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ARTICLE

Interaction networks in health human area: a longitudinal study for Rio Grande do Sul

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ABSTRACT

The article aims to characterize interaction networks among actors - research groups and organizations – in the human health area in Rio Grande do Sul. Data were obtained from the DGP/CNPq to build interaction networks for the years 2010, 2014 and 2016. It was observed that there was an increase in groups and interactions over this period. Most of the research groups establish interactions with only one partner. Therefore, more actors join the networks over time, but do not interact much among each other. This identified characteristic is typical of innovative systems in emerging countries, whose interactions among actors are scarce. There are similarities among the networks (such as the relevance of some central actors and firms as peripheral actors), but there are also aspects that differentiate them (universities stand out as partners in the most recent period). Regarding the proximities, geographical and organizational proximities are highlighted as important concepts to explain interactions among different actors.

Keywords | University-organizations collaboration; Interaction networks; Health human area; Rio Grande do Sul

1. Introduction

Academic research has gone through several changes in the last few decades. The main aspect to th ese changes is a great increase in collaborative research and the formation of research teams, which establish the standard for research activity (ARCHIBUGHI; FILLIPETTI, 2015). The main determinants for this increase are the specialization, interdisciplinarity and complexity of science nowadays (OLECHNICKA; PLOSZAJ; CELIŃSKA-JANOWICZ, 2019).

These determinants are critical for research in the human health area, which is the focus of this paper. The generation of knowledge and innovation is triggered by interactions among several agents, engaging multidisciplinary teams that interact in systematic processes of learning by doing and learning by interacting (METCALFE; JAMES; MINA, 2005; WINDRUM; GARCÍA-GOÑI, 2008; CONSOLI; MINA, 2009; MORLACCHI; NELSON, 2011; NELSON *et al.*, 2011). As a result, networks structured by multiple agents are the typical organization means to generate knowledge and carry out innovative processes in the health area in an evolutionary process.

In this context, our goal is to analyze the research groups' interaction networks in the health sciences area in Rio Grande do Sul by examining the key actors in the process of knowledge generation and diffusion and determining their location. Consequently, the paper's objective is to examine how these networks have been characterized over time and how they have evolved regarding these two features.

In order to conduct this research, Rio Grande do Sul (RS) was chosen as subject. This state has the third highest number of research groups in health sciences, and the third highest number of groups that inform interactions with organizations in Brazil, surpassed only by São Paulo and Rio de Janeiro (BRASIL, 2016). The Metropolitan Region of Porto Alegre is one of the regions of Brazil with the greatest scientific specialization in health, as pointed out by Chaves and Albuquerque (2006) and corroborated by other authors, such as Britto *et al.* (2012), Tatsch, Batisti and Fraga (2013), Botelho and Tatsch (2015), Caliari and Rapini (2016), and Tatsch *et. al.* (2019). In this region, there is a concentration of health services, especially the high complexity ones. There are also five teaching and research hospitals, besides many other private and public establishments specialized in different levels of health services. The state of Rio Grande do Sul, overall, encompasses a set of industrial-based firms (chemical, biotechnological, mechanical, electronic and materials), especially small- and medium-sized; as well as a good variety of undergraduate and graduate courses in the health sciences area (TATSCH, 2012; LAMBERTY, 2014; BOTELHO; TATSCH, 2015).

Secondary data were collected from the National Council for Scientific and Technological Development's (CNPq) Directory of Research Groups (DGP) for the years 2010, 2014 and 2016 in order to identify the actors that stand out in the innovative health system in RS and their interactions. Networks were developed based on these data, showing the interactions between research groups in health sciences and various organizations, such as industrial firms, hospitals, educational and research organizations, etc. The Social Network Analysis (SNA) was implemented to create these networks. Thus, it was possible to perform a longitudinal analysis, evaluating the fluctuations in the network's characteristics over time.

The article is divided into five sections besides this introduction. In the second part, the theoretical framework that supports this study is explained briefly. In the following section, methodological procedures are described; subsequently, the results of the study are presented and their discussion is carried out. The final considerations are in the last part of this paper.

2. Theoretical framework

In the area of neo-schumpeterian and evolutionary approaches, the analysis of how the interactions that produce knowledge and innovation are developed is central. Interactions established with suppliers, competitors, clients, public and private funding agencies, universities and research centers are considered, since they rank among the most important agents (LUNDVALL, 1988; 1992).

Interactions between firms and universities and/or research centers are greatly important in science-intensive sectors, which in turn increase their share in modern economies (MOWERY; SAMPAT, 2006; ETZKOWITZ; LEYDESDORFF, 2000; PONDS; OORT; FRENKEN, 2007). These interactions are increasing, as are the interdisciplinary requirements that support innovations with higher degrees of complexity. Therefore, the need to bring together a wide and diverse set of knowledge makes the collaboration of different actors, at regional, national or international levels, a fundamental requirement for innovation generation.

These interactions, as pointed out by the literature, especially by the regional systems approach, are facilitated by territorial proximity (COOKE, 1998; ASHEIM; GERTLER, 2006; ASHEIM; SMITH; OUGHTON, 2011).

The particular nature of historical, cultural, social, and economic conditions in the territories enables the emergence of learning by interaction and the development of skills and capacities on a local level, which is important for innovation generation. The construction of such capacities depends heavily on tacit knowledge, which requires geographical proximity, due to its production and use. Thus, knowledge spillovers are considerably localized, depending on territorial and cognitive proximity (FELDMAN; KOGLER, 2010; GARCIA, 2017).

An important part of this literature states that, in addition to territorial proximity, other dimensions of proximity must be considered, especially when it is necessary to gather different types of knowledge to foster innovative processes (BOSCHMA, 2005; KNOBEN; OERLEMANS, 2006; PONDS; OORT; FRENKEN, 2007; BROEKEL; BOSCHMA, 2012).

Thus, it is important to consider the organizational (regarding how the relations are shared in an organizational arrangement, either within or among organizations), social (socially embedded relations between agents at the micro-level), institutional (associated with the institutional framework at the macro-level) and cognitive proximity (related to the absorptive capacity and the different actors and organizations' learning potential). These different proximities are critical to understand the different types of partnerships and networks formed at a local level to generate new knowledge and innovations (BOSCHMA, 2005; GARCIA, 2017). According to Boschma (2005, p. 71), "[…] too much and too little proximity are both detrimental to learning and innovation." Territorial proximity is of great importance for knowledge transmission, especially tacit knowledge, but it can result in some type of lock-in. In order to access new knowledge, the other forms of proximity could replace and complement geographical proximity.[1]

The importance of interactions between different actors at different development stages of knowledge and innovation generation is also analyzed by Powell *et al.* (2005). Based on the biotechnology field, the authors show how different types of firms, organizations and financing structures constitute the networks in a dynamic and evolutionary process. Networks are being shaped and modified by interactions over time and, with new challenges and objectives, new networks are formed. Depending on the stage, some actors are more important than others, such as universities when

1 It is worth mentioning that Boschma (2005) and other authors, such as Konoben and Oerlemans (2006), show that there may be interconnections among the different concepts of proximity and that these definitions are not always precise. For Konoben and Oerlemans (2006), for example, the cultural and institutional proximities are part of the 'organizational proximity', while Ponds, Oort and Frenken (2007) employ the term 'institutional proximity' in the same way as 'organizational proximity'.

scientific challenges arise, or venture capital funds when new financing structures are required. Considering "[…] the analogy of the dance hall, both the music and the dancers shift over time" (POWELL *et al.*, 2005, p. 1188).

For the human health area, this theme is approached by a set of works that highlight the importance of considering various types of interactions in order to support the innovative process (METCALFE; JAMES; MINA, 2005; POWELL *et al.,* 2005; CONSOLI; MINA, 2009; MORLACCHI; NELSON, 2011; NELSON *et al.*, 2011). These studies analyze the complexity, the interdisciplinarity and the diversity of agents involved in the innovative activities in the health field.

