http://dx.doi.org/10.20396/rbi.v17i2.8649987

ARTIGO

Determinants of inventive collaborations in Brazilian interregional and international networks

*Raquel Coelho Reis**

*Eduardo Gonçalves*** https://orcid.org/0000-0003-2017-3454

*Juliana Gonçalves Taveira**** https://orcid.org/0000-0001-5487-8669

Received: 29 July 2017 Revised version: 29 November 2017 Accepted: 24 February 2018

ABSTRACT

The paper investigates the regional and structural determinants of the links in social networks of inventive collaboration among regions in Brazil. In order to do this, we make use of a patent applications database that registers collaborations among Brazilian inventors and Brazilian and foreign inventors. As possible determinants of the links in Brazilian co-patenting networks, we take into account variables that capture economic, technological, and demographic density aspects of Brazilian regions, as well as the topology structures of the nodes in the networks. The approach considers the Zero-inflated negative binomial (ZINB) model, which considers the absolute number of interregional links among inventors from different regions. The formation of interregional patenting links was found to have been positively affected by the number of internal links to the region, by the number of inventors, by university and business R&D capacity, and mainly by the degree of centrality of the region. In the case of international networks formed between Brazilian and foreign inventors, the links are positively affected only by R&D capacity, especially industrial, and by the degree of centrality. In addition, the degree of internationalization of a network seems to positively affect the establishment of interregional networks.

* Universidade Federal de Juiz de Fora (UFJF), Juiz de Fora (MG), Brasil. E-mail: raquelcoelhoreis@gmail.com.

** Universidade Federal de Juiz de Fora (UFJF), Juiz de Fora (MG), Brasil. E-mail: eduardo.goncalves@ufjf.edu.br.

*** Universidade Federal de Juiz de Fora (UFJF), Governador Valadares (MG), Brasil. E-mail: julianagtaveira@gmail.com.

KEYWORDS | Innovation Networks; Co-patenting Activity; Centrality; ZINB; REGIC

JEL CODES | O31; O33; L14; R10

Determinantes das colaborações inventivas nas redes brasileiras de copatenteamento inter-regional e internacional

RESUMO
O presente artigo objetiva investigar os determinantes regionais e estruturais do número de ligações entre regiões nas redes de colaborações inventivas brasileiras. Para tanto, utilizam-se dados de copatenteamento entre inventores brasileiros e entre brasileiros e estrangeiros. Como possíveis determinantes do número de ligações, consideram-se tanto os aspectos econômicos quanto os tecnológicos e de densidade demográfica das regiões, além das estruturas de ligações dos nós nas redes. A investigação é realizada com o modelo para dados de contagem, Binomial Negativo Inflado em Zeros (ZINB). Como principais resultados, contatou-se que a formação de laços inter-regionais de patenteamento é afetada positivamente pelo número de ligações internas à região, pela escala de inventores, pelo potencial de realizar P&D empresarial e universitário e, principalmente, pelo grau de centralidade da região. No caso das redes internacionais, realizadas entre inventores brasileiros e estrangeiros, os laços são positivamente afetados apenas por potencial de P&D, especialmente o empresarial, e grau de centralidade. Além disso, nota-se que o grau de internacionalização de uma rede afeta positivamente o estabelecimento de redes inter-regionais.

PALAVRAS-CHAVE | Redes de Inovação; Copatenteamento; Centralidade; ZINB; REGIC

CÓDIGOS-JEL | O31; O33; L14; R10

1. Introduction

Recent studies have questioned the relevance of spatial proximity in the occurrence of knowledge exchanges, highlighting the role of relational proximity. The interaction between agents in networks would be able to generate exchanges of information and knowledge that can lead to innovations, even over long distances (BOSCHMA, 2005; MAGGIONI; UBERTI, 2007; BRESCHI; CATALINI, 2010; GUAN et al., 2015). Social innovation networks are considered structures that can channel and spillover flows of technological knowledge among agents belonging to the same network (POWELL; OWEN-SMITH, 2004). If the agents of the network are located in different regions, such flows can benefit regions in different ways, raising the level of regional competitiveness (COOKE et al., 1997). In order to overcome technological barriers, networks develop and raise levels of local innovation (POOT et al., 2009), allowing for the acquisition of new technologies from developed countries (HERSTAD et al., 2014). In this sense, collaborations between distant regions within the same country and/or between countries form networks that function as channels of knowledge over long distances and between different nationalities (GUAN et al., 2015).

Thus, from the perspective of the networks of invention, it would be possible for other still very isolated Brazilian regions to actively participate in the innovation generation process. That is, through collaborations with more technologically developed regions, less innovative regions could overcome their technological barriers. However, what are the conditions of the regional economic structure and the characteristics of the network structure itself which explain the number of links that a region can establish with other regions in Brazil or with other countries in order to generate innovation? An understanding of the factors that lead regions to connect with agents and external regions can help in the formulation of regional and innovation policies in Brazil to promote development and innovation in backward regions and to mitigate technological distances between Brazilian regions and developed countries.

It should be noted that recent work on network analysis has been increasingly trying to incorporate the simultaneity of the influence of individual, local and relational issues in the investigation of innovation. Cassi and Plunket (2015) consider individuals (nodes) in distinct regions in their analysis, Grillitsch and Nilsson (2015) approach the subject from the perspective of firms (nodes) in different regions, while Guan et al. (2015) focus on network structures. However, there are no studies that investigate regional co-patenting networks from the perspective of regions like we do, incorporating characteristics of the nodes as the characteristics of the region. It is here that the present article differs from others, besides being an analysis of the Brazilian case. More specifically, the article investigates the determinants of the number of links among regions during the process of patenting technological activities in Brazil. For this, local aspects are considered in economic, technological, and population density terms, as well as the relevance of the node structure in the network for the occurrence of ties. Both the networks formed only by Brazilian inventors (interregional network) and those with the presence of foreigners (international network) are investigated. In methodological terms, the Zero Inflation Negative Binomial (ZINB) model is used because the dependent variable, the number of absolute connections, is a counting variable, and the data assume an over-dispersion condition and an excess of zeros.

