mentioned earlier, the factor scores obtained using the factor analysis method should have a mean equal to 0 and a standard deviation equal to 1 owing to the normalization of the data. In practice, the values tend towards 0 and 1, respectively, since the theoretical values will be obtained only in the presence of a perfect solution for the factor model (STATACORP, 2009). The mean scores on the NISRDI in 2000 and 2010 are very close to 0, as was to be expected, but the standard deviation is a little further from its theoretical value; nevertheless, it moved closer to that value in the closing year of the period. An analysis of the minimum and maximum values for each year shows that the index scores for microregional science, technology and innovation are widely dispersed.

Table 8
Descriptive statistics for the national innovation system regional development index (NISRDI), 2000 and 2010

	NISRDI 2000	NISRDI 2010
Mean	0.0000000031	0.0000000032
Standard deviation	0.9014307	0.9610738
Minimum	-0.2139641	-0.3060349
Maximum	15.23716	11.65406

Source: Prepared by the authors, on the basis of data from the National Institute of Industrial Property (INPI), the Institute for Science Information (ISI) and GEOCAPES.

For the purposes of this study, the NISRDI is used as a tool for evaluating the spatial continuity and scope of the Brazilian innovation system. The index serves as an indicator of the level of development of local STI institutions, and the distribution of its values for the different microregions therefore serves as a parameter for gauging the spatial breadth of the national innovation system. Plotting these values on maps showing the various subregions in Brazil provides a depiction of the spatial continuity of the national innovation system on a microregional scale. The national innovation system is regarded as having spatial continuity in areas where most of the microregions within a microregion cluster display significant local STI activity as measured using the categories defined below. On the other hand, the presence of many microregions that have weak STI structures or no such structure at all are interpreted as areas in which the geographic distribution of the national innovation system is spatially discontinuous.

To facilitate the analysis, Brazil's 558 microregions were divided into five categories based on their NISRDI rating. The first group includes microregions with negative values or values equal to the mean (0). The microregions in this group are those with weak or non-existent local STI networks and are therefore areas in which the continuity of the Brazilian national innovation system breaks down. The other groups are defined as follows:

- Group 2: an NISRDI rating of between 0 and 1
- Group 3: an NISRDI rating of between 1 and 2
- Group 4: an NISRDI rating of between 2 and 3
- Group 5: an NISRDI rating greater than 3

The groups were divided by single-unit intervals because the standard deviations of the factors are supposed to be equal to 1, according to the theoretical factor analysis model. These categories thus are arranged in ascending order of level of development as measured by the NISRDI microregion ratings. Before proceeding to a survey of the spatial continuity of the Brazilian national innovation system, however, a pre-assessment of the categories of microregions defined on the basis of the NISRDI index needs to be conducted (see table 9).

As can be seen from table 9, a total of 481 microregions (89% of the total) had negative NISRDI ratings in 2000. That group's mean values for patents, articles and postgraduate professors per million inhabitants were extremely low in comparison to the values registered for the other microregions. Most of the microregions with active local STI networks were concentrated in the category corresponding to NISRDI ratings of between 0 and 1. Some of the main state capitals, such as São Paulo, Rio de Janeiro, Brasilia, Porto Alegre and Belo Horizonte, had NISRDI ratings of between 1 and 2. The other two groups —the ones with values greater than 2— were chiefly composed of microregions in which the main city was medium-sized, with the microregion of São Carlos, in São Paulo, registering the highest value on this index in the year 2000. The only microregion in either of those two groups whose main city was also a state capital was Florianopolis, which had the fourth-highest NISRDI rating in the country for that year.

