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ARTICLE

The uneven geography of knowledge in agriculture: regional inequalities in Brazilian sugarcane production

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ABSTRACT
During the 2000s and 2010s, the growth in sugar and ethanol production stimulated the expansion of sugarcane in new regions of Brazil, reducing the concentration in the state of São Paulo. This paper aims to investigate whether the rise in sugarcane production in peripheral areas has led to the growth of knowledge capabilities. In order to consider regional asymmetries, the article uses the differentiated knowledge base (DKB) approach in association with regional innovation systems (RIS) and core-periphery relations. Data on formal employment and scientific research on the Central-South region are analyzed from 2003 to 2017. The results show that there are limits to the diffusion of sugarcane knowledge as an important part of knowledge production remains concentrated in the regions of early growth in São Paulo.

KEYWORDS | Regional Innovation Systems; Regional Inequalities; Core-Periphery; Biofuels; Sugarcane.

1. Introduction

Brazil is the world's largest producer of sugar boasting 20% of global production in the 2017/2018 harvest (USDA, 2020); and the second largest producer of bioethanol, holding 28% of the world's production in 2015 (IEA, 2020). The country is the largest producer of sugarcane, the main input for ethanol and sugar production, with a share of 39% of the world's production in 2017 (FAOSTAT, 2020). The Central-South region concentrates the highest share of Brazilian sugarcane, sugar, and ethanol production. In the 2017/2018 harvest, the Central-South held 93% of sugarcane, 93% of sugar, and 94% of bioethanol production in Brazil (UNICADATA, 2020). The principal producer in this region is the state of São Paulo.

Since the 2000s São Paulo's share in the Central-South region in terms of ethanol and sugar production has fallen. While in the 2000/2001 harvest São Paulo represented 70% of ethanol production, 77% of sugar, and 72% of sugarcane, in the 2017/2018 harvest, these values fell to 51%, 68%, and 60%, respectively (UNICADATA, 2020). In this context, the boom in bioethanol production during the 2000s induced the movement of the sugarcane frontier towards Goiás, Minas Gerais, Mato Grosso do Sul, and Paraná.

Considering the change in the spatial distribution of sugarcane in the Central-South region, this paper aims to investigate whether the rise in sugarcane production in peripheral areas has led to the growth of knowledge capabilities. The idea considers that Brazil's success with sugarcane "is the result of a virtuous trajectory of technological learning strongly based on incremental innovations" (FURTADO; SCANDIFFIO; CORTEZ, 2011, p. 156). Therefore, sugarcane growth does not only depend on natural conditions, but also requires a domain of technologies to create a profitable production. The hypothesis of this study is that the knowledge behind sugarcane growth follows a different pattern compared with the geographical changes in production.

The results show that there are certain factors that limit the diffusion of sugarcane knowledge. While the particular characteristics of the natural environment (ANDERSEN; WICKEN, 2020) act as a force of attraction for knowledge creation in the periphery, located closer to the producers, the structure of Regional Innovation Systems (RIS) (ASHEIM; GERTLER, 2005; COOKE; URANGA; ETXEBARRIA, 1997) acts in the opposite direction, concentrating knowledge production at the regions of early growth in São Paulo (largely in Campinas, Piracicaba, and Ribeirão Preto). The Differentiated Knowledge Base (DKB) approach, distinguishing between analytical and synthetic knowledge (ASHEIM; COENEN, 2005; ASHEIM; GERTLER, 2005; ASHEIM; BOSCHMA; COOKE, 2011; PLUM; HASSINK, 2013), is used to carry out the analysis

The Central-South region is divided into six subsystems: one representing the core and the others the periphery. The analytical knowledge is then studied in two dimensions: according to education levels of the labor force in agronomic and co-related areas and in terms of sugarcane academic publications. Synthetic knowledge is also studied according to two dimensions: in relation to the technical qualification and worker experience.

The paper is divided into four parts in addition to the introduction. The following section provides a theoretical discussion on the framework of the geography of knowledge that underlies this paper. Section 3 provides a conceptual discussion on the meaning of analytical and synthetic knowledge in the sugarcane sector. Section 4 presents the methodology, procedures for regionalization and the data used. Section 5 presents the regional changes in terms of production of the cases studied. Section 6 presents the results that sustain the arguments made so far. Conclusions are presented in the final section.

2. The uneven geography of knowledge

Knowledge and learning are central to competitiveness in modern capitalism (LUNDVALL, 1992; LUNDVALL; JOHNSON, 2016) and the key forces driving uneven geographical development (ASHEIM, 2012; ASHEIM; COENEN, 2005; ASHEIM; GRILLITSCH; TRIPPL, 2016; BALLAND; RIGBY, 2017; COOKE; LEYDESDORFF, 2006). In addition to the traditional sources of spatial differentiation, based on the division of the economy into departments, sectors, and individual units (SMITH, 1984), the division of knowledge also becomes a driver of regional inequalities (HOWELLS, 2012). From this perspective, going beyond the distinctions between industrial and agricultural regions (MYRDAL, 1957), the research aims to capture the regional differences in knowledge capabilities. With that in mind, this item associates three theoretical frameworks: regional innovation systems (RIS), DKB, and core-periphery relations.

Although knowledge is an individual-centered phenomenon, it involves interactions and interdependencies in its formation and development (HOWELLS, 2012). The RIS concept is used as an instrument to explain this process. RIS combines a systemic perspective of innovation, highlighting interactive learning and knowledge exchange, from a geographical perspective, showing the importance of social, cultural, and institutional contexts, the need for geographical proximity for knowledge creation, and the low mobility of workers. It also emphasizes the importance of innovation-promoting actors, such as universities, research centers, and firms (ASHEIM; GERTLER, 2005; ASHEIM; GRILLITSCH; TRIPPL, 2016; COOKE; URANGA; ETXEBARRIA, 1997; ISAKSEN; MARTIN; TRIPPL, 2018).

The presence of these actors and the interaction between them varies. Different regions have different systemic capabilities with particular strengths and weaknesses to boost innovation and knowledge (TÖDTLING; TRIPPL, 2005). RIS has a variegated nature that drives regional transformation (ISAKSEN; MARTIN; TRIPPL, 2018). There are both well-developed RIS, with strong innovation networks, and poorly developed RIS that are less adept at knowledge generation and diffusion (TÖDTLING; TRIPPL, 2005), and deal with systemic failures (COENEN *et al.*, 2017).

Depending on their structure and organization, the RIS can produce different types of knowledge. This distinction, considering the categories of analytical and synthetic knowledge, can be made using the DKB approach[1] (ASHEIM, 2007; ASHEIM; COENEN, 2005; ASHEIM; GERTLER, 2005). The differences between them depend on four elements: "the rationale of knowledge creation, the way knowledge is developed and used, the criteria for successful outcomes, and the interplay between actors in the processes of creating, transmitting and absorbing knowledge" (ASHEIM; BOSCHMA; COOKE, 2011, p. 897). It is important to highlight that this distinction refers to a mode of conceptual abstraction. In practice, the regions and activities combine elements of analytical and synthetic knowledge (ASHEIM; BOSCHMA; COOKE, 2011).