In addition to this introduction, the paper is divided into four more sections. In the second, a literature review on invention networks and their role in technological knowledge spillovers is presented, in addition to the hypotheses to be tested. In the third section, we present the description of the empirical strategy used as well as the database and variables. In the fourth section, the results are presented and discussed. The final section presents the main results of the research and future possible extensions.

2. Networks and innovation

Networks are channels through which agents absorb external knowledge by connecting to other agents, and can thus constitute channels whereby diffusion of codified and tacit knowledge occurs (ROTHWELL et al., 1974). The transfer of tacit knowledge occurs because networks generate mutual trust among their members during the invention process, by sharing resources, knowledge, and common goals (GRANOVETTER, 1973, 2005). In addition, a positive relationship between innovation networks and innovative performance is assumed, since partnerships in inventions tend to incorporate more knowledge and thus generate more innovation (SINGH; FLEMING, 2010).

Efficiency in generating innovations is linked to the characteristics of the inventors, the place where they are inserted, and the networks they are part of in order to have access to various sources of knowledge. Proximity between agents facilitates the existence of knowledge exchange between them (AGRAWAL et al.,

2006) and reduces transaction and transportation costs (BRESCHI; CATALINI, 2010), tending to produce a dense social network (AUDRETSCH, 1998). However, social interactions arising from occasional business meetings, trade fairs and technical exhibitions, and scientific congresses, along with advances in information technology, enable social contacts between agents to be maintained and strengthened even over great geographic distances. This type of social closeness is known as relational (CASSI; PLUNKET, 2015). From the perspective of intentional knowledge transferences, relational and technological neighborhoods stand out as relevant for the generation of innovation (GRILLITSCH; NILSSON, 2015).

The relationship between both types of proximity, geographic and relational, may be complementary and is evidenced by local buzz and global pipelines. Local buzz is the process of local interaction between agents that share the same geographic space, allowing for the creation and sharing of knowledge. The agglomeration of companies, universities, inventors, and other agents creates externalities of knowledge that would be limited spatially. On the other hand, connections between distant agents in space, called global pipelines, can strengthen the local environment through access to new external sources of knowledge that cross the local boundaries (BATHELT et al., 2004; STORPER; VENABLES, 2004). Knowledge exchange channels spanning long distances can be seen by the presence of networks of collaborations, strategic alliances, temporary jobs, and global social networks in general (KNOBEN; OERLEMANS, 2006; POWELL et al., 1996).

When considering local buzz and global pipelines as complementary mechanisms of access to knowledge, the question arises as to whether regions with strong internal links among their inventors, i.e., with an intense local buzz process, also have intense external connections as a source of renewal of technological knowledge.

According to Granovetter (1973), a group of nodes connected together by strong ties form a cluster. However, strong links between agents may lead to a lower flow of new external knowledge, while weak links with agents outside the region may lead to new inventors and consequently new information (CAPALDO, 2007). Weak links connect agents, providing different information and promoting innovation in the network. Network interactions usually start with weak links and can evolve into stronger links (WU, 2012).

In the absence of external connections, networks with many internal links tend to make the knowledge of the region obsolete and redundant and may cause the region to suffer the negative effects of lock-in, a situation in which inventors successively create technologies of the same type, industrial structures (HASSINK, 2005). The spatial dimension of lock-in occurs when clusters become trapped in specific technologies (NARULA, 2002).

Therefore, in order to avoid this, agents belonging to regions (nodes) with dense internal links seek to participate in other networks, external to the region. In this way, they can acquire new knowledge to be used in overcoming local technological barriers and generating innovation. This allows us to formulate the following hypothesis of investigation *H1: Regions with many internal links also tend to have a higher number of collaborations with other regions.*

In addition to the number of internal links between inventors in the same region, the number of external links may be related to the total number of inventors that the region itself has. Bettencourt, Lobo and Strumsky (2007) find that the proportion of inventors in a metropolis is directly associated with local patent production. They also claim that the volume of patents in the metropolis is positively related to the connectivity in metropolitan networks of inventors. Therefore, it is assumed that the number of inventors in the region may be related to the regional capacity to absorb external knowledge. According to Marrocu et al. (2013), the ability of a region to absorb external knowledge is associated with the skills of its most educated individuals and high spending on research in the region. Thus, it can be assumed that *H2: The interaction between internal links and the number of inventors in the region increases the number of connections with other regions.*

It should be noted that collaborations with research institutions have been a means of improving and evolving innovation in recent years (POWELL et al., 1996). According to Lastres and Cassiolato (2009), innovation occurs through several types of collaborations between agents, and new policies are incentives to innovation aimed at promoting collaborations through R&D activities and consequently technological diffusion.

One justification for the existence of networks between universities and other research institutions and companies is the high cost of maintaining R&D. Therefore, partnerships with other organizations make research less costly and allow for complementary knowledge. The number of interregional links is therefore a direct function of regional research capacity, in this case, both business and university R&D.

As a result, invention networks can arise from partnerships in R&D activities, which bring the benefits of research investments to members, as well as the absorption of more sophisticated knowledge (ERNST, 1994). In addition, social and political conditions can facilitate links between groups of inventors, and there are competitive advantages to those who access relevant knowledge early. These advantages motivate joint research partnerships as a means of sharing ideas (POWELL; GIANNELLA, 2010). Thus, it is expected that the higher the level of R&D, the greater the number of links between the regions in the co-patenting networks, due to the existence of partnerships and inventive collaborations during the region's R&D production process. Thus, one can formulate the following hypothesis *H3: Regions with greater capacity to produce R&D have greater external inventive collaborations.*

In addition to the question of the structures of the regions where the inventors are inserted and the idea of geographical proximity, it is considered that the way in which the agents insert and position themselves in the network is relevant for the absorption and sharing of knowledge (PONDS et al., 2010). In network analysis, therefore, both geographic and relational issues must be analyzed.