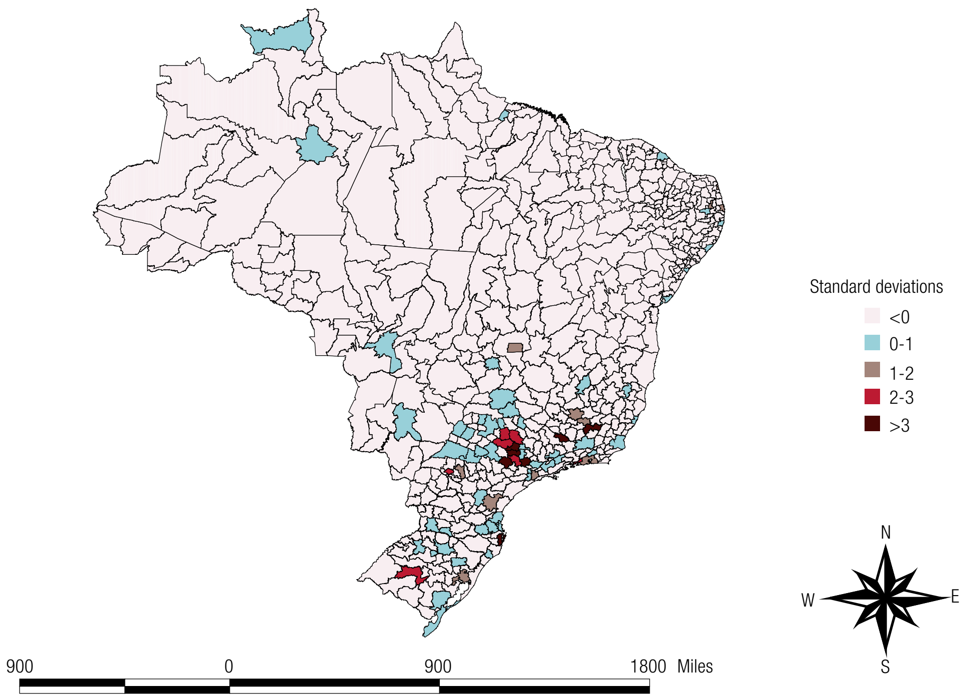
Table 9
Features of microregions grouped according to their ratings on the national innovation system regional development index (NISRDI), 2000

NISRDI	Number of observations	Mean values		
		Patents per million inhabitants	Articles per million inhabitants	Postgraduate professors per million inhabitants
<0	481	7.28	3.16	0.49
0-1	55	49.87	66.32	137.13
1-2	10	63.89	214.29	501.77
2-3	5	40.21	363.65	825.33
>3	7	65.94	1046.05	1837.94
Total	558	13.53	29.48	53.38

Source: Prepared by the authors, on the basis of data from the National Institute of Industrial Property (INPI), the Institute for Science Information (ISI) and GEOCAPES.

The microregions in the various categories are shown on map 1. The darker the shading, the higher the NISRDI rating, or, in other words, the higher the level of development of the local STI network.

Map 1
Brazil: national innovation system regional development index (NISRDI) and spatial continuity of the system, 2000



Source: Prepared by the authors, on the basis of data from the National Institute of Industrial Property (INPI), the Institute for Science Information (ISI), GEOCAPES and Ipeadata.

The distribution of the various categories of microregions in Brazil shown in map 1 demonstrates, as was to be expected, that the microregions with more well-developed local STI assets in 2000 were primarily located in the south-eastern and southern portions of the country. That concentration, as depicted by the shaded areas on the map, is associated with a greater degree of continuity in the national innovation system and is particularly marked in the area known as the "mining triangle" and in the area to the south of that region. Accordingly, the greatest degree of NIS continuity is seen along the southern coast. The other regions do, however, contain isolated areas in which some microregions have higher index ratings. Nevertheless, in the north-east, central-west and north and in some parts of Minas Gerais and Espírito Santo, the Brazilian innovation system exhibited very little spatial continuity or none at all in the year 2000.

As suggested by the figures shown in table 9, most of the microregions in Brazil had weak STI networks in 2000. The portion of the national innovation system located in the State of São Paulo, meanwhile, had the greatest degree of spatial continuity, since that is where the largest proportion of microregions with substantial STI institutional frameworks were located. In other words, a large number of microregions in that state are part of the national innovation system. This fits in with the central hypothesis underpinning this study, which is that higher levels of economic development are linked to broader NIS coverage. The small number of unshaded microregions in the State of São Paulo thus indicates that Brazil's national innovation system was displaying the greatest degree of spatial continuity precisely in the state with the highest level of economic development.

Table 10 shows the different features of the NISRDI groupings of microregions in 2010. Although the group with negative ratings on this index was still the most numerous one, it was smaller than before and the number of microregions in the other categories was higher. This signals an increase in the national innovation system's spatial continuity, as is reflected in the increase in the number of microregions that were participating in that system. STI indicators were also noticeably better overall than in 2000. Although this trend has already been discussed in previous sections, it is of importance in this analysis as well, since even the microregions with weak STI networks boosted their levels of scientific and technological production and expanded their educational and research activities.