Analytical knowledge is created through cognitive, abstract, and rational processes or formal models. It is developed via the "know-why" learning process, by studying the principles of nature, the human mind, and society (LUNDVALL; JOHNSON, 2016). The codified dimension, related to the application of scientific methods and the documentation of the results, is the most frequent form of transmission; it also has a tacit dimension related to the learning involved in the time invested in research (STORPER, 2013). Research centers are the main actors engaged in the production of analytical knowledge.

1 DKB literature also discusses the symbolic type of knowledge. Symbolic knowledge is a creative process associated with the creation of meaning, desire, and aesthetic qualities (ASHEIM; GRILLITSCH; TRIPPL, 2017). This is more characteristic of creative and cultural industries. As the focus of this paper is on DKB in sugarcane, the conceptual analysis is focused on analytical and synthetic knowledge.

Synthetic knowledge, on the other hand, is created through observation or the combination of existing knowledge to solve specific problems (ASHEIM; COENEN, 2005). It is developed through the “know-how” learning process through testing, experimentation, and practical work (ASHEIM; BOSCHMA; COOKE, 2011; LUNDVALL; JOHNSON, 2016). Hence, this type of knowledge can be partially codified. Nevertheless, the transmission is more complicated insofar as its tacit dimension, gained by individual experience, is of major importance. Therefore, the main actors are the customers and suppliers (ASHEIM; BOSCHMA; COOKE, 2011).

According to Boschma (2018), initially, the knowledge base literature drew attention to case studies that identified which knowledge types were predominant in different regions. The literature then evolved to a combinatorial approach analyzing how the innovative capacity of firms and regions enhance combinations among different types of knowledge. Including the combinatorial dimension, the conceptual approach also considers the possibility of regions producing both analytical and synthetic knowledge.

When applying this approach to a national economy, with continental dimensions, such as Brazil, it is necessary to consider: a) the presence of several subsystems with different levels of economic development, that change according to the evolution of regional structures (FURTADO, 1967); and b) the role of regions in the spatial division of labor (MASSEY, 1995). The geographical discontinuity of technical progress creates a core region, which is the initial area of economic development, and a periphery, which is the “late” region in terms of technological and organizational progress (RODRÍGUEZ, 2006). The uneven development between the core and the periphery begins with the differentiation in productive structures (industrial and agricultural regions). Nevertheless, these inequalities evolve into knowledge terms as the core areas attract investments in human skill formation and R&D activities. From this perspective, core-periphery interdependencies are not only based on the exchange of physical commodities but can also be understood regarding the exchange of knowledge.

Summarizing the arguments given here, the core is a region with a mature RIS, in which analytical knowledge creation is more likely to be concentrated; while the periphery has a weakly developed RIS that is more closely connected with synthetic knowledge. The core-periphery interdependence creates structural relations that constitute a force of uneven geography of knowledge in national economies.

3. Sugarcane knowledge base

The spatial organization of learning and innovation varies according to the knowledge base (BOSCHMA, 2018; MARTIN; MOODYSSON, 2013). The purpose of this section is to discuss the knowledge base in sugarcane, presenting the meaning of analytical and synthetic knowledge relating to this activity.

Brazilian sugarcane production can be classified as an agro-industrialized system (PAGE; WALKER, 1991). These are systems defined by an agrarian development process, anchored in science and technological evolution and inter-connected with manufacturing and universities. This system depends on an intersectoral combination: farming depends on seeds from the breeder; machines and tools from the machining industry; on irrigation; and on fertilizers and pesticides that come from the chemical industry (WALKER, 2004). As Walker (2004, p. 15) pointed out, the progress of modern agriculture "requires, above all, human knowledge and practical labor skills, and advances in technology are commonly made through human learning".

The production of this knowledge and skills differs in services and manufacturing due to the geographical dispersion (MALERBA, 2004) and the strong influence of ecological conditions (ANDERSEN; WICKEN, 2020). Innovation can compensate for variations in nature, but not eliminate them (POSSAS; SALLES-FILHO; SILVEIRA, 1996). Each technology needs to be able to adapt to the regional particularities (PAGE, 1996). Farming requires an optimum combination of temperature, moisture, and nutrients that vary from place to place. Plants have biological characteristics, related to the seed response and the resistance to pests and diseases, that vary in different environments. Climate conditions, in terms of temperature, precipitation, and the solar energy received, also change from place to place, demanding specific techniques. The same is true for soil conditions and their capacity to provide nutrients to the plant (GRIGG, 1995). As mentioned by PALMER (1972), "a miracle seed in one ecologically and environmentally determined location cannot be assumed automatically to repeat its performance anywhere else in the world".

The literature recognizes the importance of biophysical conditions in knowledge generation in activities such as viniculture (GIULIANI; MORRISON; RABELLOTTI, 2011). This relation can be found in all agricultural systems (PAGE, 1996). In agribusiness, although the final product does not change, such as in the example of wine given above, the methods of production must change.

Sugarcane is heavily dependent on nature. It is a semi-perennial crop that must remain in the field from 12 to 18 months (depending on the harvest planning). Therefore, it requires a complex management system during the period of the plant's growth. The efficiency of production depends on the right choice of varieties with a high concentration of sucrose, and resistance to pests, diseases, and water stress; that can adapt to the local climate, soil type (in terms of its chemical, physical and morphological attributes); and can adapt to the cutting system (mostly mechanized) (GALVAO; FORMAGGIO; TISOT, 2005; LANDELL *et al.*, 2003).

In the sugarcane knowledge base, analytical knowledge refers to science-based knowledge that creates new varieties and new potentialities to improve physical management. It refers to multidisciplinary knowledge (mainly related to agrarian sciences and biology) produced in universities and research centers using experimental fields. Synthetic knowledge refers to the farming practices based on the experience acquired and local conditions. Although this is not related to scientific principles, it is essential to understanding the behavior of the crop in the region.

For example, one particular study presents the theoretical potential of sugarcane to achieve productivity close to 212 t/(ha year), while the national average is around 75 t/(ha year) (WACLAWOVSKY *et al.*, 2010). To achieve this result, the researchers had to understand "the complexities of the sugarcane genome, develop statistical genetics for highly polyploid genomes and identify genes associated with sucrose content, drought resistance, biomass and cell wall recalcitrance" (WACLAWOVSKY *et al.*, 2010, p. 267). This is considered the analytical knowledge in sugarcane. Nevertheless, for this level of productivity to become a reality in the fields, another type of knowledge is also required. Tacit knowledge of how the sugarcane variety will respond to the particularities of each region must be obtained. This is a complex process and deals with different challenges that cannot be predicted in labs. It requires knowledge, accumulated over time. This is considered the synthetic knowledge in sugarcane.