To sum up, the interactions that support the innovative process in the health area are related to, on the one hand, the need to integrate different knowledge fields (biology, chemistry, physics, engineering, etc.) in order to develop innovative activities, and, on the other, the need to integrate the economic sectors involved in the medical area (notably the pharmaceutical and machinery and equipment industries) with medical services. These services and the knowledge they provide regarding the functioning of the human body and its complex and differentiated responses to treatments are crucial for the evolution of innovations in a markedly evolutionary and path-dependent process (MINA *et al.*, 2007; NELSON *et al.* 2011).

Among the interactions that lead to innovation in the human health area, the most important one is among university hospitals, their research groups and the drugs and medical devices industry (DJELLAL; GALLOUJ, 2005; WINDRUM; GARCÍA-GOÑI, 2008; BARBOSA; GADELHA, 2012; THUNE; MINA, 2016).

> *Hospitals perform multiple functions in health innovation systems. They are the major providers of health-care services. They are adopters and users of new technologies (thus the demand side of externally generated innovation). They are potential developers of processes and organizational innovations (THUNE; MINA, 2016, p. 1545).*

In general, the various types of interaction and knowledge generation that support innovation in the human health field are not present in developing countries. There are several historical and structural aspects that hinder/limit the development of health innovation systems, usually related to structural aspects of demand.

Albuquerque and Cassiolato (2002) argue that the health innovation system in Brazil presents certain characteristics, as: i) a chemical-based industry, which produces pharmacological products and mainly comprises multinational companies whose research and development activities (R&D) focus on their countries of origin; and ii) a small mechanical, industrial, electronic, and materials-based industry, whose demand is mostly met by imports. These characteristics significantly limit the interactions that could generate innovative dynamics to the health innovation system.

Chaves and Albuquerque (2006), by discussing relations between scientific and technological activities for the health field in Brazil, show that there is a disconnection between these activities. If, on the one hand, there is low scientific production, insufficient to trigger a virtuous circle that generates technological production; on the other hand, the local technological production is equally small and insufficient to stimulate the creation of new scientific research fields.

Botelho and Tatsch (2015) also reinforce the frailty of the health innovation system in Brazil. The case studies of two Brazilian states (Minas Gerais and Rio Grande do Sul) showed that the stage of production and commercialization of products and services becomes difficult to achieve due to the lack of institutional and financial support. Financial support to bear the high costs of the testing phase for application in human beings is also restricted.

Paranhos and Hasenclever (2011) detail these aspects by showing – using data from Innovation Research (Pintec, in Portuguese acronym) and CNPq – that national pharmaceutical firms interact in a very limited way with universities, which differentiates them from foreign firms. The focus of these firms on the production of generic drugs (which do not represent an innovation for the market) and its small size and financing difficulties are the main reasons for a low and little complex interaction pattern. These factors also explain the low volume of R&D spending.

When analyzing the relationship between the new drugs launched in Brazil between 2000 and 2004 and the diseases that affect most of the population, Vidotti, Castro and Calil (2008) conclude that, in addition to the industry having controlled the number of new drugs launched, most of these drugs were not new in therapeutic terms, reinforcing, along with other databases, Paranhos and Hasenclever's (2011) conclusions on the low innovative content of Brazil's drug industry.

However, this situation seems to be changing in recent years, due to stimuli from industrial policy and innovation plans implemented in Brazil in the 2000's. These plans focused in fostering the innovative activities of Brazilian firms. In this sense, in a recent work, Paranhos *et al.* (2019) show how the largest Brazilian pharmaceutical firms are increasing their spending on R&D and establishing partnerships with universities. The increase in this type of partnership was also identified by Alves, Vargas and Britto (2018) for young and small Brazilian biotechnology firms focused on human health, characterized as Science Based Firms. Unfortunately, these changes are still very restricted in terms of firms and sectors in the health field.

Given the interactive nature of knowledge generation in the human health area, we examine how the networks have been characterized over time and how they have evolved in terms of their characteristics and features.

3. Methodological procedures

The Social Network Analysis (SNA) was adopted in this study to analyze the interaction networks among research groups, which integrate Rio Grande do Sul's regional health systems and organizations in general. In order to analyze the networks, data from the research groups released by the Directory of Research Groups of the National Council for Science and Technological Development's (DGP/CNPq) censuses 2010, 2014 and 2016[2] were used.

From the DGP/CNPq's dataset, a selection was made to consider only research groups in the health sciences area located in the state of Rio Grande do Sul and which informed interactions with at least one organization in the three censuses examined. This selection defines the sample of the present study (354 interactive groups in total, considering the three years analyzed. See Table 1). Those groups that establish interactions were then labeled according to the following criteria: 1) acronym of the group's institution of origin; 2) acronym of the area of knowledge[3]; and 3) number of groups in the same area of knowledge located in the same institution.

Afterward, the labels were checked for asymmetry among the three analyzed years, since some groups ceased to exist and others were created after 2010. As a result, the research groups' labels in 2014 and 2016 do not follow an uninterrupted numerical order, as occurred in 2010 and as can be seen in the networks' figures presented below.

Subsequently, labels for the organizations that interacted with the research groups were also created, considering: 1) an acronym of the organization's name; 2) the type of the organization (Association, College, Firm, Public Institution, University,

2 Last census available. Data from the DGP/CNPq's censuses are reported biannually, except for 2012, when there was no census, as informed at: http://lattes.cnpq.br/web/dgp/censos-realizados/.

3 The health sciences knowledge area consists of nine sub-areas. The following acronyms were created for these areas: *phed* for physical education; *nur* for nursing; *phar* for pharmacy; *pot* for physiotherapy and occupational therapy; *st* for speech therapy; *med* for medicine; *nut* for nutrition; *dent* for dentistry; and *ch* for collective health.

and Hospital)[4]; and 3) the location of the organization (Local (L) for organizations based in the Metropolitan Region of Porto Alegre (RMPA); Rio Grande do Sul (RS) for organizations based in the state, except for the ones in RMPA; Brazil (BR) for organizations located in the country, except for the ones in RS; and Foreign (F), for organizations from abroad. Lastly, the labels created for each census were used to set up quadratic matrices, necessary for data processing according to the SNA.

The Social Network Analysis (SNA) method was chosen for the network analysis because it allows the examination of interactions to go beyond the descriptive statistic of secondary data, providing a look into relevant indicators for the purpose of this study, such as density and centrality of the actors in the network. A dynamic study is carried out based on three networks (2010, 2014 and 2016).

The density (Δ) was calculated based on the following formula:

$$\Delta = \frac{2L}{g(g-1)} \quad (1)$$

where g is the number of nodes included in the graphic. The density interval of a graphic remains at 0 if there are no lines present (L = 0) and 1 if all possible lines are present (L = g(g - 1)/2) (WASSERMAN; FAUST, 1994).

To measure the *centrality degree*, we adopted a method developed by Freeman (FREEMAN, 1978). For this measuring, the central actors are the ones with the most connections to other actors in the network. The centrality degree (D^c) of a node is found by applying this formula:

$$D^c = \frac{di(g)}{(n-1)} \quad (2)$$

where $di(g)$ is the number of connections established by each actor; and $(n-1)$ is the number of total connections presented in the network minus 1. The result varies between 0 and 1 and informs how well a node is connected in terms of direct connections. This study used the central tendency measurement $\bar{x} = \frac{\sum ni}{g}$ indicated by Freeman (1978) to find the mean of the connections (the results are informed in Table 6).

