An analysis of the relation between geographical and cognitive proximity in university-industry linkages

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Abstract

This paper examines the relation between geographical and cognitive proximity by applying this subject to the university-industry collaboration. Previous studies have shown that non-spatial forms of proximity can substitute for the benefits of geographical proximity because they can stimulate collaboration and interactive learning between the partners. The paper uses data from collaboration between university and industry in Brazil and a measure for cognitive proximity based on correspondence analysis. The main results show that cognitive proximity can substitute for geographical proximity because shared capabilities and expertise between the collaborating firm and the academic partner stimulate long distant collaboration. In this way, the results of this paper provide new empirical evidence about the relation between geographical proximity and a form of non-spatial proximity. In addition, the results also add a new driver, cognitive proximity, which affects long-distance university-industry collaboration.

Keywords: geography of innovation; university-industry linkages; geographical proximity; cognitive proximity.

JEL Codes: O18; O31; R58

1. Introduction

There is a huge debate in the literature about the role of geographical proximity in fostering innovation. Several studies have noted that local flows of information and knowledge sharing play a very important role in interactive learning (Glaeser et al., 1992; Gertler, 2003; Storper and Venables, 2004). However, recent studies have indicated that geographical proximity is not a sufficient condition to foster interactive learning because, by itself, it cannot generate complementarities and synergies that can stimulate interaction among local actors (Gilly and Torre, 2000; Boschma, 2005; Broekel, 2015). In this way, geographical proximity can be supplemented by other forms of non-spatial proximity shaped by, for example, cognitive proximity among actors. Cognitive proximity can be defined as the similarities in the way actors perceive, interpret, and evaluate new knowledge, and it implies that actors sharing the same knowledge base are better able to learn from each other (Noteboom, 2000; Boschma, 2005).

Based on this assumption, the aim of this paper is to examine the relations between geographical and cognitive proximity in university-industry collaborations. Universities have been playing an increasing role in fostering innovation, and collaboration between university and firms is one of the most important channels to transfer new academic knowledge to industrial R&D. In this way, a dataset of 4,337 collaborations between firms and academic research groups in Engineering and Agricultural Sciences in Brazil was used to examine how geographical and cognitive proximities among universities and industry shape their interactions. In this way, the contribution of this paper is to present new empirical evidence on the relations between two dimensions of proximity, cognitive and geographical proximities. In addition, this subject is applied to university-industry collaborations, which allow us to add new empirical findings regarding the drivers of geographical distance of collaborating firms and academic research groups. Another contribution is a new index to measure cognitive proximity.

In order to achieve this aim, the paper is organised into five sections beyond this introduction. Section two presents the main conceptual background regarding geographical and non-spatial forms of proximity. Section three provides a brief description of the data and the main methodological issues, including the way to measure cognitive proximity, and section four presents the econometric modelling. Section five presents the results and discusses the main evidence on the effects of the cognitive proximity in the geographical distance of university-industry collaboration. Finally, the last section presents concluding remarks and policy implications.

2. Theoretical remarks

2.1. Geographical and cognitive proximity

The main assumption regarding the importance of geographical proximity is that such proximity facilitates knowledge sharing and, thereby, interactive learning and innovation. In fact, many authors state that geographical proximity is an important precondition for knowledge sharing, knowledge transfer and technological acquisition (Gertler, 1995; Knoben and Oerlemans, 2006; Huber, 2012). The role of tacit knowledge in innovation is the primary basis for the importance of geographical proximity. Tacit knowledge requires the existence of linkages among actors, and it is best accumulated through experience. The relationship between tacit knowledge and context is reflexive because tacit knowledge both defines and is defined by the social context: tacit knowledge can be successfully shared between two or more actors only when they also share a common social context. Tacit knowledge is a primary determinant of the geography of innovation, and its context-specific nature renders it “spatially sticky” (Gertler, 2003).