4. Methodology

This section introduces the methodology in two parts. The first presents the regional division that will define the core and the periphery areas. The second presents proxies for analytical and synthetic knowledge in sugarcane. From a temporal perspective, the empirical analysis was performed in detail for 2003, 2010, and 2017, which allows us to show two different periods in the sugar-energy sector: 2003 to 2010 represents a period of increasing and positive expectations while 2010 to 2017 marks a time of stagnation (BACCARIN; OLIVEIRA; MARDEGAN, 2020).

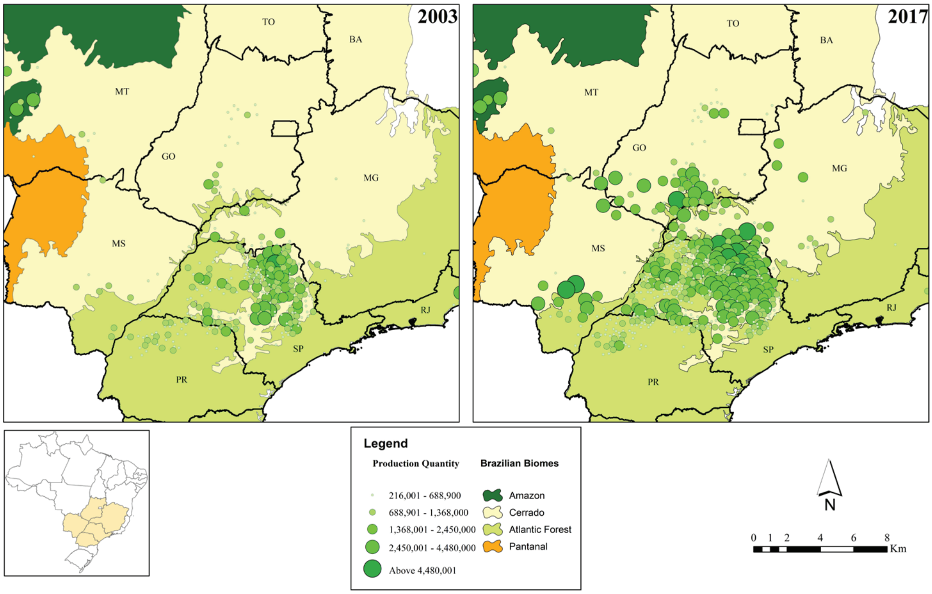
4.1 The regional division of sugarcane production in the Brazilian Central-South

The first step is to propose a regional division of sugarcane production in the Brazilian Central-South region that will support the data analysis. This regionalization is based on the historical shift of the sugarcane frontier, which includes two important periods. The first took place in the 1970s, influenced by the National Alcohol Program (Proalcool), a program implemented by the State to reduce the use of gasoline amidst the international oil crisis (MORAES; ZILBERMAN, 2014). This program stimulated the growth in sugarcane in the west of São Paulo, a region with better infrastructure, fertile soils, good climate conditions, and closer proximity to the São Paulo capital, the main national consumer market. The second occurred in the 2000s, after the introduction of flex-fuel vehicles in the Brazilian domestic market (FURTADO; SCANDIFFIO; CORTEZ, 2011). The growth of bioethanol demand in the 2000s took place at a time when the west of São Paulo was dealing with problems with competition for sugarcane, which led to increased land prices (PALLUDETO *et al.*, 2018). Therefore, investments in bioethanol prioritized zones where sugarcane was not a relevant activity, such as the western region of São Paulo, the south of Goiás, the triangle of Minas Gerais, and the southwest of Mato Grosso do Sul (CALDAS *et al.*, 2017). Map 1 illustrates this process showing the production of sugarcane across regions in different biomes, over two years: 2003 and 2017.

- São Paulo Early Expansion Region (SPER) represents the region of expansion during the 1970s and the main sugarcane producer;
- São Paulo Frontier Region (SPFR) represents the new region of expansion in the far west of São Paulo during the 2000s;
- Minas Gerais Frontier Region (MGFR) represents a continuous region of São Paulo expansion into the Cerrado Biome during the 2000s;
- Goiás Frontier Region (GOFR) also represents a region of growth during the 2000s in the Cerrado Biome, but further from São Paulo;
- Mato Grosso do Sul Frontier Region (MSFR) represents a region of expansion in the 2000s mainly in the Atlantic Forest Biome;

- Paraná Frontier Region (PRFR) is an older region of growth in the Atlantic Forest Biome. It presented a less representative increase of sugarcane in the 2000s compared to the other frontier regions.

MAP 1
Shift in the sugarcane frontier from the Brazilian Central-South region, from 2003 to 2017



Source: based on IBGE-PAM data

First using the different stages of production, then the different federal units outside São Paulo, and finally the regional classification given by the Brazilian Institute of Geography and Statistics (IBGE), at a mesoregional level (see Table 1), six regional productive systems of sugarcane were devised

The SPER represents the core region while the others are classified as peripheral regions. Table 1 shows the different mesoregions in this regionalization and provides some general information about the share of each region in Brazilian GPD and sugarcane harvested area.

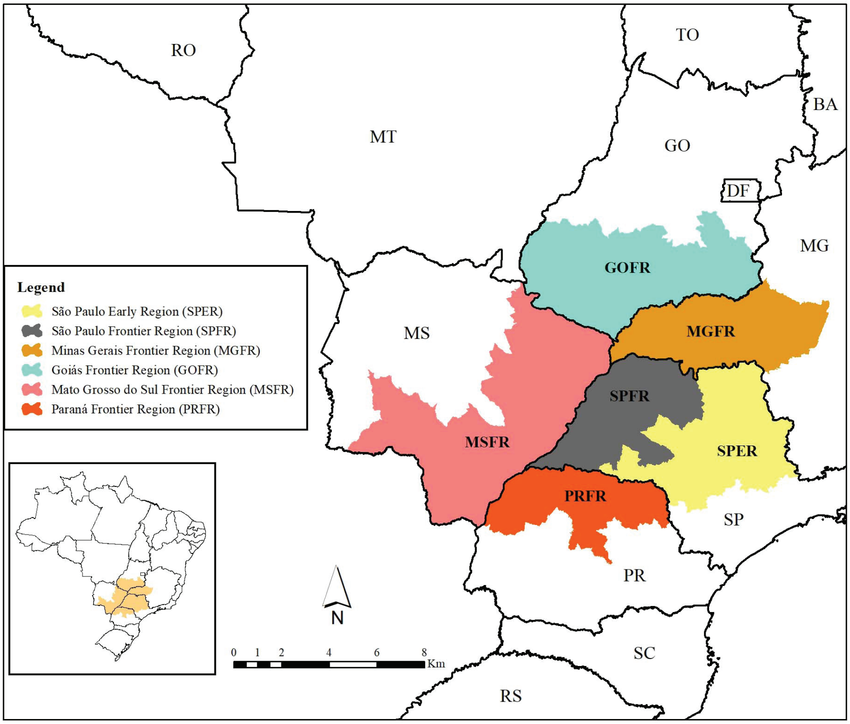
As noted in Table 1, in 2017 SPER outperformed the others in terms of GDP; and in terms of share of the harvested area in both years. SPFR also stands out from the others located in the periphery, with a share of harvested area approximately three times higher than its counterparts. PRFR is the only region with a decrease in the share of the harvested area from 2003 to 2017, although its share in GDP remains among the highest in 2017. The regional division is summarized in Map 2.