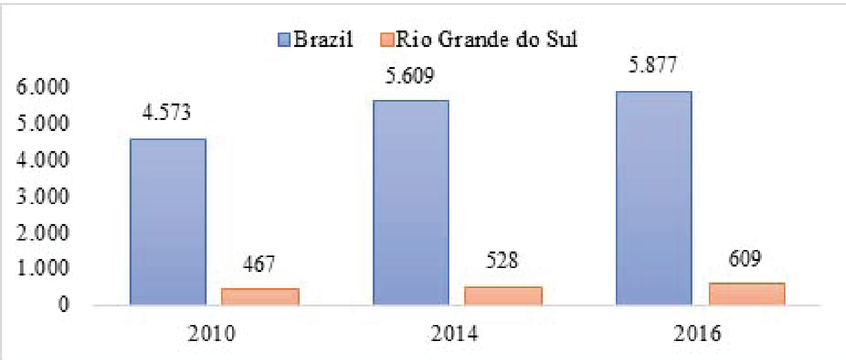
4 The Brazilian Ministry of Education classifies higher education institutions in categories. Colleges comprise a set of courses and academic activities within a specific branch of knowledge. Universities, on the other hand, encompass a set of colleges, which house activities related to different areas of knowledge in the same institution. In this paper, we adopt this classification.

Software Ucinet and Gephi were used. By using Ucinet[5], structure and position (density and centrality) measurements were extracted to help understand the networks' dynamics. This software offers a great number of analytical routines; among them, there is the routine to detect the central subgroups (whose results can be seen next in Table 7). Gephi[6], on the other hand, was applied specifically to visually explore the networks. It allows the user to better manipulate networks' forms and colors.

4. Results

Rio Grande do Sul occupies the third position among Brazilian states in the total number of research groups as well as in the number of health sciences groups. From 2010 to 2016, there is an important increase in the number of research groups in this knowledge area in Brazil and in Rio Grande do Sul (Figure 1). RS's participation in the total amount of groups in this area, however, remained relatively stable; in average, it represents 10% of Brazil's total. The state of São Paulo has the largest participation in total (Figure 2).

FIGURE 1
Total number of groups in the health area in Brazil and RS (2010, 2014, 2016)



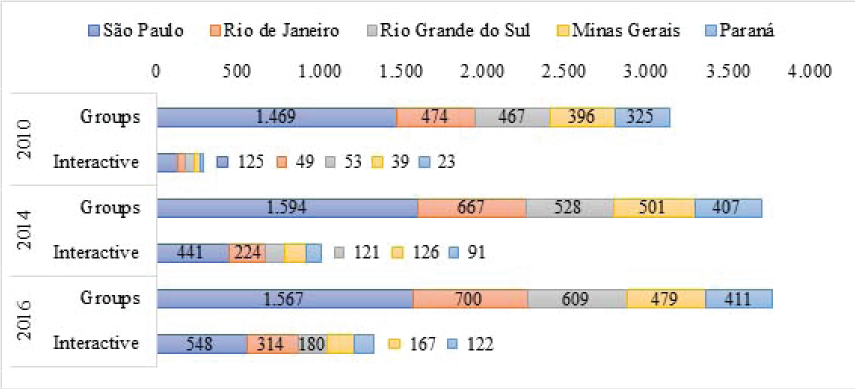
Source: DGP/CNPq's censuses 2010, 2014 and 2016.

RS is also in the third position regarding the number of research groups that inform partnerships with various organizations. Figure 2 allows a better visualization of this position.

5 https://sites.google.com/site/ucinetsoftware/home

6 https://gephi.org/

FIGURE 2
Total groups (and interactive groups) in the health sciences in Brazil and in the main states (2010, 2014, 2016)



Source: DGP/CNPq's tabular plane and censuses 2010, 2014 and 2016.

Regarding the interactive research groups in the health sciences area in RS, Table 1 shows the total number of such groups in the censuses used, as well as the number of organizations with which they interact. Lastly, on the third column of Table 1, information on the total of interactions established between research groups and organizations is presented. There was a significant increase in the number of groups that reported interactions with organizations and in the number of organizations and interactions over the period analyzed. Between 2010 and 2014, there was an 85% increase in interactions reported by research groups. Between 2014 and 2016, the increase was equivalent to 53%.[7]

On Figure 3, these interactive groups are distributed by their distinctive knowledge areas in the health sciences. The number of interactive groups in the medicine area was the most significant in all years, representing, in average, a little over a third of the total of interactive groups in the health sciences area. In the other knowledge areas, the number of groups in all years grew, except in speech therapy and nutrition.

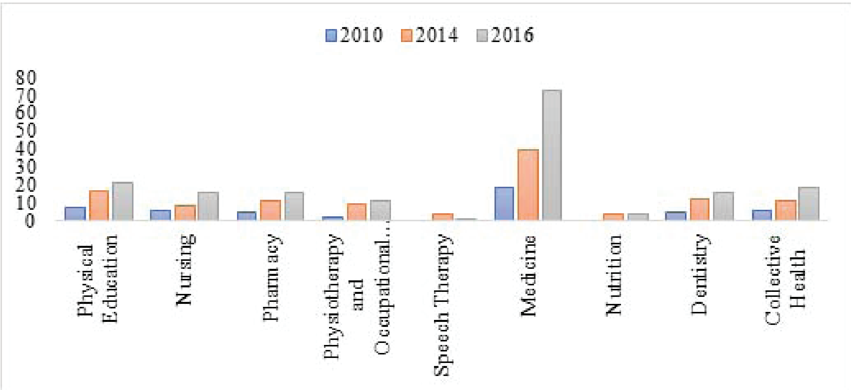
7 It is important to pay attention to a methodological aspect that helps to explain this significant increase in interactions. As of 2014, the question in the questionnaire answered by the group leaders regarding the partners with whom they interact has been modified. Until then, it was questioned whether there was interaction with the 'productive sector', which in most cases was understood by respondents as interaction with firms. As of 2014, the question was changed to regard interactions with partner organizations in a broader sense, which motivated the identification of partners in addition to firms. This is the case of universities as partners. Thus, academic cooperation, for example, has become more visible.

Table 1
General statistics for the health sciences in RS:
groups, interactions, and organizations (2010, 2014, 2016)

	Interactive groups	Interactive organizations	Interactions
2010	53	112	130
2014	121	150	240
2016	180	200	368

Source: DGP/CNPq's censuses 2010, 2014 and 2016.

FIGURE 3
Groups' distribution by knowledge area (2010, 2014, 2016)



Source: DGP/CNPq's censuses 2010, 2014 and 2016.

Table 2 informs the institutions where the groups are based as well as their location. Most groups are in universities, but not all. For example, there are groups situated in hospitals. Regarding the location of institutions that host the groups, although a greater number of institutions are located outside the Metropolitan Region of Porto Alegre (RMPA), the most interactive research groups are in RMPA. In this location, the most relevant institutions, in number of groups, are the Federal University of Rio Grande do Sul (UFRGS)[8] and the Pontifical Catholic University of Rio Grande do Sul (PUCRS). Together, they host, in average, 46% of all interactive

8 Tomassini (2017) analyses health knowledge production in Brazil based on research projects using Lattes Plataform's database. The author shows main network and subnetwork institutions with greater centrality degree and betweenness centrality. It is observed that the four institutions that present the greatest centrality degree and betweenness centrality are: University of São Paulo (USP), Federal University of Rio Grande do Sul (UFRGS), Oswaldo Cruz Foundation (FIOCRUZ) and State University of Rio de Janeiro (UERJ).

research groups in RS. Also, in RMPA, Porto Alegre Clinical Hospital (HCPA)[9] – UFRGS's teaching hospital – stands out because of the significant increase in the number of groups. Among other cities in RS, the number of groups per institution in relation to the total did not vary significantly in the period analyzed.