From the relational perspective, some measures are used in empirical studies of co-patenting networks more often, such as density, centrality, and connectivity of nodes and links (BETTENCOURT; LOBO; STRUMSKY, 2007; BETTENCOURT et al., 2007; LOBO; STRUMSKY, 2008; MIGUELLÉZ; MORENO, 2013; HE; FALLAH, 2014). This perspective also investigates the relationship between the nodes, whether they are central or intermediate, and a consequent efficiency of knowledge spillovers derived or obtained by these nodes (BURT; TALMUD, 1993; GILSING et al., 2008). Intermediate agents, nodes between two or more subgroups in the networks, capture greater degrees of novelty and different knowledge (GILSING et al., 2008). Moreover, it is evident that the structures of the nodes impact knowledge flows, and networks with shorter and more clustered ties can spillover knowledge further and quickly without great loss of information (GRANOVETTER, 1985; BARABÁSI; ALBERT, 1999; EBEL et al., 2002; SEN et al., 2003; HE; FALLAH, 2014).

Agglomeration measures intend to incorporate the idea that more populated regions tend to promote greater interaction between its agents to facilitate face-to-face contacts and collaborations, which impact the innovation production process (STORPER; VENABLES, 2004; MORENO et al, 2005a, 2005b). Such a relationship of greater ease of interaction between agents may therefore attract new collaborations from other regions. This attraction can be identified by increasing the centrality of the nodes (regions), making them hubs for other knowledge flows and strengthening the network (MATOS, 2002; MATOS; BRAGA, 2002).

Centrality can influence performance in generating new links during the innovation generation process because central nodes function as a means of connecting adjacent nodes through weak loops (WASSERMAN; FAUST, 1994). It is noteworthy that core nodes influence innovation networks as they tend to incorporate greater knowledge flows when connecting to other nodes (ROXENHALL, 2013). These ideas allow us to formulate the last hypothesis – *H4: The greater the centrality of the node (region), the greater the number of inventive collaborations.*

3. Data description and empirical strategy

3.1. Database

The geographical unit of this analysis is the merge of Brazilian municipalities according to the concept of Regions of Influence of Brazilian Cities (REGIC). By including urban agglomerations and the influence of regions on others, the most disaggregated level of REGIC will be used so as to capture an urban-regional division of Brazilian economic polarization. This level of regional aggregation covers 482 regions of urban articulation, that is, areas of housing and population displacement. The data were collected at the municipality level and later summed up to the REGIC level through the identification of the municipal codes and corresponding REGIC, according to information from the Brazilian Institute of Geography and Statistics (IBGE).

The variables, number of links, patents, and inventors, were constructed from the patent database, made available by the National Institute of Intellectual Property (INPI), for the period 2000-2011.

Information on the number of employees, industrial characteristics of the region and workers who potentially develop innovative and R&D activities, called technical-scientific personnel (POTEC), come from RAIS, provided by the Ministry of Labor and Employment (MTE). According to Araújo et al. (2009), POTEC and R&D expenditures, both external and internal, have a high correlation, suggesting that this is an adequate proxy for measuring innovative effort.

Data for university R&D potential comes from the Coordination for the Improvement of Higher Education Personnel (CAPES). In this case, we consider data from academic staff with PhDs in higher education institutions in the areas of Engineering, Exact and Earth Sciences, Agrarian Sciences, Biological, and Health Sciences, which potentially create technologies to be transferred to the productive sector.

Imports of capital goods is measured as the volume of goods imported into Brazil in Real, based on the annual data of economic indicators and trade of the

Brazilian municipalities of the Secretariat of Foreign Trade (SECEX). Finally, data on population, economic production, and geographical area of the regions were extracted from IBGE.

3.2. Method of estimation

The main objective of this study is to analyze the determinants of the number of connections among regions in interregional and international co-patenting networks in Brazil. The present study analyzes the connections that occurred in the 482 Brazilian regions between the years 2001 to 2011. In the Brazilian case, the occurrence of two distinct types of networks can be seen: interregional co-patenting networks, corresponding to the links between Brazilian inventors located in different regions of the country; and international co-patenting networks, comprising links among Brazilian and foreign inventors.

As the number of connections between inventors in the network can assume counting variable characteristics, the best estimation model should be identified. When identifying counting data, i.e., assuming integer and non-negative values, the Poisson distribution model, which assumes the same mean and variance of the data, is usually applied. However, there are occasions when the variance is higher than the mean, that is, over-dispersion occurs.[1] In these cases, the Negative Binomial model is applied, which corrects the problem by adding a parameter of unobserved heterogeneity to the Poisson.

However, in cases with the presence of excess zeros, which generate bias in the results, the use of zero-inflated models is suggested. In this context, two models stand out: Zero Inflated Poisson (ZIP), and Zero Inflated Negative Binominal (ZINB). These assume two distributions. The first considers the distribution adjusted to integer values and greater than zero and the second the probability of occurrence of null values. The distributions of the ZINB and ZIP models treat the over-dispersion of the variance with the mean in a similar way (ZANIBONI; MONTINI, 2015); however, studies have found better results regarding the significance of the variables and statistics for ZINB estimations, when compared to ZIP (CARVALHO; LAVOR, 2008; ZANIBONI; MONTINI, 2015).

1 Over-dispersion may occur through the omission of unobserved variables, abundant zeros in the sample, high correlation between the data, and/or variability of the mean.

As possible determinants of the number of connections between regions, information on the local aspects of economic, technological infrastructure, population density, and the characteristics of the connections and architecture of the node in the network are used.

Table 1 shows the descriptive statistics of the dependent variables,[2] absolute interregional and international links, considering the period of analysis, 2001 to 2011, in order to verify which model is the most appropriate. When comparing the mean of the variables with their variance, we can note the presence of over-dispersion, so the negative binomial model is the most appropriate. From Table 1 it is possible to highlight the presence of excess zeros at the base. In the interregional network, more than 70% of the database is composed of regions that assume null values of connections, while in the international network, 95% assume values equal to zero. Therefore, it is necessary to verify which model best fits the data, which considers the normal distribution or the inflation of zero.