Table 10

Features of microregions grouped according to their ratings on the national innovation system regional development index (NISRDI), 2010

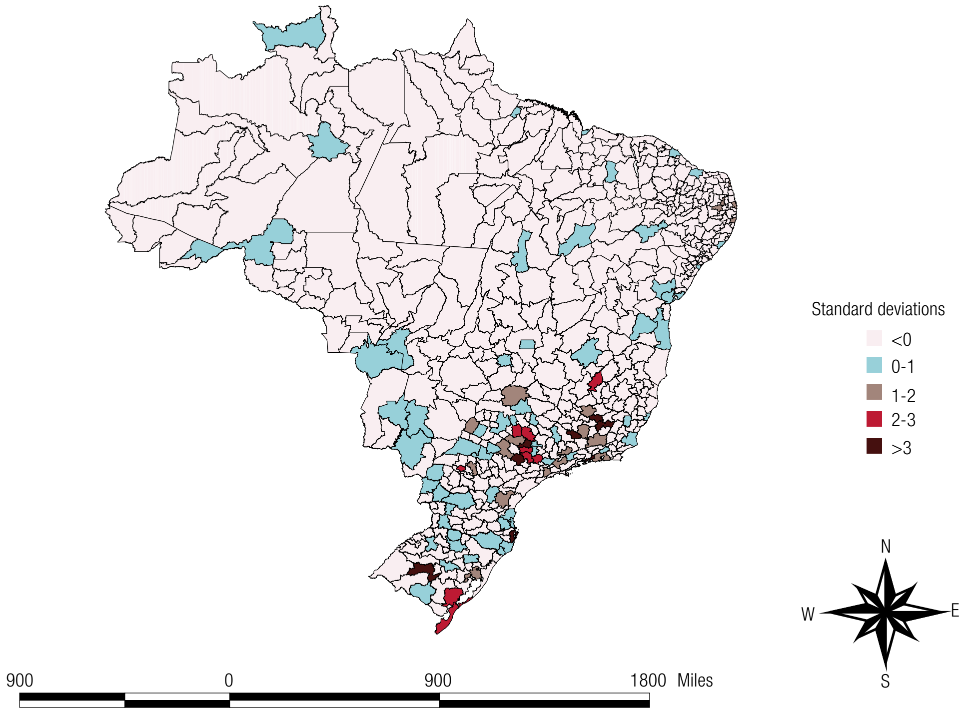
NISRDI	Number of observations	Mean values		
		Patents per million inhabitants	Articles per million inhabitants	Postgraduate professors per million inhabitants
<0	458	10.72	23.11	2.76
0-1	66	40.89	217.68	269.01
1-2	18	45.96	522.35	733.37
2-3	8	57.32	968.13	1039.01
>3	8	71.16	2477.13	2508.77
Total	558	16.96	110.96	108.61

Source: Prepared by the authors, on the basis of data from the National Institute of Industrial Property (INPI), the Institute for Science Information (ISI) and GEOCAPES.

Technological production, as measured by the average number of patent applications per million inhabitants, declined between 2000 and 2010 in microregions with intermediate levels of development in terms for their STI institutions (NISRDI ratings of between 0 and 2) but strengthened in the group with more advanced STI networks (an NISRDI rating of over 2). This suggests that the regions with more developed STI structures were in a better position to build upon their existing technological innovation capacities.

A comparison of maps 1 and 2 shows that the spatial continuity of Brazil's national innovation system expanded between 2000 and 2010, especially in the south and south-east, where there were more microregions with high NISRDI ratings. Substantial STI networks also took shape in other microregions, however, especially in the central-western and north-eastern parts of the country. This signals the presence of a trend towards an increasing degree of spatial continuity in the national innovation system in 2010, as more and more microregions in the country began to establish solid science and technology structures. As noted at the outset of this study, this trend dovetails with the regional process of income deconcentration that has been witnessed in Brazil in recent years.

Map 2
Brazil: national innovation system regional development index (NISRDI) and spatial continuity of the system, 2010



Source: Prepared by the authors, on the basis of data from the National Institute of Industrial Property (INPI), the Institute for Science Information (ISI), GEOCAPES and Ipeadata.

Generally speaking, the continuity of Brazil's innovation system increased in geographical terms over the 10-year period covered in this study. The development of the country's national innovation system appears to have advanced more rapidly in the southern part of Brazil and especially in the central and western regions, as well as spreading to more microregions in Minas Gerais and Rio de Janeiro. São Paulo remains the state in which the greatest percentage of microregions are active participants in Brazil's national innovation system, since the level of development of local STI institutions rose in many of these areas.