TABLE 2
Number of interactive groups per institution and location (2010, 2014, 2016)

	Entity	2010	2014	2016
RMPA	INEDI College	0	0	1
	HCPA (Porto Alegre Clinical Hospital)	3	10	18
	Conceição Hospital	0	0	1
	IBTEC (Brazilian Institute of Technology for Leather, Footwear, and Artifacts)	1	1	1
	IC-FUC (Institute of Cardiology)	2	1	3
	IPA (Methodist University Center – IPA)	0	2	2
	PUCRS (Pontifical Catholic University of Rio Grande do Sul)	8	12	26
	UFCSPA (Federal University of Health Sciences of Porto Alegre)	0	9	12
	UFRGS (Federal University of Rio Grande do Sul)	20	41	51
	ULBRA (Lutheran University of Brazil)	0	3	5
	UNISINOS (University of Vale do Rio dos Sinos)	0	1	2
Total groups in the Metropolitan Region of Porto Alegre (RMPA)		**34**	**80**	**122**
RS	FURG (Federal University of Rio Grande)	0	1	3
	ICCA (Institute of Cardiology of Cruz Alta)	0	0	1
	IFFar (Farroupilha Federal Institute)	0	0	1
	IMED College	0	2	3
	SETREM (Três de Maio Educational Society)	0	1	1
	UCPEL (Catholic University of Pelotas)	0	1	1
	UCS (University of Caxias do Sul)	2	4	5

(continued)

9 HCPA is considered as a national reference in university hospitals. This hospital is a model for management of university hospitals, playing an important role in the sphere of the National University Hospital Recovery Program. Since 2009, it was chosen by the Ministry of Education to transfer its management model to the other university hospitals.

TABLE 2
Number of interactive groups per institution and location (2010, 2014, 2016)
(continued)

	Entity	2010	2014	2016
RS	UFPEL (Federal University of Pelotas)	2	5	8
	UFSM (Federal University of Santa Maria)	3	8	12
	UNICRUZ (University of Cruz Alta)	4	4	4
	UNIFRA (Franciscan University Center)	2	3	4
	UNIJUI (Regional University of the Northwest of the State of Rio Grande do Sul)	1	2	2
	UNIPAMPA (Federal University of Pampa)	1	2	3
	UNISC (University of Santa Cruz do Sul)	1	1	1
	UNIVATES (University of Vale do Taquari)	0	1	4
	UPF (University of Passo Fundo)	3	3	4
	URCAMP (University of the Campaign Region)	0	1	0
	URI (Integrated Regional University of Alto Uruguai and Missões)	0	2	1
Total groups in Rio Grande do Sul (except RMPA)		**19**	**41**	**58**
Total groups		**53**	**121**	**180**

Source: DGP/CNPq's censuses 2010, 2014 and 2016.

Six types of organizations were identified as partners with which the research groups interacted: Association, College, Firm, Public Institution, University, and Hospital. Table 3 shows the types of partner organizations in the period analyzed. It is possible to see that firms and universities are the most common type of partners for the research groups. **Firms** stand out in all three censuses, while **Universities** do so only in 2014 and 2016.

If, on the one hand, from 2010 to the most recent years, there is a decrease of partner firms; on the other, in this same period, there is a significant increase of collaborating universities. In other words, research groups increasingly interact with researchers from other research and education institutions. Therefore, the University-University interaction becomes increasingly important for knowledge generation in health sciences research in the studied networks.[10]

10 It is worth mentioning again the highlight made in footnote 7.

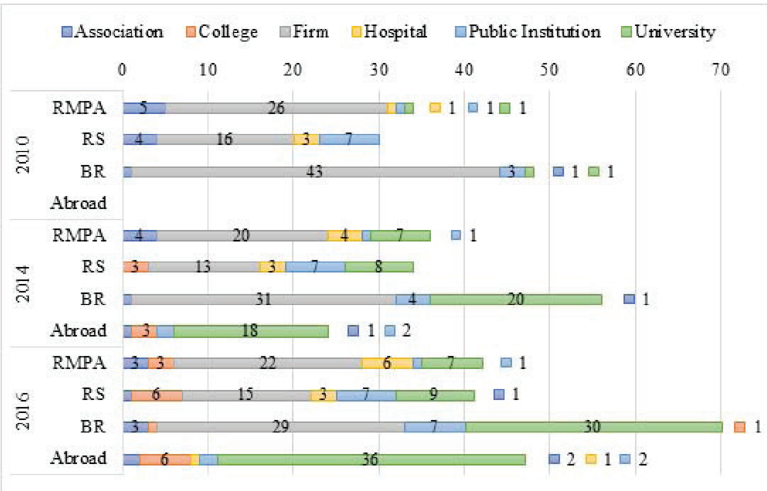
TABLE 3
Organizations by type (2010, 2014, 2016)

	2010	2014	2016
Association	10	6	9
College	0	6	16
Firm	85	64	66
Hospital	4	7	10
Public Institution	11	14	17
University	2	53	82
Number of organizations	112	150	200

Source: DGP/CNPq's censuses 2010, 2014 and 2016.

As it can be seen in Figure 4, in the three years inspected, the partner organizations are mostly located in Brazil. In 2010, 2014 and 2016, firms, which have an important role, are located, by order of significance, in Brazil, in the Metropolitan Region of Porto Alegre and in RS. It is worth mentioning the fact that, when considering the sum of firms in RMPA and in other cities in the state, RS comprises approximately 50% of all firms. The rest is situated in other Brazilian regions. There are no interactions reported with firms located abroad.

FIGURE 4
Distribution of organizations by location (2010, 2014, 2016)



Source: DGP/CNPq's censuses 2010, 2014 and 2016.

Foreign countries only appear as *loci* for organizations in 2014[11], gaining even more prominence in 2016. It is interesting to notice that the "Foreign" location concentrates 24% of the partners in 2016 – the second most relevant location. In this last year, most of the partners (18%) are characterized as foreign universities.

Table 4 shows the classification of the organizations by their economic activity. Data were obtained for 2010, 2014 and 2016 and reinforce the considerations made so far. The participation of organizations classified as "Education" varied significantly over the three years consulted. In 2010, such organizations represented only 4% of the total. In 2016, however, this number had increased to 47%. Regarding organizations labeled as manufacturing industry, there is a decrease both in absolute numbers and in its relative participation in the three censuses.

TABLE 4
Organizations by economic activity (2010, 2014, 2016)

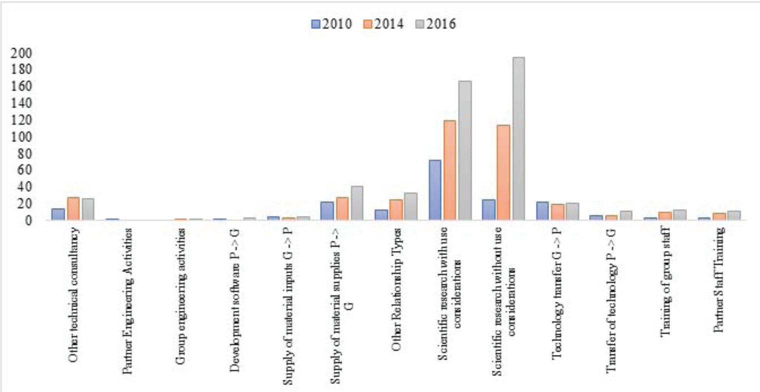
National Classification of Economic Activities (CNAE)	2010	2014	2016
Public administration, defense, and social security	9	10	11
Agriculture, livestock, forestry, fishing, and aquaculture	1	1	1
Professional, scientific and technical activities	5	2	4
Commerce; repair of motor vehicles and motorcycles	9	11	9
Construction	1	0	1
Education	5	60	94
Manufacturing industry	59	41	39
Information and communication	1	0	0
Other services	2	4	4
Health care and social services	20	18	22
Unclassified	0	3	15
Total	**112**	**150**	**200**

Source: DGP/CNPq's censuses 2010, 2014 and 2016.

11 It is important to observe that, according to information regarding the DGP's censuses, it was only in 2014 that the following information was incorporated: participation of groups in research networks, egress, foreign collaborators, equipment, and software.

In the three years examined, thirteen types of relationships[12] established between research groups and organizations were identified. Figure 5 shows the information regarding the informed frequency of such types of relationship in 2010, 2014 and 2016. In the first two censuses, the most informed type of relationship with organizations was "scientific research focused on the immediate use of results". In 2016, the most recurrent relationship was "scientific research not focused on the immediate use of results". In all censuses, "engineering activities" and "development of non-routine software" were the least frequent types of relationship.