Geographical proximity is commonly defined as territorial, spatial, local or physical proximity. The importance of geographical proximity lies in the fact that small geographical distances facilitate both planned and serendipitous face-to-face interactions and therefore foster knowledge sharing and innovation. In this way, geographical proximity facilitates the exchange of tacit knowledge among actors (Gilly and Torre, 2000; Gertler, 2003). The larger the geographical distance between two actors, the more difficult tacit knowledge transfer becomes (Knoben and Oerlemans, 2006).

However, recent studies have noted that geographical proximity alone cannot generate synergies and complementarities, and it is not suffice to generate interactive learning among local actors (Boschma, 2005; Broekel, 2015). In fact, the spatial dimension can be supplemented by other forms of non-spatial proximity shaped by organizational, social, institutional and technological linkages (Paci et al., 2014).

Based on this assumption, five dimensions of proximity can be put forward: organizational, social, institutional, cognitive, and geographical proximity. By analysing these five dimensions, one can examine whether geographical proximity still plays a role in interactive learning and innovation, since other dimensions of proximity can also fulfil this role (Boschma, 2005). If geographical proximity can be assumed to actually facilitate interactive learning and knowledge sharing, other dimensions of proximity are also important in strengthening the ways in which actors collaborate.

Organizational proximity can be defined as the extent to which linkages are shared—within and between—an organizational arrangement; thus, organizational proximity is a powerful mechanism of coordination, even at long geographical distances, for interactive learning (Gilly and Torre, 2000; Boschma, 2005; Knoben and Oerlemans, 2006; Fitjar and Rodrigues-Pose, 2013). Social proximity results from the assumption that economic relations are embedded in social contexts (Granovetter, 1985; Gertler, 2003), and it could be a powerful tool for learning. Social relations not only coordinate transactions but also constitute vehicles that enable knowledge sharing, owing to the existence of mutual trust, kinship, and experience (Boschma, 2005; Capello and Faggian, 2005; Knoben and Oerlemans, 2006; Autant-Bernard et al., 2007;). Institutional proximity is commonly associated with the institutional framework at the macro level, and it facilitates collective learning because it allows free knowledge transfer among actors based on a common space of representations, models, norms, procedures, applied rules and action (Boschma, 2005; Knoben and Oerlemans, 2006).

The role of cognitive proximity is primarily related to the assumption that knowledge is not a public good that is produced outside the economic system (Lissoni, 2001; Giuliani and Bell, 2005; Capello, 2009). Nevertheless, knowledge creation and innovation are often cumulative, and such accumulation relies on the capacity of a firm to learn with this new knowledge. In this way, the tacit and idiosyncratic nature of a firm's knowledge base implies that access to relevant knowledge is not a sufficient condition and that the effective knowledge transfer requires absorptive capacity to identify, interpret and exploit new knowledge (Cohen and Levinthal, 1990; Nooteboom, 2000; Boschma, 2005). Complementary absorptive capacity between two partners is required, and overlaps in actors' knowledge bases are essential for efficient communication (Broekel, 2015). For each new technology, a firm must dominate a minimum level of knowledge, under which it is not able to bridge the knowledge gap, and collaboration requires a minimum level of cognitive proximity between two actors. Cognitive proximity is commonly defined as the similarities in the way actors perceive, interpret, and evaluate new knowledge (Knoben and Oerlemans, 2006) or the degree of overlap in two actors' knowledge bases (Broekel, 2015). Several authors have mentioned the similarities between cognitive and technological dimensions of proximity (Breschi et al., 2003; Knoben and Oerlemans, 2006; Krafft et al., 2014)

Relations among the different dimensions of proximity are far from being understood. It is essential to consider the different types of proximity from a dynamic perspective because current proximity structures may affect actors' future collaborations (Balland et al, 2015; Broekel, 2015). For example, actors who frequently interact are more likely to become cognitively closer because they can learn more from each other and improve their communication structures.