TABLE 1
Descriptive analyses of absolute linkage variables
Regions of Influence of Brazilian Cities (REGIC) – 2001-2011

Networks	Regions (REGIC)					
	N	# Zeros	Average	Variance	Min	Max
Interregional (LinkBB)	5,302	3,871 (73%)	0.75	2.34	0	9.49
International (LinkBE)	5,302	5,042 (95%)	0.10	0.29	0	5.76

Source: Authors' own.

For this, using Maximum Likelihood Estimation (MLE), the z-Vuong test, developed by Vuong (1989) and presented in Table 2, is performed. The null hypothesis of this test considers that the methods of inflated distributions are equal to those of normal distribution in terms of model explanatory capacity, while the alternative hypothesis is that the zero inflation method is better. The z-vuong test demonstrated that the ZINB is better at fitting the data than the pooled version, without inflated zeros. This test indicated that the ZINB test was significant at the

2 The appendix contains the table with the descriptive statistics of the independent variables and a matrix with the correlation among them. Correlations above 0.7 were found between the variables of economic participation (GDP) and betweenness centrality, and between internal links and their interaction with the scale of inventors. However, the regressions were estimated excluding and, in a second step, including variables that were potentially a source of multicollinearity. It was found that the results did not change. In addition, tests were performed on the dispersion of variables and no problems of multicollinearity were found.

1% level, assuming values of 66.42 and 23.54 for interregional and international networks, respectively. Thus, to explain the determinants of the number of connections in the co-patenting networks, the Zero-Inflated Negative Binomial (ZINB) model was used to compute possible biases caused by heterogeneity.

TABLE 2
Z-Vuong test for zero-inflated models – 2001-2011

Network	*Z-Vuong* ZINB test	*Z-Vuong* ZIP test
Interregional (LinkBB)	66.42***	52.87*
International (LinkBE)	23.54***	11.02**

Source: Authors' own based on Stata software.
Note: Significance Level: ***0.01; **0.05; * 0.1.

In terms of descriptive statistics, Table 3 reports the ranking of the regions that have the most links within each of the networks considered. Figure 1 shows the geographical distribution[3] of the number of connections in the interregional and international co-patenting networks in Brazil. Table 3 shows the presence of more links in the most innovative and industrial Brazilian regions, such as Belo Horizonte, São Paulo, Rio de Janeiro, Curitiba, Campinas, and São Carlos. Although the São Paulo region is generally the leader in terms of innovation and patenting in Brazil, Belo Horizonte is positioned as the region that has the most interregional links of inventors. The loss of the preponderance of São Paulo in this case may be related to the fact that inventors concentrate in São Paulo and perform internal collaborations in the region. On the other hand, in international networks, formed between Brazilian and foreign inventors, the number of connections between São Paulo and others in the period 2001-2011 reached more than double that of Belo Horizonte.

It should be noted that the 15 regions that connect the most within the network account for the majority of the connections, 59% in the case of interregional networks and 89% in international networks. In general, these regions are concentrated in the Southeast and correspond, for the most part, to the capitals of these states (Table 3, Figure 1). They are regions that have better infrastructure, educational centers, and large population. It is therefore important to investigate the association between these characteristics and the number of connections of the region in the network.

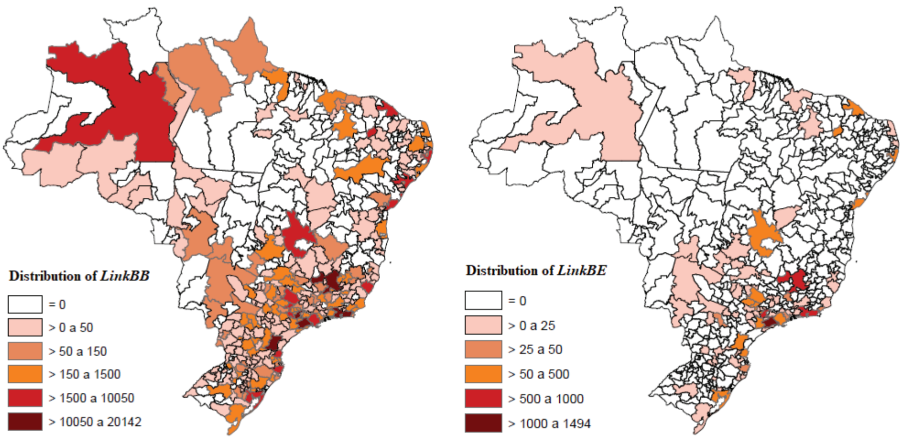
3 The test of the presence of spatial autocorrelation, I de Moran, was performed. However, the result was not significant, pointing to the lack of spatial autocorrelation in the data of interregional patenting networks.

TABLE 3
Ranking of the 15 Brazilian regions by number of connections
Regions of Influence of Brazilian Cities (REGIC) – 2001-2011

	REGIC	*Link*BB	REGIC	*Link*BE
1º	Belo Horizonte	20,142	São Paulo	1,494
2º	São Paulo	19,868	Belo Horizonte	669
3º	Rio de Janeiro	17,692	Rio de Janeiro	622
4º	Curitiba	10,867	Campinas	519
5º	Campinas	10,360	Joinville	359
6º	Porto Alegre	5,485	Salvador	203
7º	Florianópolis	4,397	São José dos Campos	171
8º	Recife	3,407	Curitiba	166
9º	Salvador	3,351	Brasília	158
10º	Ribeirão Preto	2,425	Porto Alegre	107
11º	São Carlos	2,413	Recife	90
12º	Aracajú	2,377	São Carlos	89
13º	Brasília	2,279	Fortaleza	70
14º	São José dos Campos	2,005	Araraquara	69
15º	Fortaleza	1,804	Limeira	66
% - 15 first		0.59		0.89
Total of *links* in the network		149,869		5,450

Source: Authors' own.

FIGURE 1
Distribution by regions (REGIC) of the number of *links* in interregional *(LinkBB)* and international *(LinkBE)* networks in Brazil – 2001-2011



Source: Elaborated by ArcGis.
Note: *LinkBB* = connections among inventors of Brazil; *LinkBE* = connections among Brazilian and foreign inventors.