FIGURE 5
Frequency of type of relationship (2010, 2014, 2016)



Source: Elaborated by the authors based on DGP/CNPq's censuses 2010, 2014 and 2016.

Regarding UFRGS, since it is the institution that hosts most health research groups in RS, it is worth describing the characteristics of the organizations with which their groups interact. As it can be seen in Table 5, most of the partners are in Brazil. A significant part of these are in RMPA. Among the types of partner organizations that predominate are universities and firms. By 2016, 35 partners were other universities and 14 were firms.

12 1) Technical consultancy activities not included in any of the other categories; 2) Non-routine engineering activities including the development of prototype, first unit of the series or pilot project for the partner; 3) Non-routine engineering activities including the development/manufacture of equipment for the group; 4) Development of non-routine software for the group by the partner; 5) Supply, by the group, of material inputs to the activities of the partner with no connections to a specific project of mutual interest; 6) Supply, by the partner, of material inputs to the group's research activities with no connections to a specific project of mutual interest; 7) Other predominant types of relationships that do not fit into any of the other types; 8) Scientific research focused on the immediate use of results; 9) Scientific research not focused on the immediate use of results; 10) Transfer of technology developed by the group to the partner; 11) Transfer of technology developed by the partner to the group; 12) Staff training of the group by the partner, including courses and in-service training; 13) Staff training of the partner by the group, including courses and in-service training.

TABLE 5
Location of UFRGS's partner organizations (2010, 2014, 2016)

	2010	2014	2016
Local	16	19	21
Regional	1	4	6
National	8	16	26
International	-	13	14
Number of organizations	**25**	**52**	**67**

Source: DGP/CNPq's censuses 2010, 2014 and 2016.

Next, to better qualify the actors and their interactions, results are presented based on the SNA. The networks – Figures 6, 7 and 8 – represent the interactions among the research groups and their partners for the three years studied (2010, 2014 and 2016). The 'nodes' that appear in the networks indicate the actors that compose them and the lines connecting these nodes represent the interactions. All existing connections (in- and out-degree) are taken into consideration, which enables the description of both actors that inform interactions (the research groups) and their partners (universities, firms, hospitals, etc.). The gray nodes represent the research groups and the colorful ones represent their partners. The nodes colored yellow represent public institutions; the green ones, the firms; purple represents universities; black represents associations; blue represents colleges; and red represents hospitals. The larger the size of the node, the higher the number of this actor's interactions (indicating its larger centrality in the network).

Comparing the figures, it is possible to perceive that, throughout the years, networks include more nodes/actors (which statistical data described previously had already shown). Although there is an increase in the total number of actors, it does not mean that all of them are necessarily interconnected.

Below, based on the social network methodology and on the calculus of indicators, it is possible to qualify this analysis and better understand the characteristics of knowledge generation networks in the health area studied here. Table 6 presents the indicators.

FIGURE 6
Network of Interactions, 2010

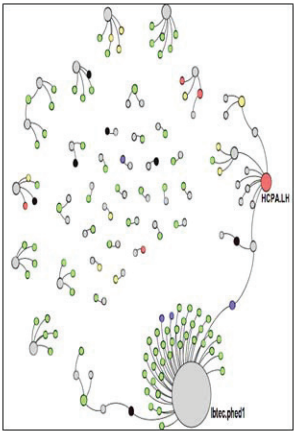


FIGURE 7
Network of Interactions, 2014

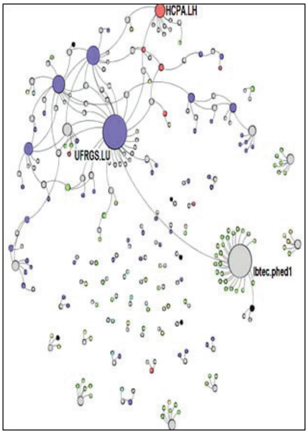
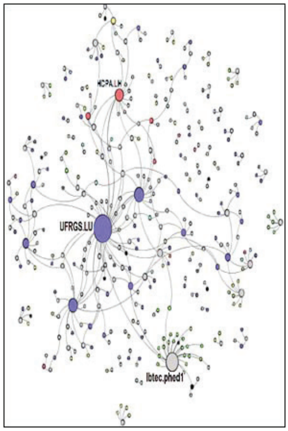


FIGURE 8
Network of Interactions, 2016



Source: DGP's data from 2010 with Gephi 0.9.2.
Legend: **Research Group** ◯ **Partner Organizations by color**: Public Institution ◯ | Firm ◯| University ◯ | Association ● | College ◯ | Hospital ◯

TABLE 6
Indicators of networks' structure and position

Network index	2010	2014	2016
Density			
Mean	0.005	0.003	0.003
Std deviation	0.068	0.057	0.050
Centrality degree			
Freeman's method (Mean)	0.788	0.885	0.968

Source: Data from DGP/CNPq's censuses 2010, 2014 and 2016 with Ucinet

Regarding structure indicators, 'density' is defined by the sum of all existing connections, divided by the theoretical number of possible connections. In the case of the 2010 network, the density was 0.005, stating that 0.5% of possible connections are present in the network. In 2014 and 2016, this indicator revealed even less dense networks, i.e. 0.003 (0.3% of the possible connections are present). Also, there are actors with different behaviors in terms of number of interactions. This is due to the relatively high values (higher than one unit of mean) of this indicator's standard deviation. This indicator reveals that, despite the increase in the number of actors and interactions over time in the networks, this was not enough to make the network denser. That is because most actors report having only one interaction with another actor. In other words, it is possible to state that, due to the increase in the number of actors, there was an increase in the interactions' potential; however, it is verified that, in fact, the new actors entering the network connect with one or few actors. Therefore, there is an increase in the volume of nodes, but not in the density of the interactions. In the Figures, this becomes explicit when we observe the most peripheral group.

We also calculated the centrality degree. As described in the methodology section, we used the measuring of central tendency indicated by Freeman (1978) to find the mean of the connections. We verified that, in average, actors present 0.79 centrality in 2010, 0.88 in 2014, and 0.97 in 2016. This indicates that, in average, there is one connection or less per actor. Thus, the networks have more interaction than interactive actors, featuring the characteristic of interaction dilution in networks. This result corroborates the characteristic of interaction dispersion in the networks already reported by the other indicator analyzed. The results of standard deviation allow us to notice that in each network examined there are actors with different node sizes, which reflects distinct centrality degrees.

Analyzing the different node sizes in the Figures, we also identify their different positions in the network. The size of each node informs how many interactions it has; the greater its size, the higher the number of interactions it has in the network. Large nodes are central, and small nodes constitute the periphery of the network.

As it is possible to observe, there is an important actor in terms of centrality in all three Figures. That is the research group 'IBTEC.phe1'. This group, entitled 'Biomechanics of Footwear', belongs to the Brazilian Institute of Technology for Leather, Footwear and Artifacts (IBTEC).

It is true that, even though this actor is present in the networks for the three years, it loses centrality in more recent periods. This is made clear by the loss in its node size, as well as the number of connections.

In Table 7, we present precisely these scores per actor. The connections' normalized data are presented in the aims of better identifying the networks' central actors. This normalization is necessary due to the distinct size of the three networks.

The Table shows that a small group of actors (five to be more precise) correspond to approximately one third of all connections, indicating its important role in the networks' dynamic over the years.

As it is possible to observe, the actor 'IBTEC.phe1' is present in the years 2010, 2014 and 2016 with, respectively, 23.5%, 12.5% and 10.3% of connections in the network.