Several empirical studies have also examined whether non-spatial forms of proximity can be a substitute for geographical proximity. The results obtained in a study from the

Canadian infection and immunity research networks show that both institutional and geographical proximities are very important in supporting collaboration. In addition, institutional proximity can compensate for the lack of geographical proximity to support collaboration (Lander, 2015). Geographical and cognitive proximity may induce a process of interactive learning and knowledge dissemination among actors, often without a conscious decision on the part of the involved actors (Paci et al., 2014). Substitution effects, in which non-spatial proximity substitute geographical proximity as a tool for interaction, were empirically found between cognitive and geographical proximity in collaborative innovation projects in the Danish clean tech industry (Hansen, 2015). Regarding scientific collaboration, network proximity also alleviates the impeding effects of geographical distance on collaboration (Bergé, 2016). In addition, studies on industrial clusters have shown the importance of non-local relations of local producers, supported by the presence of cognitive proximity among actors (Vale and Caldeira, 2007) or intermediated by technological gatekeepers (Morrison, 2008; Hervas-Oliver and Albors-Garrigos, 2014). However, other studies show that, in specific contexts, such as among small firms, relations between geographical and cognitive proximity could be complementary in nature because interactions characterized by both geographical and cognitive proximity are more likely to be realized than linkages characterized by only geographical proximity (Broekel and Boschma, 2011).

It is important to mention the role of temporary geographical proximity. The increasing mobility of people, information and goods has reduced the constraints of collaboration at long geographical distances, since many types of interactions can be fulfilled temporarily through travel and distant online meetings (Torre and Rallet, 2005). Such collaboration clearly occurs through the emergence of communities of practice, epistemic communities or forums of professionals, which enable participants to exchange information and share knowledge even at long distances (Knoben and Oerlemans, 2006; Maskell et al., 2006; Torre, 2008; Torre, 2014). In this way, temporary geographical proximity can also be an important tool for fostering interactions between two actors. It can also be a good, even though it may not be a perfect substitute of the mechanisms of geographical proximity. Temporary geographical proximity can also create—and strengthen—cognitive proximity among actors.

Finally, it is important to mention the "proximity paradox", which highlights the negative effects of proximity. In its different dimensions, proximity may also have negative effects on knowledge sharing and innovation, owing to lock-in and a lack of openness and flexibility (Boschma, 2005; Boschma and Frenken, 2011). For example, cognitive proximity can enable communication among actors and thereby foster interactive learning. However, too much cognitive proximity can be detrimental to innovation and learning since it not only decreases the potential for learning but also increases the risk of lock-in and undesirable spillovers to local rivals (Boschma, 2005). Thus, too little cognitive proximity implies communication problems, while too much cognitive proximity implies a lack of sources of novelty (Nooteboom, 2000; Cassi and Plunket, 2014). In fact, technological (or cognitive) proximity is the dimension of proximity that seems to be most subject to the proximity paradox, since previous empirical results show that higher cognitive proximity decreases innovative performance (Cassi and Plunket, 2014).

2.2. Geographical proximity of university-industry collaboration

The same assumptions regarding the role of geographical proximity in fostering interactive learning and innovation among actors in general can be applied to university-industry linkages. Universities have being playing an increasing role in supporting innovation. Academic research represents an important source of new knowledge, and collaboration projects with universities can help firms solve their innovation problems, especially when such problems are closer to the technological frontier (Nelson, 1959; Klevorick et al., 1995; Cohen et al., 2002). Recently, analyses of university-industry collaboration have devoted increased attention to the role of geographical proximity between academic research and industrial R&D, and strong empirical evidence has shown the benefits associated with university-firm co-location. Previous findings have generally revealed the existence of geographically bounded spillovers from academic research to industrial innovation (Jaffe, 1989; Audretsch and Feldman, 1996; Mansfield and Lee, 1996; Anselin et al., 1997; Arundel and Geuna, 2004; Laursen et al., 2011; D'Este and Iammarino, 2010; Garcia et al., 2013; De Fuentes and Dutrénit, 2014).