TABLE 1
Regional Division: share in Brazilian GPD and sugarcane harvested area

Regional Division	IBGE Mesoregions	% in Brazilian GDP (2017)	% in Brazilian Sugarcane Harvested Area	
			2003	2017
SPER	Campinas, Piracicaba, Bauru, Araraquara, Ribeirão Preto, and Assis	7.56	40.32	32.87
SPFR	São José do Rio Preto, Araçatuba, Presidente Prudente, and Marília	1.78	11.18	22.07
MGFR	Triangulo Mineiro/Alto Paranaíba	1.43	2.64	6.25
GOFR	South Goiás	0.91	1.72	7.36
MSFR	East Mato Grosso do Sul and Southwest Mato Grosso do Sul	0.86	1.79	6.28
PRFR	Northern Paraná, Central North Paraná, and North Pioneer of Paraná	1.66	6.40	5.73
Total	-	**14.2**	**64.05**	**80.56**

Source: based on IBGE-PAM and IBGE-PIB Municipalities

MAP 2
Regional division of sugarcane production



Source: Conceived by the authors

4.2 Measuring Analytical and Synthetic Knowledge in sugarcane

Analytical knowledge is studied in two dimensions. First, an analysis of the codified component that makes it accessible in scientific publications or patents is carried out (MARTIN; MOODYSSON, 2013). It is also used as an instrument to portray the role of universities and research centers in each region. To do so, we use publications in academic papers related to sugarcane, collected from the Brazilian Lattes Platform, internationally recognized as an example of good practices in the registration of scientific production (PERLIN *et al.*, 2017). Over 5 million academic CVs are registered on this platform, therefore it is the broadest mechanism to analyze Brazilian scientific production in general and by area of research. This database is advantageous for geographical studies. Based on the researcher's professional address, it is possible to identify the location and year of publication. However, as mistakes are frequent when information is completed by the researcher - different ways of writing the name of cities and universities, for example, additional efforts were taken to standardize the data.

CVs were downloaded in XML format (Extensible Markup Language) using Web Scrapping techniques (MITCHELL, 2018) and the software Captchas Negated by Python reQuests – CNPQ (SOUZA, 2018). A shell script was used to organize the data – around 5 million files and 200 GB (JOHNSON, 2009). The conversion from XML to a more reader-friendly structure was carried out in R using the package getLattes (R CORE TEAM, 2020; SOUZA; SABINO, 2020).

To access all papers on sugarcane, first, those with the following words in the title were filtered: *cana-de-acucar* or *cana de acucar* or sugarcane. This resulted in 5,586 papers and 7,229 authors (including co-authors). The authors with no professional address were excluded, resulting in 5,155 papers and 4,295 authors. This data, nevertheless, included all types of publications about sugarcane. Thus, for a more specific view of the knowledge applicable to sugarcane production, only the papers related to the areas of Agrarian Science, Biological Science, Exact and Earth Science, or Engineering were selected. After this final selection, 4,942 papers and 3,920 authors (including co-authors) remained.

To use and produce this type of knowledge, the workforce must have some research experience or university training (ASHEIM; BOSCHMA; COOKE, 2011). Therefore, the second dimension of analytical knowledge concerns formal qualification. For this study, we used the data from the Annual Social Information Report (RAIS). This database considers microdata on formal employment, however, as the levels of formality in this sector are increasing, the sample used is considered representative enough. The selection of the professions related to this type of knowledge was made according to the Brazilian occupational classification system (CBO). Considering agriculture technologies as multidisciplinary (POSSAS; SALLES-FILHO; SILVEIRA, 1996), the occupations related to analytical knowledge combine jobs, both directly and indirectly, related to agriculture[2]. In this sense, one important difference from the DKB literature is that agronomic engineering is considered an occupation related to analytical knowledge. Even though these professionals develop know-how on the local conditions of the farms (as in the synthetic knowledge definition), , they are considered a proxy of analytical knowledge given that they are more dedicated to studies, research, analysis, and evaluations for scientific and rational experimentations, that allow new methods of production (CONFEA, 2021). Therefore, in agriculture, engineers use and stimulate a theoretical understanding on technologies based on scientific principles.[3]To capture the dimension of these jobs across the entire sugarcane production chain, we considered four sectors at a 4-digit level of disaggregation from the National Classification of Economic Activities (CNAE 2.0).[4] sugarcane crops (0113), sugar production (1071), sugar refining (1072), and ethanol production (1913).[5] The first refers to agricultural production. The others refer to milling. Although the focus of the paper is on farming, the inclusion of mills is necessary since it is common that the processing plant also owns the land and provides the labor for the sugarcane production.

Synthetic knowledge is also analyzed in two dimensions. Technical professions were considered a proxy for synthetic knowledge (PLUM; HASSINK, 2013). The role of this professional on farms is related to technical assistance, the execution of projects, and supporting experimentations (CFTA, 2021). They have a high school diploma and technical training. Their skills are more related to the capacity to solve practical problems on the farms than to codify scientific comprehension. The CBO was also used to select professions related to this type of knowledge. Following

2 To reach this classification, we first built a ranking of occupations within the sugarcane sector, based on the frequency and share in total employment within each region. From this large group of jobs, we selected the ones within the Biological Sciences, Agronomic and Engineering sectors, since they are more related with agricultural technologies.

3 Chart 1 in the Appendix shows all the occupations that were considered.

4 Compatible with ISIC Rev. 4.

5 Although the paper focuses on the farm production, the inclusion of activities related to sugarcane processing was necessary. Due to a vertical integration process, the ethanol and sugar plants can also own the sugarcane fields. On these occasions, the employment data is concentrated in the activities of sugar and ethanol production and not on sugarcane crops. On the one hand, one problem related to this decision is the inclusion of professionals that are working in the processing plants in areas that are not connected with agriculture. On the other hand, it makes it possible to capture a broader dimension of the production.

the same model used for analytical knowledge, professions directly and indirectly associated with agriculture were combined.[6] Based on RAIS, the second dimension of synthetic knowledge is given by the work experience within the firm (in months). Experience is necessary to acquire specific skills and capabilities associated with local conditions. If the workers spend more time in the mill and working on the sugarcane crops, this type of knowledge is expected to increase.

Therefore, using these metrics, we aim to identify the regions from Map 2 where a RIS can be developed: a) on the basis of both synthetic and analytical knowledge; and b) primarily on the basis of one of the two.

For a better contextualization of the results, the following section presents a regional qualification of the sugarcane sector and its evolution.

5. Frontier movement and regional changes in sugarcane production

Graph 1 presents the temporal evolution of the area of sugarcane in the regions previously specified. In all the regions analyzed, the harvested area with sugarcane from 2003 to 2017 increased. In absolute terms, however, this growth is more intense in the São Paulo regions (SPER and SPFR). The graph also shows the two time periods related to sugarcane production. The first, between 2003 and 2010, when the regions experienced a sharp growth in sugarcane production. The second after 2010, when sugarcane growth rates fell, and after 2013 when it stabilized.