TABLE 7
Normalized centrality degree measures (actor score)

Groups - 2010	Normalized degree (%)	Groups - 2014	Normalized degree(%)	Groups - 2016	Normalized degree(%)
IBTEC.phed1	23.5	IBTEC.phed1	12.5	UFRGS.LU	10.3
HCPA.LH	4.8	UFRGS.LU	8.0	IBTEC.phed1	6.6
UFSM.phar1	3.6	UFSM.RSU	5.0	UFCSPA.LU	4.7
UNICRUZch1	3.0	UFCSPA.LU	4.5	UFSM.RSU	4.5
UNISC.pot1	3.0	HCPA.LH	3.5	HCPA.LH	4.0
Network reached	**38.0**	**Network reached**	**33.5**	**Network reached**	**30.0**

Source: DGP/CNPq's data with Ucinet.

Besides IBTEC, another actor that is prominent for these three years is Porto Alegre Clinical Hospital (HCPA.LH), UFRGS's teaching hospital. The hospital appears as an important partner to research groups. The university itself (UFRGS. LU) is also prominent, especially for the years 2014 and 2016, since it corresponds, respectively, to 8% and 10.3% of all connections. It is also worth highlighting that both HCPA and UFRGS gain centrality as research groups' partners, while IBTEC. phed1 does so as a research group. It is possible to check this information observing both the color of the nodes and the acronyms here employed.

Other relevant features emerge when networks are analyzed according to the geographical location of their actors. Figures 9, 10 and 11 highlight this attribute in the networks.

As it can be observed, the predominant geographic location of the actors in the networks is 'local'. It should be noted that such local actors are in a central position in the network. This can be observed by the predominance of large and medium-sized aqua green colored nodes. The actors located in RS and Brazil follow up. The international actors, identified by the color black, only enter the network in 2014. Such foreign actors interact fairly with the group of larger nodes (which are those with the highest number of interactions). Therefore, it can be implied that networks will become more complex over time due to the entry of more actors with different positions in the network and different geographic locations.

FIGURE 9
Geographic location network, 2010

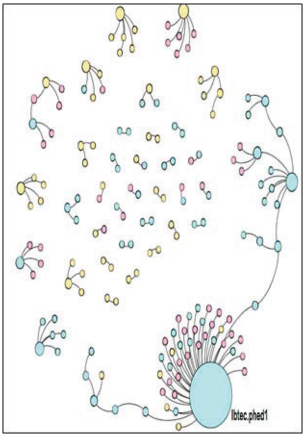


FIGURE 10
Geographic location network, 2014

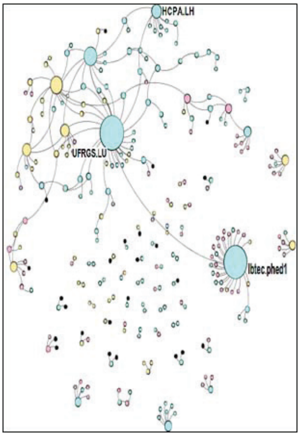
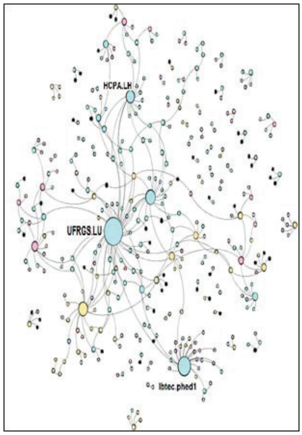


FIGURE 11
Geographic location network, 2016



Source: DGP's data from 2010 with Gephi 0.9.2.

Legend: **Location:** Local (L) | State of Rio Grande do Sul (RS) | Brazil (BR) | Foreign (F)

5. Results discussion

As pointed out by the literature, it was possible to verify the presence of multiple actors in the networks analyzed in this paper. We also observed, by analyzing the networks' evolution over the years, that they have an increasing number of actors. The number of research groups in the health area has increased and they have significantly expanded their partnerships since 2010. Such findings reinforce, as pointed out by the literature, that collective efforts are increasingly evident and necessary for advances in science and innovations.

Universities are key actors in the networks examined and gain prominence over the years. They are both research groups' main locus and investigation partners. Besides, they are also central in the networks. Such results corroborate the literature that also reinforces that the complexification of knowledge leads to an increase in collaborations with this type of actor. This is also observed in the present study, given the evolution of partnerships with universities. Over the years analyzed in this study, there was an expressive increase in partner universities.

This conclusion also corroborates the findings of other studies in which university-university interaction (groups-groups/researchers-researchers) is key to generating knowledge in the health sciences field. Nelson *et al.* (2011), for example, indicate the existence of multipath ways and mechanisms involved in the evolution of medical knowledge and medical practice. The interactions identified between universities reveal one of these paths to medical progress: scientific advances, responsible for a better understanding of the human body and the diseases' pathologies.

Regarding the universities as *loci* of research groups, UFRGS stands out: this university had 51 research groups in 2016, which represents 28% of all research groups with interactions in the health sciences area in RS. These groups interacted with 67 organizations in this year (35 were universities). Most of them are in Brazil. UFRGS also gains prominence as an important partner for other institutions' research groups. All these findings point out to this university's important role in RS's health innovative system.

Another actor that is part of RS's technological and scientific infrastructure is the laboratory IBTEC. This laboratory's research group (IBTEC.phe1) is, as we have seen so far, a central actor in the three analyzed periods. The prominence of this actor reveals a particular characteristic of RS's human health system. It is an actor whose specialty is the physical education area. Different private firms from the footwear sector of Vale do Rio dos Sinos region demand the services of IBTEC. These findings are in line with the literature that characterizes this region as an important shoe-producing cluster of Brazil.

Still regarding the prominent actors in the networks, we observed that hospitals, even though they are not as expressive in numbers as other actors, are central in the network. This is the case of HCPA, UFRGS's teaching hospital. Such finding agrees with what the literature that emphasizes the relevance of health services in knowledge and innovation generation networks in this research field has proposed. This literature highlights the important role of hospitals, especially the university ones, given that these work as means among different domains and knowledge sources, such as scientific, clinical, technical and commercial (DJELLAL; GALLOUJ, 2005; WINDRUM; GARCÍA-GOÑI, 2008; NELSON *et al.*, 2011; THUNE; MINA, 2016).

Firms, on the other hand, pointed out by the literature as important agents in the processes of knowledge application and innovation generation, are frequent partners of the research groups analyzed in this study. The number of firms, in absolute terms, is significant in the networks studied in this paper. However, their participation has decreased since 2010. Besides, in all years studied, they appear as peripheral actors in the networks (see green nodes in Figures 6, 7 and 8, as well as the lack of presence of firms among the main central actors, according to Table 7).

Thus, this study's findings indicate that, even though in the health field the relation between science and technological knowledge may be narrow, as pointed out by international literature based on the reality of developed economies, in the case investigated here, this is not evidenced.

As to the specifics of emerging countries, these results reiterate and complement the literature on the university-industry interactions in Brazil. Several studies point to the fact that these relations are still scarce in the country's scientific and technological scenario.

Regarding the type of relationship between actors in the networks, it is verified that, over the years, the partners tend to become more research-oriented. That is so precisely due to the significant increase, already emphasized in partnerships between universities (U-U). In 2016, the most prominent type of relation was "Scientific research not focused on the immediate use of results"; which is related to the partners' profile previously described. This type of interaction usually implies bidirectional knowledge and information flows. Therefore, the actors involved present similar absorptive capacity.

On the other hand, in the first two censuses, the most informed type of relationship with organizations was "Scientific research focused on the immediate use of results"; which may be explained by a greater participation of firms as partner organizations in 2010 and 2014 in comparison to 2016. Nevertheless, in all censuses, "Engineering activities" and "Development of non-routine software" were the least frequent types of relationship, which are related to technology development and diffusion. Also, the relationships that involve technology transfer were not very usual over the years analyzed. All these findings lead us to believe that collaborations have evolved in a way to focus more on stages of science development and less on the creation of technologies. This result indicates that, over time, the actors changed, such as discussed by Powell *et al.* (2005). Such change may occur due to some disruption that the innovation support policies, held in the period of 2004-14, have suffered, in which one of the focuses was the university-industry interaction. Such discussion, however, is not part of this study's scope, but still deserves some attention in future studies that aim to understand the influence of public innovation policies in these collaborations.