Although firms often prefer to collaborate with geographically close universities, certain factors can induce firms to collaborate with universities in geographically distant locations (D'Este and Iammarino, 2010; Laursen et al., 2011; Muscio, 2013; De Fuentes and Dutrénit, 2014; Garcia et al., 2015). Normally, if a firm requires unique, complex, and tacit knowledge, it will seek out a university that can solve its innovative problems regardless of the geographical location of the university. The main factor that affects firm collaboration with geographically distant universities is the firm's absorptive capacity. Firms with high absorptive capacity have a greater range of potential academic partners; therefore, they are able to search for and find academic partners beyond their geographically proximate environment (Laursen et al., 2011; Garcia et al., 2015). In addition, the quality of the university is another factor that affects the geographical distance of university-industry collaborations. High quality universities are able to attract geographically distant firms to collaborate, since top research groups can master a broad and complex set of capabilities that can help firms solve their innovative problems, especially when firms require state-of-the-art knowledge (D'Este and Iammarino, 2010; Muscio, 2013; Garcia et al., 2015).

Increasing attention has been devoted to the examination of the main factors that affect the geographical distance of university-industry collaboration. Previous studies have identified the factors that encourage firms to search for geographically distant universities for collaboration. However, no study has considered the different dimensions of proximity as factors that affect firms' decision to collaborate with geographically distant universities.

3. Data and methodology

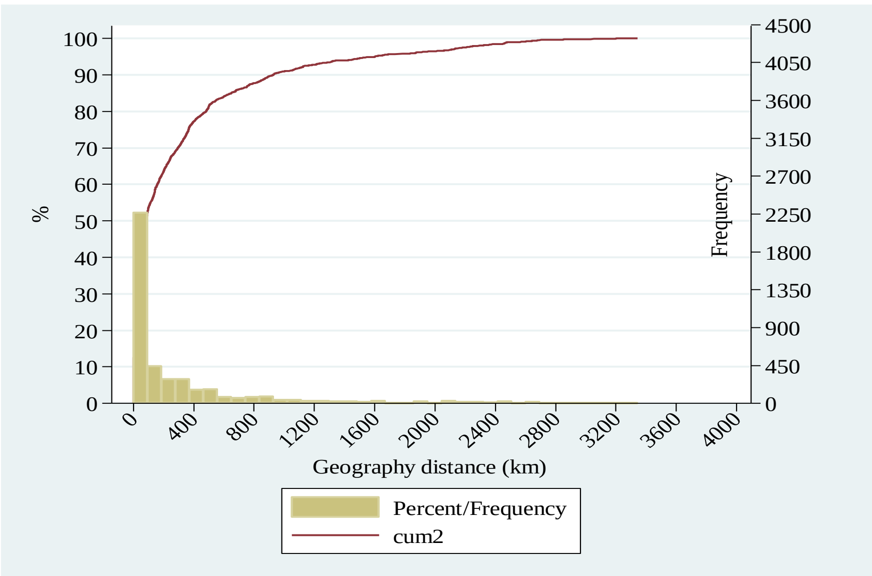
3.1. Database

The main database used to examine the relation between geographical and cognitive proximity provides basic information on university-industry linkages in Brazil. The data were gathered from the Brazilian Ministry of Science and Technology by exploiting the CNPq Directory of Research Groups of the Lattes platform. This database provides a broad set of data on the activities of academic research groups in Brazil and covers their main features, such as scientific field, number of researchers, research performance, and collaborating firms. Information on the collaborating firms from the Brazilian Ministry of Labour, such as size, industrial sector, localization, and labour force qualification, was added to these data. The final database includes 4,337 collaborations involving 3,063 firms and 1,738 Engineering and Agrarian Science research groups in 2010 from all Brazilian regions. Engineering and Agrarian Science are the most important knowledge fields involving collaboration in Brazil (Suzigan et al., 2009; Garcia et al., 2015).