It should also be noted that the regions that are most connected in the interregional network are also those with the greatest links in the international network, i.e., regions that have more than 150 connections via collaborations during the period of analysis. It is also possible to note the small number of regions with a high volume of connections, as well as a large number of regions that do not link to any other region through partnerships or that do not have innovation.

3.3. Estimation model

In order to standardize the scale against which variables are measured and to avoid collinearity problems, all variables, including dependent ones, are in logarithmic scale, except dummy variables. In addition, the explanatory variables were used in time-lagged form in order to mitigate possible endogeneity problems; thereby, for the period of analysis t, the independent variables measured in period t-1 were considered.

Thus, the empirical strategy of this article is based on the following general equation:

$$Links = \beta_0 + \beta_1(LinkINT_{pat}) + \beta_2(Number_{inv}) + \beta_3(LinkINT_{inv}) + \beta_4(RD_{ind}) + \beta_5(RD_{univ}) + \beta_6(Bet) + \beta_7(Emp_{ind}) + \beta_8(Agglomeration) + \beta_9(GDP_{total\_GDP}) + \beta_{10}(CG_{GDP}) + d_{reg} + d_{metro} + \varepsilon \tag{1}$$

Being *Links* the dependent variable; β_0 is the constant term; ε, the error term; the other terms represent the independent variables and control dummies, detailed below.

3.3.1. Dependent and main independent variables

Links (dependent variable): is given by the absolute number of connections in the node (region). This variable was constructed from the identification of the inventors of the patents, considering that there were collaborations during the process of technological production (formation of bonds), in which the patent application has more than one inventor. Thus, for the interregional network, each time a Brazilian was registered as inventor of a patent with another Brazilian from a different region, a link was recorded for each region of the inventors, per year and for each patent application. The link variable, when given by the Brazilian-Brazilian relationship, is represented by *LinkBB*. On the other hand, the links between Brazilians and foreigners, called *LinkBE*, account for the number of ties between a Brazilian inventor and a foreigner one.

$LinkINT_{pat}$: is given by the ratio between the number of internal connections to the node and the patents generated in the region. It aims to capture whether there is a relationship between the fact that the region has many internal links and the existence of interregional and/or international connections. A positive relationship is expected with both the number of interregional or international connections, according to Hypothesis 1.

$Number_{inv}$: is constructed from the number of inventors of the node in relation to the population of the region, in order to measure the proportion of inventors. It should be noted that, in this case, the measure takes all inventors in the region into account, both those who have partnerships and those who do not (individual inventors).

$LinkINT_{inv}$ ($LinkINT_{pat}$ x $Number_{inv}$) is constructed from the interaction of $LinkINT_{pat}$ with $Number_{inv}$, in order to investigate Hypothesis 2. In this way, a positive sign is expected.

RD_{ind} : is the proxy for industrial R&D, given by the number of employees in techno-scientific professions (POTEC) in relation to the total number of employees in the region, multiplied by 10,000 to transform the data into whole numbers in order to better capture the effects of the variable on the dependent variable. A positive relationship is expected among the number of links between regions and R&D activities associated with inventive activities.

RD_{univ}: is the proxy for university R&D that is built considering the number of doctors, permanent or visitors in postgraduate centers and in technological areas, in relation to the total population of the region, multiplied by 10,000. As with industrial R&D, it is expected to be positively related to the number of connections between regions, according to Hypothesis 3.

Bet: is the centrality measure[4] between the node constructed from Gephi 0.9.1 network analysis software and calculated as capturing distinct knowledge of organizations:

$$C_C(V_k) = \frac{1}{\sum_{j=1}^{n} \text{dist}(v_j, v_i)} C_C(V_k) = \frac{1}{\sum_{j=1}^{n} \text{dist}(v_j, v_i)} \quad (2)$$

4 The measures of centrality most used in the literature are the degree of centrality closeness and betweenness. However, as our purpose is the investigation of the intermediation of links, only the betweenness centrality is used. Borgatti et al. (2013) emphasize that the closeness measurement is less suitable for networks with disconnected nodes, as in this research.

being *Cc(Vk)* the centrality of node *k*, given by the geodesic distance in which the node *k* intermediates links between nodes *i* and *j*. With the coefficient normalized between 0 and 1, the closer to one, the greater the probability of the node (region) mediating knowledge exchanges in the network. In the case of the network of inventors, and according to Hypothesis 4, a positive signal is expected, because if the node is central, there will be agglomeration around it, allowing greater connections. The measure is calculated for both networks, denominated *BetBB* in the interregional network and *BetBE* in the international network.

3.3.2. Control variables

The other variables included in equation (1) are control variables that capture characteristics of local infrastructure and economic aspects, and they alleviate possible problems of spatial heterogeneity.

Emp_{ind}: represents the industrial share of the region and is given by the ratio of the number of employees in the extraction and manufacturing industries to the total number of employees in the region. The relationship between the degree of industrialization and networks is positive in local networks, since the industrial sector is the most patented and links with other agents in order to stay informed and competitive.

Agglomeration: is defined as population by area (km²) of the region (node), measure of demographic density representative of urbanization economies. As more populous regions generally have better infrastructure, the agglomeration is expected to capture more links among regions.

GDP_{total_GDP}: is the variable of economic magnitude, constructed from the proportion of the Gross Domestic Product (GDP) of the region in relation to the GDP of the country. It aims to control the effect of more economically developed regions, which tend to be more innovative.

CG_{GDP}: represents the import of capital goods and is given by the proportion of spending on imports of capital goods in relation to regional GDP. It tries to capture the spillover of rented knowledge through purchases of goods with embedded technologies.

d_{reg}: represents the regional dummy that assumes value 1 if the node is in the South and Southeast regions, and 0 otherwise. It aims to control characteristics of regional innovation systems not captured by the other variables.

d_{metro}: is the dummy for a presence of a metropolitan area, based on the 26 microregions with headquarters of metropolitan regions. The dummy assumes value 1 if the region has a metropolis, and 0 otherwise. It has the function of controlling for the fact that metropolises are preferred spaces in the creation of innovation (CARLINO et al., 2007; ARAUJO; GARCIA, 2016).