In regards to the location of partner organizations, we observed that the geographical proximity is a critical factor in interactions. It was identified that, in 2016, 41.5% of all organizations with which the groups interact are in RS. As previously mentioned, according to Cooke (1998), Asheim and Gertler (2006), Asheim, Smith and Oughton (2011) and other authors on 'geography of innovation', such as Boschma (2005), Feldman and Kogler (2010) and Garcia (2017), the interactions are facilitated by territorial proximity.

Geographical proximity, however, as highlighted by several authors and mentioned previously, may be replaced or complemented by other types of proximity (BOSCHMA, 2005; KONOBEN; OERLEMANS, 2006; PONDS; OORT; FRENKEN, 2007; BROEKEL; BOSCHMA, 2012; GARCIA, 2017); which was also identified in the present paper.

When we observe the partnerships with firms, it is possible to verify that almost 50% of partner firms are located in RS, which indicates that the geographical proximity may be an explanatory factor for this type of collaboration. On the other hand, the geographical proximity does not seem to be a condition for the occurrence of collaborations with universities. That is so because, in 2016, around 80% of these partners were not located in RS, and among these, more than 40% were located abroad. This reality leads us to suppose that, in the case of university-university interactions, other types of proximity, such as cognitive and organizational, may better explain their establishments. Several authors highlight that the common codebook facilitates academic collaboration.

Ponds, Oort and Frenken (2007) found similar results when they analyzed the case of science-based sectors in the Netherlands. They conclude that geographical proximity is more important for collaboration between academic and non-academic organizations than for academic collaboration. According to the authors, this type of proximity facilitates the collaboration between organizations with different socio-economic structures.

Regarding the university-industry interactions identified in this study, it is possible to verify, based on the literature, that the geographical proximity helps deal with a possible cognitive hiatus (BOSCHMA, 2005; PONDS; OORT; FRENKEN, 2007). Such hypothesis seems to make sense regarding the reality of emerging countries like Brazil, where firms usually present low absorptive capacity. Such characteristic may lead to cognitive distancing compared to the universities, which may hinder communication and learning between them. As collaborations require a proximity level, such distancing may help explain the frailty of university-industry interactions. Ultimately, if the characteristics identified in the networks analyzed by the present study, on the one hand, allow us to make such suppositions, which corroborate those mentioned in the literature; on the other, they need to be better investigated in future studies.

6. Final considerations

This paper's objective was to analyze the features of interaction networks among research groups and other organizations in the health sector in Brazil, especially regarding key actors and their locations. To do so, Rio Grande do Sul was the case examined. A longitudinal analysis was performed, evaluating the variations of the networks' characteristics over time.

This analysis contributes to the literature in two main aspects. First, the study reveals important characteristics of collaboration networks in the human health area, a subject not very-well explored in Brazil, which helps to better understand the knowledge network dynamics in this area. In general, it contributes with studies on network formation in the area of evolutionary approach. Second, it allows us to identify specificities of the interaction networks' dynamic in emerging countries.

It was found that, in general, the groups interact with few partners despite the innumerable opportunities that are presented in the network. That means it is necessary to enlarge the flows for knowledge exchange in a bidirectional way to articulate the actors and organizations in order to improve the health and national innovation systems. Thus, public policy actions must seek to promote such articulations.

Public policy also has a key role in strengthening and expanding the country's technological and scientific research infrastructure. Regarding the statement on collective efforts being increasingly evident and necessary for science and innovation advances, it is not possible to simply do without a robust infrastructure. Therefore, so that RS and Brazil are able to advance technologically, science and technology promotion policies must have a strategic character and be supported by a significant amount of resources.

Finally, it is worth mentioning that there are, based on this paper's findings, interesting points to be further explored in future studies. It is essential to better identify the reasons that facilitate and hinder collaborations between research groups and organizations. Qualitative studies based on empirical research may help in this direction. Studies of this nature allow an in-depth understanding of the functioning of research groups, as well as of other actors interacting in networks. Another path to follow in future studies is to explore combinations of DGP/CNPq with other databases, such as the ones on scientific papers and patents, so as to expand the networks' analysis in terms of performance in technological and scientific production.

References

ALBUQUERQUE, E.M.; CASSIOLATO, J.E. As Especificidades do Sistema de Inovação do Setor Saúde. *Revista de Economia Política***,** v. 22, n. 4 (88), out.-dez. 2002.

ALVES, N.G.; VARGAS, M.A.; BRITTO, J.N.P. Interações universidade-empresa: um estudo exploratório sobre as empresas de biotecnologia em saúde. *Econômica*, Niterói, v. 20, n. 1, p.31-60, jun. 2018.

ARCHIBUGI, D.; FILIPPETTI, A. *The Handbook of Global Science, Technology, and Innovation.* UK: Wiley Balckwell, 2015. p. 1-11.

ASHEIM, B.; GERTLER, M.S. The geography of innovation: regional innovation systems. *In*: FAGERBERG, J.; MOWERY, D.C. *The Oxford Handbook of Innovation*, Oxford University Press, Oxford, 2006.

ASHEIM, B.; SMITH, H.; OUGHTON, C. Regional Innovation Systems: Theory, Empirics and Policy. *Regional Studies*, v. 45, n. 7, p. 875-891, 2011.

BARBOSA, P.R; GADELHA, C.A.G. O papel dos hospitais na dinâmica de inovação em saúde. *Revista de Saúde Pública,* v. 46, n. 1, p. 68-75, 2012.

BOSCHMA, R. Proximity and Innovation: A Critical Assessment. *Regional Studies,* v. 39, n. 1, p. 61-74, 2005.

BOTELHO, M.R.A.; TATSCH, A.L. Health services and Innovation in Brazil: an analysis based on teaching and research hospitals in Rio Grande do Sul and Minas Gerais. *In*: CASSIOLATO, J.E.; SOARES, M.C.C. (org.). *Health innovation systems, equity and development.* 1. ed. Rio de Janeiro: E-papers, 2015. p. 355-381.

BRASIL. Conselho Nacional de Desenvolvimento Científico e Tecnológico. *Censo 2010*. Disponível em: http://lattes.cnpq.br/web/dgp. Acesso em: 04 de março de 2019.

BRASIL. Conselho Nacional de Desenvolvimento Científico e Tecnológico. *Censo 2014*. Disponível em: http://lattes.cnpq.br/web/dgp. Acesso em: 04 de março de 2019.

BRASIL. Conselho Nacional de Desenvolvimento Científico e Tecnológico. *Censo 2016*. Disponível em: http://lattes.cnpq.br/web/dgp. Acesso em: 04 de março de 2019.

BRITTO, J.; VARGAS, M.A.; GADELHA, C.A.G.; COSTA, L.S. Competências científico-tecnológicas e cooperação universidade-empresa na saúde. *Revista de Saúde Pública*, v. 46, n. 1, p. 41-50, 2012.

BROEKEL, T.; BOSCHMA, R. Knowledge networks in Dutch aviation industry: the proximity paradox. *Journal of Economic Geography*, v. 12, n. 2, p. 409-433, 2012. https://doi.org/10.1093/jeg/lbr010.

CALIARI, T.; RAPINI, M. A Infraestrutura Científica em Saúde. *In:* DE NEGRI, F.; SQUEEF, F. (org.) *Sistemas Setoriais de Inovação e Infraestrutura de Pesquisa no Brasil*. Brasília: IPEA, 2016 p. 115-168.

CHAVES, C.V.; ALBUQUERQUE, E.M. Desconexão no sistema de inovação do setor saúde: uma avaliação preliminar do caso brasileiro a partir de estatísticas de patentes e artigos. *Revista de Economia Aplicada,* v. 10, n. 4, p. 523-539, 2006.