The national innovation system also expanded its network in the central-western region of the country. In addition to the microregions of Campo Grande, Cuiabá, Goiânia and Brasilia, which already formed a part of the national innovation system in 2000, other microregions in this region had begun to participate in the system by 2010. The newly integrated microregions were Alto Pantanal (neighbouring on the microregion of Cuiabá) and Dourados and Aquidauana (neighbouring microregions of Campo Grande). It is thus apparent that the central-western microregions that were more recent entrants into Brazil's national innovation system are located near microregions that were already part of the system in 2000. The three microregions of Mato Grosso do Sul mentioned above are close to microregions that are at a similar level of development in the states of São Paulo and Paraná. Thanks to these factors, the spatial continuity of Brazil's national innovation system expanded beyond the south and south-eastern regions to embrace the central-western part of the country.

In the north-east, an inland shift in the trend of the expansion of the national innovation system was observed. The system's coverage spread out towards the south of Bahia, encompassing the microregions of Vitória da Conquista and Ilhéus-Itabuna. The microregions of Petrolina, Alto Médio Gurgueia and Teresina also became active participants in the national innovation system. Although fewer microregions in the northern part of the country were incorporated into the system, its spatial continuity increased in that region as well. In these two regions and in a large part of the states of Minas Gerais and of Espírito Santo and in the central-western region of the country, map 2 continues to contain many unshaded areas. In other words, in contrast to what has occurred in the wealthier parts of the country, the national innovation system displays almost no continuity at all in the poorer regions. This state of affairs provides further evidence of the relationship between the innovation system's spatial continuity and economic development. The information provided by maps 1 and 2 and by the data evaluated throughout this study indicate that the southern and south-eastern parts of the country not only have higher levels of scientific and technological production but also have more researchers and a better spatial distribution of STI assets. These findings cannot be considered in isolation from the developmental disparities that separate these regions from the rest of the country.

V. Concluding observations

The analysis conducted for the purposes of this study indicates that Brazil's national innovation system is undergoing a regional integration process. Between 2000 and 2010, technological, scientific and teaching and research activities began to be undertaken in an increasing number of the country's microregions. This shift occurred in tandem with the income deconcentration process that has been observed in Brazil in recent years.

The statistics on technological and scientific production show that the Brazilian microregions' involvement in these activities was much greater in 2010 than it was in 2000. The same is true of teaching and research activities. However, while this does indicate that the spatial continuity of the national innovation system has increased, that continuity is almost wholly confined to the southern and south-eastern regions of the country. As noted earlier, the microregions in those two portions of the country are much more actively involved in the national innovation system than the rest of Brazil's microregions, which continue to exhibit areas of discontinuity.

The dichotomy between the southern/south-eastern region and the rest of the country cannot be dissociated from the regional economic disparity that has traditionally existed in Brazil. Clearly, the greater level of economic development of the south and south-east is inevitably linked with its stronger STI network, which is not only quantitatively larger than those of the other regions but is also more evenly distributed. This fact allows a larger number of microregions to gain access to the benefits derived from integration into the national innovation system. In other words, the microregions in the southern and south-eastern portions of the country are better able to reap the benefits of technical and scientific information and knowledge flows and of advanced education and research, which have a positive impact on both technologically advanced and more traditional sectors.

The spatial distribution of NIS assets in the State of São Paulo is noteworthy in this respect. Both the STI indicators that were studied in isolation from one another and the NISRDI point to the intensive involvement of that state's microregions in Brazil's national innovation system in the two reference years. The fact that this is the most highly developed state in the country establishes a direct link between its NIS performance and the hypothesis being advanced here regarding the need for a better distribution of NIS assets throughout the country. In other words, the regionally balanced distribution of NIS assets in the state with the highest level of economic development in the country indicates that this could be an approach for speeding up the pace of national development.

In general, the results of this analysis indicate that the expansion of scientific and technological production and of the educational and research activity in Brazil over the 10-year period studied here was fueled by improvements in the regional distribution of these assets. The expansion of the national innovation system also heightened its spatial continuity. Nevertheless, much remains to be done in terms of the innovation system's regional integration. That integration process will, in turn, help to broaden the regional economic integration process so that more microregions can take part in and benefit from scientific and technological advances, whether in industry, agriculture or specialized service sectors, as the country's more developed regions are already doing. Thus, economic development and the consolidation of the national innovation system necessarily entail the regional deconcentration of both income and NIS assets.

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