4. Results

Table 4 shows the results obtained for the interregional network (*LinkBB*) and international network (*LinkBE*), using a robust Pooled ZINB Panel.

From the interregional network, columns (1) and (2), it can be seen that the number of internally generated patents in the region ($LinkINT_{pat}$) has a positive relationship with the number of connections between inventors of distinct regions in the network. This corroborates Hypothesis 1, which stated that regions whose inventors link to each other internally also tend to link to inventors from other Brazilian regions. Such a phenomenon would be a way of not letting the knowledge of the region become obsolete due to the need to complement the skills and knowledge of the different agents/institutions within the inventive process. Thus, the result found is in dialogue with Granovetter's (1973) hypotheses that regions with internal links (strong ties) also tend to connect with other regions (weak ties).

The number of inventors ($Number_{inv}$) in both specifications is shown to be significantly related to the number of interregional collaborations of invention. One possible explanation for this may be the fact that regions with a large number of inventors have a higher capacity for absorption.

To test Hypothesis 2, we included in the regression the interaction between the internal connections to the node and the number of inventors of the region. The interaction tested whether interregional links would be driven by the amount of inventors powered by the number of internal links. This variable was negative, contrary to what was expected, but without statistical significance. The result suggests some lock-in effect.

Industrial R&D capacity showed a positive sign and was statistically significant, suggesting that higher R&D capacity generates more links among the inventors of different regions. University R&D capacity, in turn, obtained a positive and higher coefficient, compared to the capacity to perform industrial R&D. These results corroborate Hypothesis 3 that regions capable of producing R&D foster strong links and tend to have greater technological output from collaborations in networks with other Brazilian regions.

The centrality betweenness (*BetBB*), besides being positive, proved to be the most influential variable for the number of connections with the node. When considered as hubs, nodes tend to attract more connections with other agents acting as intermediaries for new connections. The result corroborates Hypothesis 4 that the centrality structures of the nodes are ways of making them centers of attraction, promoting new connections with adjacent nodes. According to Guan et al. (2015), a central node is less restricted within the network, which indicates that centrality is a factor that makes it more open to connections.

Employee participation in industry (Emp_{ind}) had a positive coefficient, suggesting that the larger the industrial structure of the region, the greater the chance of innovation through collaboration. This result had already been expected, since the patenting process is an activity which is closely linked to industry. In addition, it should be noted that this is the second variable that most affects connections in the interregional networks. Grillitsch and Nilsson (2015) found that firms complement the lack of absorption of knowledge and capacity to innovate in the region through greater participation of their employees in collaboration networks.

The agglomeration variable positively affects the number of interregional connections because, as expected, density positively affects innovation and interregional interaction possibilities. This suggests that regions with a high population density tend to have an urban structure that attracts inventors and facilitates the existence of collaborations among them, and it also corroborates the idea that the urban scale facilitates and enhances connections between inventors (MIGUELÉZ; MORENO, 2013).

The variable economic participation of the region in the country's GDP (GDP_{total_GDP}) suggests that the number of collaborations is related to the importance of the region's weight in national GDP.

Machine imports (CG_{GDP}) are mechanisms for absorbing external knowledge flows embedded in products. Note that there is a positive association of this variable with the number of collaborations in the network. This result suggests that this form of absorption of technological knowledge contributes to the number of ties in the interregional network, both of which can be interpreted as complementary efforts in the creation of regional innovation capacity and in the establishment of interregional ties.

The other control variables had the expected positive signs. Thus, the presence of headquarters in a metropolitan region tends to positively influence the number of connections in the networks of interregional co-patenting, as well as being located in the South and Southeast does.

TABLE 4
Determinants of the number of links in co-patenting networks in Brazil. Robust Pooled ZINB
Regions of Influence of Brazilian Cities (REGIC) – 2001-2011

Variables	**Interregional links (LinkBB)**		**International links LinkBE)**		**Robustness test (LinkBB)**	
	(1)	(2)	(3)	(4)	(5)	(6)
Internal Links per patents (*Link*INT$_{pat}$)	0.11***	0.14***	0.03	0.09	0.11***	0.14***
	(0.02)	(0.03)	(0.05)	(0.09)	(0.02)	(0.03)
Number of Inventors (Number$_{inv}$)	0.16***	0.23***	0.11**	0.27	0.16***	0.23***
	(0.05)	(0.07)	(0.17)	(0.29)	(0.05)	(0.07)
Internal Links x inventors (*Link*INTpat x Number$_{inv}$)	-	-0.07	-	-0.13	-	-0.07*
		(0.41)		(0.19)		(0.04)
Industrial R&D (RD$_{ind}$)	0.07***	0.07***	0.39***	0.40***	0.06**	0.06**
	(0.03)	(0.03)	(0.15)	(0.15)	(0.03)	(0.03)
University R&D (RD$_{univ}$)	0.20***	0.19***	0.09*	0.08*	0.20***	0.20***
	(0.01)	(0.01)	(0.05)	(0.05)	(0.01)	(0.01)
Centrality betweenness	7.78***	8.61***	20.17***	20.83***	6.30***	7.12**
	(3.53)	(3.47)	(6.46)	(6.65)	(3.68)	(3.64)
Employee participation in industry (Emp$_{ind}$)	2.09**	2.24**	-8.69	-9.68	2.27**	2.41**
	(1.04)	(1.07)	(7.79)	(8.03)	(1.07)	(1.11)
Agglomeration	0.08***	0.07***	0.04	0.03	0.07***	0.07***
	(0.01)	(0.01)	(0.04)	(0.04)	(0.01)	(0.01)
Degree of internalization of collaborations	-	-	-	-	0.14***	0.14***
					(0.05)	(0.05)
Economic Scale (GDP$_{total_GDP}$)	1.12**	1.02**	1.16	1.05	0.94*	0.83*
	(0.48)	(0.47)	(0.92)	(0.94)	(0.49)	(0.49)
Imports of capital goods (CG$_{GDP}$)	0.07***	0.07***	-0.03	-0.04	0.07***	0.07***
	(0.01)	(0.01)	(0.05)	(0.05)	(0.01)	(0.01)
Regional Dummy (D$_{reg}$)	0.12***	0.12***	0.04	0.04	0.11***	0.11***
	(0.03)	(0.03)	(0.11)	(0.11)	(0.03)	(0.03)
Metropolitan Dummy (D$_{metro}$)	0.25***	0.25***	0.13*	0.12*	0.26***	0.26***
	(0.03)	(0.03)	(0.08)	(0.07)	(0.03)	(0.03)
Constant	-0.08	-0.08	-1.31***	-1.35***	-0.02	-0.02
	(0.10)	(0.10)	(0.49)	(0.50)	(0.10)	(0.10)
Wald Test	2,688.02***	2,703.39***	353.07***	355.05***	2,863.08***	2,874.22***
Pseudo Likelihood	-2,320.23	-2,319.59	-383.22	-383.08	-2,338.19	-2,337.51
Ln (alpha) Test	-18.36***	-20.04***	-30.10***	-30.88***	-18.43***	-17.60***