3.2. Geographical proximity

Geographical proximity was measured as the distance in kilometres in a straight line between the georeferenced coordinates (latitude and longitude) of the localization (ZIP code) of the research groups and collaborating firms. The average geographical distance between research groups and collaborating firms is 316.5 kilometres. Collaborations occur at a range between 0 and 3,345 kilometres; zero-kilometres collaborations refer to research groups and firms located in the same ZIP code. A significant number of the collaborations are co-located, or at short geographical distances: 25% of all collaborations occur at a distance up to 6.9 kilometres, and half of them occur at up to 82.4 kilometres (Annex). Furthermore, at the sample level, the frequency of collaboration decreases as the distance increases (Figure 1).

Figure 1 – Distribution of the collaboration between research groups and firms, according to geographical distance



Source: Brazilian Ministry of Science and Technology.

3.3. The measurement of cognitive proximity

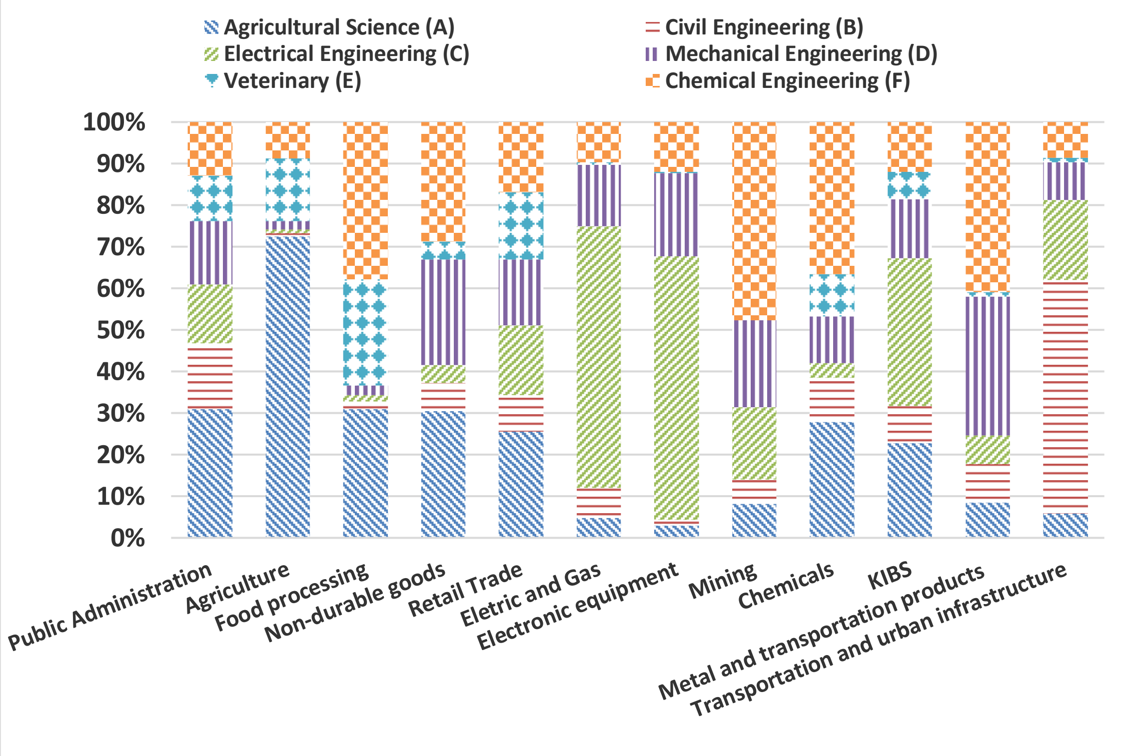
Measuring cognitive proximity is not an easy task (Boschma, 2005). In theoretical terms, cognitive proximity between two different actors refers to the similarity of their knowledge bases, and it is linked to the specific pattern of knowledge accumulation. Therefore, cognitive proximity can facilitate knowledge sharing since actors with similar knowledge bases and similar levels of absorptive capacity are more able to create specific channels for interaction. Cognitive proximity can be considered to be greater when the actors' knowledge bases are more similar (Nooteboom, 2000; Krafft et al., 2014; Broekel, 2015).