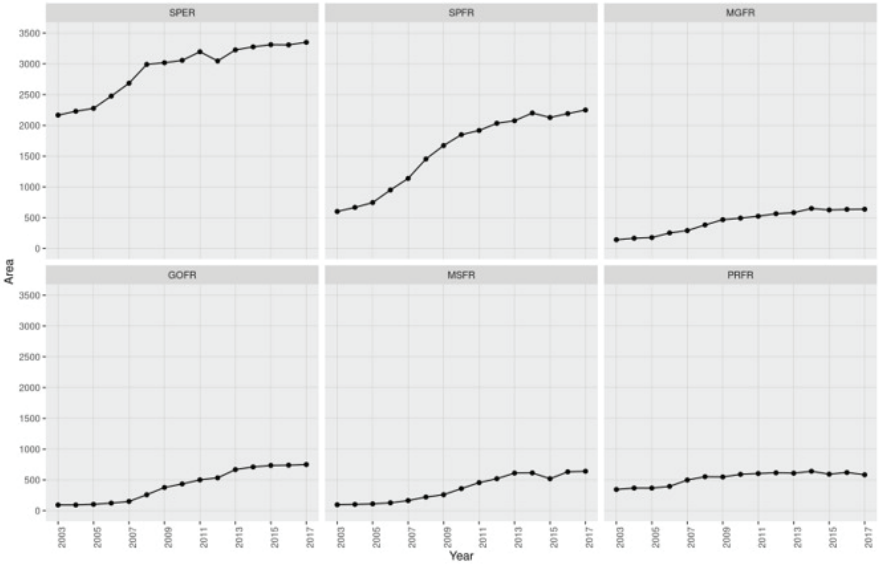
Regarding the total employment in the sugar-energy sector, most of the regions present similar behavior as shown in Table 2: a significant growth between 2003 and 2010 and a decrease between 2010 and 2017, in level (n) and shares (%). Only GOFR and MSFR increased the number of employees in both periods. Table 2 also shows the change in the regional distribution of labor.

There are two structural reasons for the reduction in employment in the sugar-energy sector. The first is the global economic crisis of 2008, in which the effects were more evident after 2011-2012 (MENDONÇA; PITTA; XAVIER, 2013). The financial crises led to a decrease in the construction of new processing plants, the acquisition of land for sugarcane, and investments in technologies for farming management. The second reason is the change from labor-intensive manual harvesting, which predominated between the 1960s and 1990s, to mechanical harvesting. This change reduced the volume of workers needed and created an

6 See Chart 2 in the Appendix.

opportunity for qualified labor to operate the vehicles (BACCARIN; OLIVEIRA; MARDEGAN, 2020).

GRAPH 1
Regional Sugarcane harvested area, from 2003 to 2017



Source: based on IBGE-PAM data

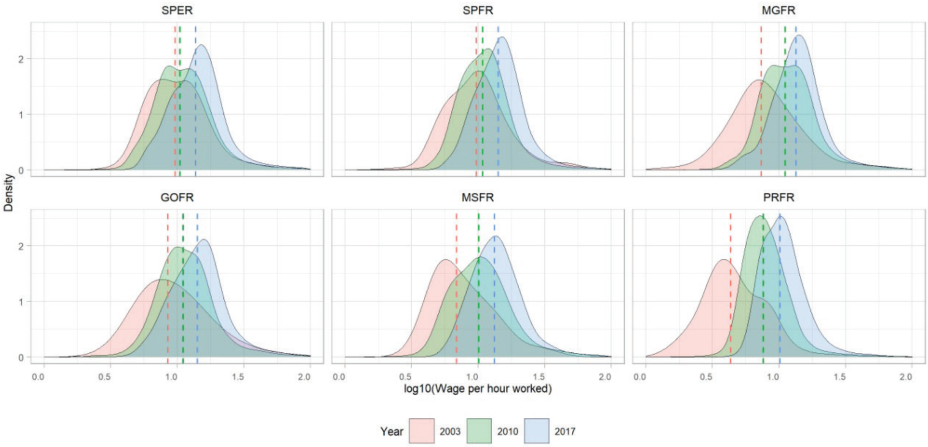
TABLE 2
Number of employees by region in sugar-energy sectors (n in thousands). Shares in relation to the sum of all regions

Year	2003		2010		2017	
Region	n	%	n	%	n	%
SPER	44.79	62.8	153.46	44.2	135.71	42.6
SPFR	6.37	8.9	78.96	22.7	73.19	23.0
MGFR	3.23	4.5	25.94	7.5	24.79	7.8
GOFR	0.23	0.3	22.02	6.3	29.16	9.2
MSFR	0.81	1.1	20.96	6.0	22.84	7.2
PRFR	15.94	22.3	46.01	13.2	32.72	10.3
Total	**71.37**	**100.0**	**347.35**	**100.0**	**318.41**	**100.0**

Source: based on RAIS data.

While the mechanization and the shift of sugarcane to new biomes that required specific techniques had the potential to stimulate new knowledge generation for the farming system, the crises slowed this process. Nevertheless, it is possible to identify some regional qualitative changes in the sugar-energy sector. To capture this, the hourly wages are used as proxies for a set of skills and capabilities (DAVID; DORN, 2013). This data for the sugar-energy sector over selected years is presented in Graph 2. Horizontal axes are given in log10 for a better visualization of the tails.

GRAPH 2
Distribution of regional hourly wages for selected years.
Values in log10 for a better visualization of the tails[7]



Source: based on RAIS data

Peripheral regions outside of the Sao Paulo state had lower average employment incomes in 2003, with PRFP having the lowest compared to the Sao Paulo regions. A shift to the right in the distributions is evident, reducing the wage gap among regions. However, the shift observed in the distributions is greater for the periphery region of PRFR considering that the gap here was wider.

Another indication of the regional change is the labor qualification in the sugar-energy sector. Using data related to five aggregate levels of formal education, Table 3 shows that, from 2003 to 2017, the share of more qualified workers increased. The most significant growth is related to workers with a high school education that,

7 Monetary values were deflated considering the INPC (*Índice Nacional de Preços ao Consumidor*), with 2017 as the base year. RAIS data preprocessing was performed in R.

TABLE 3
Regional share of workers by the level of formal education for selected years in sugarcane and other sectors.