Source: Elaborated by Stata 12 software.
Note: Standard errors are in parentheses. Statistical significance : ***0.01; **0.05; * 0.1.

From the perspective of the number of international connections (columns 3 and 4), internal patent links ($LinkINT_{pat}$) appear to have no role in explaining the number of connections in the region with other countries, indicating the non-validity of *Hypothesis 1* in the case of international networks. However, we found that the number of inventors has a positive relationship with foreign links (column 3). Thus, regions with a greater proportion of inventors in relation to the country have a greater number of partnerships abroad, which may be linked to the fact that a greater number of inventors in the region leads to greater capacity to absorb external knowledge.

In addition, when considering the results for (column 4), it is evident that the interaction between the number of internal links and the number of inventors of the region is not significant, as in the case of interregional networks. That is, the interaction between the two measures does not increase the links between agents from Brazilian regions and agents from other countries, and does not confirm the validity of Hypothesis 2 for the international network. This may be an indication that when the number of inventors is potentialized by the number of internal links in the region some lock-in effect may occur.

The industrial R&D and university R&D variables obtained positive coefficients, confirming *Hypothesis 3* of the existence of a relationship between investment in R&D and greater international flows of knowledge through connections in networks. The importance of industrial R&D suggests the existence of international networks of invention possibly between subsidiaries of multinationals and their headquarters abroad or even between foreign and domestic companies established abroad.

The centrality of intermediation (*BetBE*) was positive, suggesting the importance of nodes being intermediaries of other connections and, thus, catching greater knowledge flows, functioning like hubs, as in the result of the interregional networks. The variable was significant in both regression specifications (columns 3 and 4), which indeed corroborates *Hypothesis 4*.

The variables of imports of capital goods (CG_{GDP}), GDP participation, population agglomeration and employee participation in industry were not significant in explaining the number of connections between Brazilians and foreigners. The region control variable was non-significant, while the control dummy for the presence of a metropolis in the region was positive and significant for the case of international connections in Brazilian regions.

The regressions of columns (5) and (6) were designed to perform a robustness test in previous econometric exercises. An analysis of the interregional connections was included, controlling for the degree of internationalization of the region in the network. The regions with the highest interregional network connections are also highlighted in the international network and vice-versa. The variable that captures the degree of internationalization of the links is given by the number of international collaborations (*LinkBE*) divided by the number of total connections that occur in Brazil (*LinkBB* + *LinkBE*). The result indicates that the more Brazilian inventors are connected to foreigners, the greater the number of collaborations made in Brazil is. The result suggests some kind of intermediation between the innovative regions with some degree of internationalization and other Brazilian regions, where they can indirectly access international flows of knowledge.

In general, the results are similar to those of the interregional network, except for the interaction between internal links and inventors of the region (column 6), which was negative and significant. Although it does not confirm *Hypothesis 2*, this may be linked to the evidence that intense and varied local interactions lead to the self-sufficiency of the regions in the generation of inventions, but it can also be conducive to local knowledge redundancy (lock-in effect). Thus, three of the four hypotheses investigated regarding the determinants of the connections in networks are hold by the test of robustness. *Hypothesis 2* is unique, with an opposite result to what was expected for the Brazilian case.

Among the main differences in the determinants of the connections of the two main co-factoring networks in Brazil, interregional and international network, it should be pointed out that, while *Hypothesis 1*, with respect to internal links, is only found to be a determinant of the connections in the interregional network, *Hypothesis 2* is not significant in any of the two networks. *Hypothesis 3*, on the other hand, is confirmed in both networks, although it has a distinct result in each of them. In the interregional network, university R&D stands out as the variable with the greatest significant coefficient, while, for the international network, industrial R&D is more relevant, which can signal knowledge flows between multinational companies with foreign capital and companies or its subsidiaries established in Brazil. Finally, it should be noted that, in both networks, the centralities of the regions, *Hypothesis 4*, are the most important variables among the determinants of the occurrence of links between regions, be they Brazilian or foreign.

5. Conclusions

The literature suggests that collaborative inventions tend to generate results that are more conducive to innovation, and that coping networks are forms of direct transfers of coded and tacit knowledge. Therefore, investigating the determinants of the number of connections in the networks can help to understand and promote greater flows of knowledge, especially international flows. Regional inventions, measured by patents, were analyzed from the perspective of the analysis of social networks. Network nodes were identified as the regions where inventors are inserted, their links being characterized by co-patenting data.

In terms of the geographic distribution of connections in Brazil, we found that, considering the absolute number of connections, the great technological and educational centers of the country stand out, a fact linked to the concentration of inventors in these places. In addition, the variable that most influences the number of connections, considering both networks, interregional and international, is the betweenness centrality, thus corroborating *Hypothesis 4*, which positively associated node (region) and centrality of inventive collaborations. In addition, it is highlighted that the potential to carry out R&D activities is a relevant factor for connections in co-factoring networks. Thus, the importance of investment in R&D in central regions is shown, and these are responsible for transferring knowledge to other regions through collaborations with other localities. In this case, it is necessary to encourage relationships between regions highlighted as central, as possible intermediators of knowledge, with less innovative regions.