CONSOLI, D.; MINA, A. An evolutionary perspective on health innovation systems. *Journal of Evolutionary Economics*, v. 19, n. 2, p. 297-319, 2009.

COOKE, P. Introduction: origins of the concept. *In*: BRACZYK, H.-J.; COOKE, P.; HEIDENREICH, M. (ed.). *Regional Innovation Systems*. London: UCL Press, 1998. p 2-25.

DJELLAL, F.; GALLOUJ, F. Mapping innovation dynamics in hospitals. *Research Policy*, v. 34, n. 6, p. 817-835, 2005.

ETZKOWITZ, H.; LEYDESDORFF, L. The dynamics of innovation: from national systems and "mode 2" to a triple helix of university-industry-government relations. *Research Policy*, v. 29, n. 2, p. 109-123, 2000.

FELDMAN, M.; KOGLER, D.F. Stylized Facts in the Geography of Innovation. *In*: HALL, B.H; ROSEMBERG, N. (ed.). *Handbook in Economics of Innovation.* UK: Elsevier, 2010. p. 381-404.

FREEMAN, L.C. Centrality in social networks conceptual clarification. *Social Networks,* v. 1, n. 3, p. 215-239, 1978.

GARCIA, R. Geografia da Inovação. *In*: RAPINI, M.; SILVA, L.; ALBUQUERQUE, E. (org.). *Economia da Ciência, Tecnologia e Inovação:* Fundamentos teóricos e a economia global. Curitiba: Ed. Prismas, 2017. p. 241-275.

GELIJNS, A.C.; ROSENBERG, N. The changing nature of medical technology development. *In*: ROSEMBERG, N.; GELIJNS, A.C.; DAWKINS, H. *Sources of medical technology:* universities and industry. Washington: National Academy Press, 1995.

HANLIN, R.; ANDERSEN, M.H. Health Systems Strengthening. Rethinking the role of innovation. *Globelics Thematic Report 2016*. Denmark: Aalborg University Press, 2016.

KNOBEN, J.; OERLEMANS, L.A.G. Proximity and inter-organizational collaboration: A literature review *International Journal of Management Reviews*, v. 8, n. 2, p. 71-89, 2006.

LAMBERTY, M. *O sistema de inovação em saúde:* um estudo sobre as empresas industriais de equipamentos médicos, hospitalares e odontológicos gaúchas. 2014. Dissertação (Mestrado em Economia) – Universidade do Vale do Rio dos Sinos, São Leopoldo, 2014.

LUNDVALL, B-Å. Innovation as an interactive process: from user-producer interaction to the national system of innovation. *In*: DOSI, G. *et al.* (ed.). *Technical change and economic theory.* London: Pinter, 1988. p. 349-369.

LUNDVALL, B-Å. (ed.). *National innovation systems*: towards a theory of innovation and interactive learning. London: Pinter, 1992.

FELDMAN, M.; KOGLER, D.F. Stylized Facts in the Geography of Innovation. *In*: HALL, B.H; ROSEMBERG, N. *Handbook in Economics of Innovation* (ed.). UK: Elsevier, 2010. p. 381-404.

METCALFE, J.S; JAMES, A.; MINA, A. Emergent innovation systems and the delivery of clinical services: The case of intra-ocular lenses. *Research Policy*, v. 34, p. 1283-1304, 2005.

MINA, A. *et al.* Mapping evolutionary trajectories: Applications to the growth and transformation of medical knowledge. *Research Policy,* v. 36, p. 789-806, 2007.

MORLACCHI, P.; NELSON, R.R. How medical practice evolves: Learning to treat failing hearts with an implantable device. *Research Policy*, v. 40, n. 4, p. 511-525, 2011.

MOWERY, D.C.; SAMPAT, B.N. Universities in National Innovation Systems. *In*: FAGERBERG, J.; MOWERY, D.C.; NELSON, R.R. (org.). *The Oxford Handbook of innovation*. Oxford: Oxford University Press, 2006.

NELSON, R.R. *et al.* How medical know-how progresses. *Research Policy,* v. 40, n. 10, p. 1339-1344, 2011.

OLECHNICKA, A.; PLOSZAJ, A.; CELIŃSKA-JANOWICZ, D. *The Geography of Scientific Collaboration.* London and New York: Routledge, 2019. p. 27-60.

PARANHOS, J.; HASENCLEVER, L. The Relevance of Industry-University Relationship for the Brazilian Pharmaceutical System of Innovation. *In*: PYKA, A.; FONSECA, M.G.D. (ed.). *Catching Up, Spillovers and Innovation Networks in a Schumpeterian Perspective*. Stuttgart: Springer-Verlag Berlin Heidelberg, 2011.

PARANHOS, J. *et al*. Industry-university interaction strategies of large Brazilian pharmaceutical companies. *Management Research: Journal of the Iberoamerican Academy of Management,* v. 17, n. 4, p. 494-509, 2019.

PONDS, R.; OORT, F.; FRENKEN, K. The geographical and institutional proximity of research collaboration. *Papers in Regional Science,* v. 86, n. 3, p. 423-443, 2007.

POWELL, W.W.; KOPUT, K.W.; WHITE, D.R.; OWEN-SMITH, J. Network Dynamics and Field Evolution: The Growth of Interorganizational Collaboration in the Life Sciences. *American Journal of Sociology*, v. 110, n. 4, p. 1132-1205, 2005.

RAPINI, M.S.; CHIARINI, T.; BITTENCOURT, P.F. University–firm interactions in Brazil: Beyond human resources and training missions. *Industry* & *Higher Education*, v. 29, n. 2, p. 111-127, 2015.

TATSCH, A.L. *O arranjo produtivo e inovativo de Porto Alegre voltado aos tratamentos cardiovasculares e oncológicos*. São Leopoldo, Centro de Gestão e Estudos Estratégicos (CGEE), Universidade do Vale do Rio dos Sinos, 2012. (Relatório de Pesquisa). Disponível em: http://www.redesist.ie.ufrj.br/images/projeto_saude/textos/Estados_Rio_Grande_do_Sul.pdf. Acesso em: 02 de março de 2020.

TATSCH, A.L.; BATISTI, V.; FRAGA, W.S. O sistema inovativo da saúde gaúcho: uma análise a partir do caso de Porto Alegre voltado aos tratamentos cardiovasculares e oncológicos. *In*: ENCONTRO NACIONAL DA ASSOCIAÇÃO BRASILEIRA DE ESTUDOS REGIONAIS E URBANOS – ENABER, 11., 2013, Foz do Iguaçu. *Anais* [...]. Foz do Iguaçu: Enaber, 2013.

TATSCH, A.L.; BOTELHO, M.R.A.; RUFFONI, J.; HORN, L.S. Geração de conhecimento na área da saúde humana. *Revista Brasileira de Inovação*, v. 18, n. 2, p. 249-270, 2019.

THUNE, T.; MINA, A. Hospitals as innovators in the health-care system: A literature review and research agenda. *Research Policy,* v. 45, n. 8, p. 1545-1557, 2016.

TOMASSINI, C. Interaction networks in research projects: what they can tell us about the dynamics of knowledge production and its link with Brazil's health system. *In*: GLOBELICS INTERNATIONAL CONFERENCE, 15., 2017, Atenas. *Anais* [...]. Atenas, 2017.

VIDOTTI, C.C.F.; CASTRO, L.L.C; CALIL, S.S. New drugs in Brazil: Do they meet Brazilian public health needs? *Revista Panamericana de Salud Publica*, v. 24, n. 1, p.36-45, 2008.

WASSERMAN, S.; FAUST, K. *Social Network Analysis*: Methods and Applications. Cambridge: Cambridge University Press, 1994.

WINDRUM, P.; GARCÍA-GOÑI, M. A neo-schumpeterian model of health services innovation. *Research Policy,* v. 37, n. 4, p. 649-672, 2008.

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