Education \ Region	SPER		SPFR		MGFR		GOFR		MSFR		PRFR	
	Others	Sugarcane	Others	Sugarcane	Others	Sugarcane	Others	Sugarcane	Others	Sugarcane	Others	Sugarcane
2003												
Illiterate	0,6	1,7	0,5	0,7	0,7	1,9	2,7	--	1,4	2,0	0,6	1,8
Up to elementary school	48,1	71,8	45,0	56,8	49,2	73,0	54,1	96,0	58,1	64,4	44,2	67,8
Up to high school	37,1	21,1	40,0	33,6	36,8	19,5	32,7	0,9	29,5	31,3	42,0	20,0
College incomplete	3,1	1,6	2,9	2,2	3,0	1,8	3,1	0,9	2,6	1,1	3,5	1,1
College completed+(1)	11,1	3,8	11,6	6,7	10,3	3,8	7,3	2,2	8,4	1,2	9,7	9,3
2010												
Illiterate	0,3	1,6	0,3	0,9	0,6	1,5	0,7	1,5	0,7	0,9	0,3	1,6
Up to elementary school	30,4	63,5	28,7	57,9	36,1	61,3	40,5	56,9	40,1	55,0	30,2	63,0
Up to high school	52,0	28,9	53,5	35,4	45,6	30,6	44,9	33,4	43,8	36,7	52,1	31,7
College incomplete	3,7	1,7	3,4	1,6	4,3	2,0	3,8	3,3	3,3	2,1	4,1	1,2
College completed+(1)	13,6	4,4	14,1	4,2	13,4	4,6	10,1	5,0	12,1	5,2	13,3	2,5
2017												
Illiterate	0,2	1,0	0,1	0,4	0,7	0,7	0,5	0,8	0,4	0,4	0,2	0,8
Up to elementary school	20,6	50,3	18,9	47,0	23,8	43,5	28,6	42,8	27,1	41,2	20,8	46,5
Up to high school	57,4	39,6	60,3	43,9	52,9	45,2	52,8	45,9	54,2	48,6	56,3	46,4
College incomplete	3,4	1,8	2,9	1,7	4,4	2,6	3,6	3,1	2,9	2,8	4,0	1,8
College completed+(1)	18,4	7,3	17,7	6,9	18,2	8,0	14,5	7,4	15,5	7,0	18,6	4,6

Source: based on RAIS data.
(1) College, MSc, and Ph.D.

in general, represents the jobs with a technical qualification related to synthetic knowledge. In 2017, the share of this group was close to 40% in the SPER and up to 40% in the other regions. The number of workers with a college degree, which represented jobs related to analytical knowledge, also increased in all regions, except the PRFR. In 2017, the highest shares of workers with a college degree were found in the MGFR and GOFR regions (8.0% and 7.4%, respectively). As new regions of expansion, the opportunity arose for producers to hire a new workforce with a higher level of formal education.

Table 3 also shows that in all the regions the shares of workers with a college or high school education in the sugar-energy sector are lower when compared with the other sectors. On the other hand, the share of workers with elementary school education in the sector is always higher. This is important to understanding the sugar-energy sector. Although this activity incorporates scientific knowledge and new agricultural technologies, it is still a heterogeneous sector that combines a high and low-skilled labor force.

6. The uneven geography of sugarcane knowledge

Despite the qualitative and quantitative regional changes discussed above, the change in knowledge capabilities is a much slower process. This section presents the changes in analytical and synthetic knowledge at the core and in peripheral regions.

6.1 Analytical knowledge concentration

The first dimension related to the analytical knowledge in sugarcane concerns the publications related to sugarcane. According to Table 4, of the 3,524 publications on sugarcane in the selected regions, 81.5% were carried out by researchers in the SPER. It is also important to highlight the increase in the publications in the PRFR and the SPFR.

The concentration of the scientific production presented in Table 4 is a result of the size of the universities where published authors work. As Table 5 shows, the universities in the state of São Paulo appear among the institutions with the highest number of publications.

TABLE 4
Publication evolution according to region and year

Region	until 2003		2004-2010		2011-2017		Total	
	n	%	n	%	n	%	n	%
SPER	556	85.7	631	79.7	1,684	80.8	2,871	81.5
SPFR	24	3.7	33	4.2	133	6.4	190	5.4
MGFR	28	4.3	58	7.3	73	3.5	159	4.5
GOFR	-	-	10	1.3	38	1.8	48	1.4
MSFR	1	0.2	11	1.4	36	1.7		1.4
PRFR	40	6.2	49	6.2	119	5.7	208	5.9
Total	**649**	**100.0**	**792**	**100.0**	**2,083**	**100.0**	**3,524**	**100.0**

Source: based on Lattes Platform data

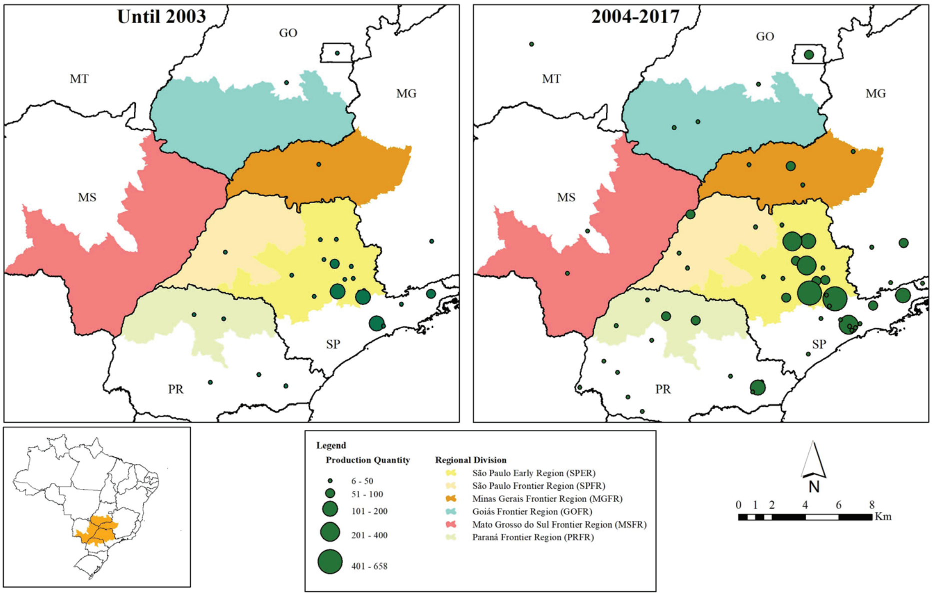
TABLE 5
Publications by university or research institution

Research Institution	Location (State)	Until 2003	2004-2010	2011-2017	Total
USP	São Paulo	185 (1)	183 (1)	410 (2)	778 (1)
UNESP	São Paulo	79 (4)	124 (2)	481 (1)	684 (2)
ESALQ	São Paulo	181 (2)	120 (3)	315 (4)	616 (3)
UNICAMP	São Paulo	69 (5)	114 (4)	346 (3)	529 (4)
EMBRAPA	Various locations	89 (3)	87 (5)	215 (5)	391 (5)
UFSCAR	São Paulo	57 (6)	47 (7S)	140 (7)	244 (6)
CNPEN	São Paulo	2 (76)	15 (20)	180 (6)	197 (7)
UFV	Minas Gerais	21 (12)	34 (10)	139 (8)	194 (8)
IAC	São Paulo	30 (8)	32 (11)	114 (9)	176 (9)
UFRJ	Rio de Janeiro	36 (7)	49 (6)	88 (12)	173 (10)

Source: based on Lattes Platform data
Nota: The number of articles from each university is calculated based on at least one author from such university. Thus, an article with more than one author from the same university does not duplicate the number of articles in that university. ** Ranking between parentheses.