Investment in partnerships between agents and research institutions, whether within industries or universities in different locations, should be stimulated through public policies. With regard to interregional networks, the potential for university R&D is relevant, and it can be stimulated and, consequently, increase interregional links, through public policies for example. International links are especially influenced by industrial R&D, which may denote the existence of networks between subsidiaries of foreign capital multinationals established in Brazil and abroad or between domestic and foreign companies established abroad. The importance and influence of these overflow mechanisms still need to be better investigated in Brazil.

Hypothesis 1, which positively associated internal links and number of interregional collaborations, was validated only in domestic interregional networks. On the other hand, the amount of inventors has a positive relationship with the number of connections between Brazilian inventors and between Brazilian and foreign inventors. *Hypothesis 2* posited that the interaction between internal links and the number of inventors in a region would increase the number of connections with other regions. However, this hypothesis has not been confirmed. The result suggests some kind of lock-in effect as there was a negative correlation for the coefficient of this variable in relation to its impact on the number of connections between different regions. Thus, higher node connections, when potentiated by the number of inventors in the region, have no effect on the increase in the number of links in innovation networks.

The import of capital goods has been found to have a positive effect on the number of connections of the Brazilian regions with other national regions, but it is not significant in the networks between Brazilians and foreigners. The positive and significant result mentioned may be due to the fact that it constitutes a mechanism for the acquisition of technological knowledge and it is complementary to the establishment of collaboration networks between inventors of different regions. Importing machinery and equipment can be used as input for the production of innovation activities, by allowing the regions to have access to knowledge that they do not produce.

The economic scale was only significant in explaining the number of ties in the national interregional networks, indicating that having a greater participation in the national GDP can increase the number of connections in Brazilian regions. It should also be noted that metropolitan regions and those located in the South and Southeast have greater interregional links. The evidence is weaker for metropolitan regions and non-existent for the South-Southeast location in the case of international networks. In particular, the latter suggests that there are important points of connection between Brazil and abroad also in other macro-regions of the country.

Public policies are still hesitant about the explicit goal of generating networks of collaborations between agents from different locations, and there is usually only local cooperation. It is suggested that, with the results presented here, policies to encourage innovation activities and promote partnerships, mainly through R&D activities, should be undertaken. It was found that, among the regions with the greatest number of connections, mainly connections with outside, São Paulo, Belo Horizonte, Rio de Janeiro, and Campinas stand out. Thus, in terms of technological policies, there is a need for greater incentive to generate collaborations and cooperation between agents of these regions, shown as more collaborative, with regions that are technologically lagging behind. In this way, greater technological production could be promoted throughout the country and not just in the South and Southeast regions.

The limitation of the research is measuring knowledge flows through patent data. There might be other flows not captured by these data, which lie beyond the scope of the study. In terms of extension and future work, it is worth investigating and highlighting which primary nodes, i.e., agents and institutions, function as gatekeepers, responsible for bridging with agents located in other regions.

Acknowledgements

The authors are grateful for the support of Fapemig, CNPq, and CAPES for funding this research, as well as the team of professionals at the National Institute of Industrial Property (INPI) responsible for patent data.

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APPENDIX

Descriptive statistics of explanatory variables (2001-2011)

Variables	Average	SD	Min	Max
*Link*INT	0.176	0.463	0	5.062
$Scale_{inv}$	0.142	0.463	0	1.753
*Link*INT x $Scale_{inv}$	0.079	0.291	0	7.037
RD_{ind}	317.607	0.839	0	6.461
RD_{univ}	0.167	0.479	0	3.581
BetBB	0.001	0.001	0	0.030
BetBE	0.001	0.001	0	0.030
BetTOTAL	0.001	0.001	0	0.030
Emp_{ind}	0.010	0.011	0	0.244
Agglomeration	3.321	1.163	0.440	7.567
Degree of internalization of Collaborations	6.513	2.461	0.266	1.513
GDP_{total_GDP}	0.002	0.010	0	0.190
CG_{GDP}	0.524	0.787	0	4.193
D_{reg}	0.489	0.500	0	1
D_{metro}	0.054	0.226	0	1

Source: Elaborated from results by Stata 12 software.
SD= Standard Deviation.

Correlation matrix among explanatory variables (2000-2010)

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)
(1) *Link*INT	1														
(2) $Number_{inv}$	0.54	1													
(3) *Link*INT x $Number_{inv}$	0.79	0.65	1												
(4) RD_{ind}	0.34	0.42	0.28	1											
(5) RD_{univ}	0.47	0.43	0.42	0.37	1										
(6) BetBB	0.27	0.30	0.28	0.24	0.34	1									
(7) BetBE	0.26	0.30	0.28	0.24	0.34	-	1								
(8) BetTOTAL	0.27	0.30	0.28	0.24	0.35	-	-	1							
(9) Emp_{ind}	0.15	0.15	0.14	0.32	0.16	0.12	0.12	0.13	1						
(10) Agglomeration	0.28	0.46	0.24	0.28	0.30	0.30	0.30	0.30	0.30	1					
(11) Degree of internalization of collaborations	0.26	0.29	0.25	0.27	0.34	0.45	0.45	0.45	0.12	0.29	1				
(12) GDP_{TOTAL_GDP}	0.24	0.24	0.19	0.27	0.29	0.83	0.83	0.83	0.14	0.32	0.46	1			
(13) CG_{GDP}	0.36	0.49	0.33	0.48	0.38	0.26	0.26	0.26	0.24	0.40	0.31	0.27	1		
(14) Dreg	0.19	0.51	0.21	0.36	0.18	0.11	0.11	0.12	0.06	0.42	0.12	0.09	0.28	1	
(15) Dmetro	0.39	0.33	0.30	0.32	0.38	0.44	0.44	0.45	0.15	0.36	0.37	0.49	0.36	0.05	1

Source: Elaborated from results by Stata 12 software.