Based on this data, Map 3 represents an initial illustration of the different types of RIS in sugarcane regions. It highlights the importance of the SPER, where different cities participate in knowledge generation.

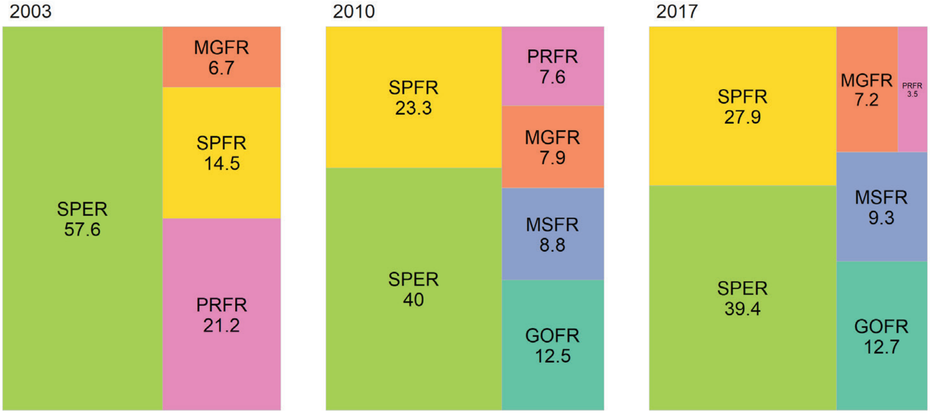
MAP 3
Regional division of sugarcane publications



Source: based on Lattes Platform data

Graph 3 illustrates the regional shares of the jobs related to analytical knowledge. This data shows the capacity of sugarcane firms in the RIS to incorporate analytical knowledge. What is interesting about Graph 3 is the reduction in the regional share of SPER. It suggests that SPER can create these qualified jobs that are absorbed by the other regions, mainly the SPFR, but also the GOFR and the MSFR that show more representative growth during the period analyzed. The situation in the PRFR is also worth mentioning since it is the region with the lowest share of this type of workforce.

GRAPH 3
Regional shares of analytical knowledge in sugarcane (%)



Source: based on RAIS data.
Nota: In 2003 the GOFR and the MSFR did not have representative shares of this type of job.

6.2 Synthetic knowledge

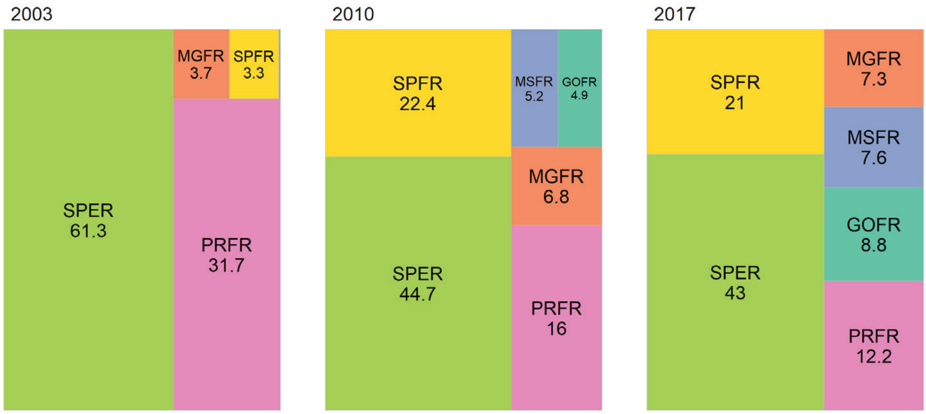
The first dimension of synthetic knowledge regards the jobs with a technical qualification in the sugar-energy sector. This is the predominant type of labor in the sector. This data shows the capacity of the RIS to produce synthetic knowledge. Graph 4 shows the change in the regional distribution of these jobs. The SPER accounted for 61.3% of the technical professions in 2003, 44.7% in 2010, and 43.0% in 2017. The PRFR also presents a reduction in the same period. On the other hand, there is a significant increase in the SPFR, GOFR, MGFR, and MSFR.

The second dimension of synthetic knowledge is worker experience. Graph 5 presents a kernel density estimation of the distribution of workers' experience in months, for each region and year. Median values are represented by the vertical lines, respectively. To avoid extreme values, we used the median value as a reference.

As mentioned in the previous sections, experience may reflect the acquisition of tacit knowledge through the learning by doing processes and local interaction. This enables specialization considering local conditions, which is also key to adapting technologies and improving performance. As observed in all the cases, there is a rise in average figures from 2003 to 2017, which is also expressed in the shift of the distributions (to the right, from the distribution in red to the blue) and a heavier right tail (more workers related to synthetic knowledge in sugarcane increasingly keeping their jobs). Major gains in experience in this period are observed for the

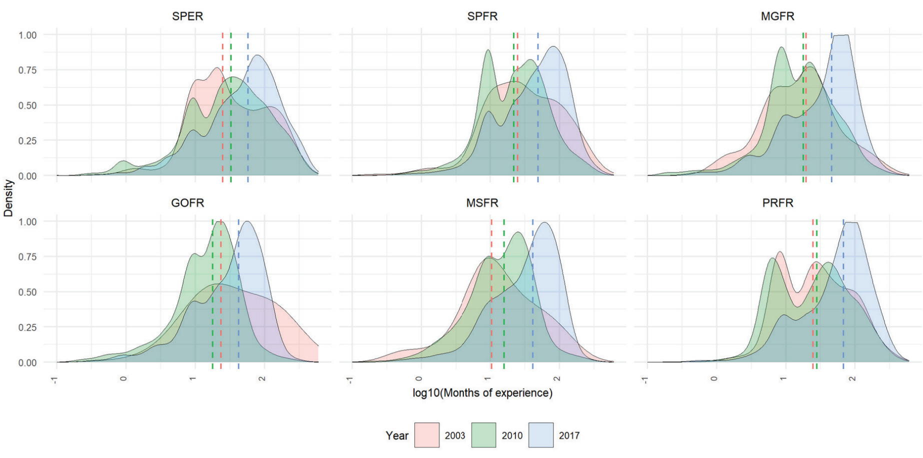
MSFR and PRFR, with an increase of 274% and 176%, respectively. The SPER and MGFR also present significant increases of around 134% in average experience. It is also important to highlight the role of the PRFR, which in 2017 presents the highest median of experience (around 68 months, or $10^{1.84}$), followed by the SPER, with a median of 58 months (approx. $10^{1.76}$).

GRAPH 4
Regional shares of jobs related to synthetic knowledge in the sugar-energy sector (%)



Source: based on RAIS data.
Nota: In 2003 the GOFR and the MSFR did not have representative shares of employment in these conditions.

GRAPH 5
Regional distribution of workers' experience in sugarcane sectors for selected years. The horizontal axis is in log10 for better visualization of the tails.



Source: based on RAIS data.

Thus, although the expansion process follows an uneven process of knowledge generation, with the center leading analytical knowledge generation, a better distribution of synthetic knowledge can be observed. Notwithstanding, heterogeneity prevails among regions.

7. Conclusions

Brazil is a country with continental dimensions characterized by asymmetries and regional specificities in its productive structure. Given the role of the country as the main producer of sugar and sugarcane worldwide, as well as the relevance of knowledge and learning capability as drivers of growth and development, this paper analyzes whether the rise in sugarcane production in peripheral areas leads to the growth of knowledge capabilities.

The theoretical framework proposed in the paper is the DKB approach in association with RIS and core-periphery relations, so as to consider regional heterogeneity in the analysis. Six regional productive systems of sugarcane were devised, with SPER as the center region and the other five regions as part of the periphery. Proxies for analytical and synthetic knowledge in sugarcane were evaluated for 2003, 2010, and 2017.

Based on the results we can conclude that the SPER has a system capable of combining sugarcane production with analytical and synthetic knowledge creation. This reinforces the idea that analytical knowledge is a consequence of a historical process of technological learning surrounding sugarcane (FURTADO; SCANDIFFIO; CORTEZ, 2011). The SPER also concentrates the main centers and universities responsible for academic research and the formation of human skills. At least three important universities are located in this region: Luiz de Queiroz College of Agriculture (ESALQ), University of Campinas (Unicamp), and two São Paulo State University (Unesp) campuses. It is also home to four of the most important research centers for sugarcane in Brazil: the Agronomic Institute of Campinas (IAC), the Sugarcane Technology Center (CTC), the headquarters of the Inter-University Network for the Development of the Sugarcane Industry (Ridesa), in São Paulo, located on the Federal University of São Carlos (UFSCar) campus, and the Brazilian Biorenewables National Laboratory (LNBR). It also benefits from the proximity to the São Paulo capital where the University of São Paulo (USP), the most important university for sugarcane research, is located. SPER also produces synthetic knowledge. Despite the reduction in the share of sugarcane production from 2003 to 2017, it is still the region with the most jobs related to this type of knowledge. During the 2000s this region suffered a loss in the share of sugarcane production and in the total jobs but maintained its core position in the indicators of analytical knowledge.

The peripheral regions, however, do not have the same knowledge capabilities, though three of the regions present better results. A number of important universities are located in the PRFR, such as the State University of Maringá (UEM) and the State University of Londrina (UEL). It is also important to highlight the role of the Federal University of Paraná (UFPR), located in the state capital. These universities boast a considerable number of publications on sugarcane. Nevertheless, in terms of professionals related to analytical knowledge, the PRFR presented a significant reduction. A similar reduction is also seen in the jobs related to synthetic knowledge. This region illustrates the case that some components of the RIS are located in the periphery, but it seems that there are failures in the local interactions.

Another peripheral region with better results is the SPFR. This region presents the highest increase in sugarcane production (both in area and employment). Regarding analytical knowledge, this region has low publication numbers highlighting the restricted role of local universities. The share of jobs related to this type of knowledge however increased. The jobs related to synthetic knowledge and the worker experience also increased during the period analyzed. In this case, the geographical proximity to the SPER appears to create a core-periphery interdependence that places constraints on the SPFR innovation system. The SPFR appears to create synthetic knowledge and attract analytical knowledge from the core.

The third region is the MGFR. This region has university centers that produce analytical knowledge for sugarcane, primarily the Federal University of Uberlandia (UFU). A number of other universities in Minas Gerais also hold a certain importance, such as The Federal University of Viçosa (UFV), which despite not being located in the same areas of sugarcane expansion, plays an important role in producing analytical knowledge. Important gains were made in synthetic knowledge in the MGFR both in terms of jobs and worker experience.

The regions in the Brazilian Centre-West presented inferior results. Both the GOFR and the MSFR played a small role in analytical knowledge generation in terms of publications, but increased the regional share of jobs related to this type of knowledge. These regions show a similar pattern of core-periphery interdependence, verified in the SPFR, that seems to attract these professionals from other regions.

Regarding synthetic knowledge, both the GOFR and the MSFR presented positive variations in worker experience and the jobs related to this type of knowledge.

Hence, this paper shows that the movement of the sugarcane frontier is not automatically followed by the movement of knowledge, which validates our hypothesis. Each region has specific potentialities and limits to create each type of knowledge. The particularities of the natural environment may represent a force of attraction for knowledge creation in the periphery. Nevertheless, the evolution of spatial structures and the RIS at the core inhibits the movement of knowledge.

Considering knowledge as a key factor in contemporary capitalism, it is important to relativize the role of agriculture in reducing regional inequalities. On the one hand, the crops move to the periphery creating a similar landscape, but, on the other hand, the knowledge – mainly the analytical knowledge – continues to follow an uneven pattern of location in the core region.

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C. Preparation of figures and tables: Fernando Mesquita, Ivette Luna; Roney Fraga Souza

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Appendix

CHART 1
Professions related to analytical knowledge

Directly Associated with Agriculture	Indirectly Associated with Agriculture
Researcher in agronomic sciences	Researcher in environmental biology
Forest science researcher	Researcher in biology of microorganisms and parasites
Agricultural engineer	Researcher in plant biology
Agronomist	Researcher in Earth Sciences and Environment
Forest engineer	Chemistry researcher
	Mechanical Engineering Researcher
	Chemical Engineering Researcher
	Biologist
	Chemical
	Weatherman
	Geologist
	Geophysical
	Geochemical
	Hydrogeologist
	Biological Sciences Teacher in Higher Education
	Chemistry teacher (higher education)
	Geophysics teacher
	Geology Teacher
	Chemical engineer
	Mechanical Engineer
	Food engineer
	Mapping engineer
	Surveyor Engineer
	Computing application engineer
	Environmental engineer
	Bioengineer
	Civil engineer (geotechnics)
	Civil engineer (hydrolog

Source: Conceived by the authors

CHART 2
Professions related to synthetic knowledge

Directly Associated with Agriculture	Indirectly Associated with Agriculture
Tractor Driver	Meteorological technician
Farm Supervisor	Surveyor Technician
Farm Supervisor	Geodesy and cartography technician
Sugarcane producer	Hydrography Technician
Sugar cane crop worker	Surveyor
Farming worker	Geophysics Technician
Harvester operator	Geology Technician
Operator of agricultural processing machines	Geochemistry Technician
Worker in the operation of localized irrigation system (micro sprinkler and drip)	Geotechnical Technician
Worker in the operation of sprinkler irrigation system (center pivot)	Biotechnology technician
Worker in the operation of conventional sprinkler irrigation systems	Machine driver (pumping)
Worker in the operation of irrigation and sprinkler systems (high propelled)	Machine driver (mechanic)
Worker in the operation of surface irrigation and drainage systems	
Support technician in agricultural research and agricultural development	
Agricultural technician	
Agricultural technician	
Forestry technician	
Agricultural pilot	

Source: Conceived by the authors