The analysis of this paper relies on university-industry collaboration. In this way, an empirical measure for the cognitive distance between academic research groups and collaborating firms was established in order to consider the relationship between academic scientific fields and sectoral industries. This measure assumes that collaboration patterns between universities and firms are not randomly distributed. Based on their main knowledge base, firms in certain industries, which face specific innovative problems, tend to collaborate more often with research groups from certain scientific fields, which master a specific set of academic capabilities. This assumption is the basis for the proposed measure of cognitive proximity between scientific fields and sectoral industries.

Previous studies have presented several measures of cognitive or technological proximity. Jaffe (1986; 1989) has proposed an empirical measure for technological proximity as the proximity of firms' technology portfolios. In this way, a technological proximity index was calculated for a pair of technologies as the angular separation or uncentred correlation of the vectors, and two technologies were considered close if they are regularly used in combination with the same third technology (Jaffe, 1986; 1989; Colombelli et al, 2014). Similar approaches were used by considering the index to measure the proximity or relatedness between two technologies (Breschi et al., 2003; Krafft et al., 2014). It is also possible to explore patterns of knowledge interactions by analysing matrices of interaction with the share of interactions for each pair of economic sectors and fields of science (Shartinger et al, 2002).

The dataset used in this paper covers two different dimensions, which involve 6 categories of research groups' scientific fields, namely, Agricultural Sciences, Civil Engineering, Electrical Engineering, Mechanical Engineering, Veterinary, and Chemical Engineering; and 12 sectoral industries, grouped by the firms' SIC, specified by numbers: Public Administration, Agriculture, Food Processing, Non-durable Goods, Retail Trade, Electric and Gas, Electronic Equipment, Mining, Chemicals, Knowledge Intensive Business Services (KIBS), Metal and Transportation Products, Transportation and Urban Infrastructure. The distribution of collaborations between research groups and firms, according to their scientific field and sectoral industry, was determined by counting the joint occurrence of all possible pairs of classifications (Figure 2). Therefore, the simultaneous use of two dimensions of correspondence analysis to shape the cognitive proximity measure configures itself as an additional contribution of this paper because previous studies limit their measure to a given dimension.

Figure 2: Distribution of collaboration according scientific fields and sectoral industries



Source: authors' own elaboration.

Notably, there are not random patterns of collaborations between scientific fields and industries. For example, the examination of collaborating firms in the Agriculture industry shows that producers interact more with Agricultural Sciences, Veterinary and Chemical Engineering research groups. Similarly, Electric and Gas and Electronic Equipment firms collaborate more often with Electrical, Mechanical, and Chemical Engineering research groups. Moreover, Transportation and Urban Infrastructure firms interact more with Civil Engineering research groups.

The dissimilar distribution of collaborations among sectoral industries and scientific fields provides a strong indication of cognitive proximity. Firms seek to collaborate with research groups that are able to help them to solve their innovative problems, and actors usually share complementary capabilities and absorptive capacity, which indicates the existence of cognitive proximity. In this way, the observed frequency will be compared with the relative contributions of the expected frequencies under independence to provide information for an empirical measure of cognitive proximity.

Correspondence analysis can be used to assess this type of relationship between categorical variables. Correspondence analysis allows the graphical representation the categories in rows (r) and columns (c) from a decomposition of the associations of a contingency table (Beh, 2004). The classic method of simple correspondence analysis is driven by the singular value decomposition of a measure of association based on the chi-square statistic (Greenacre, 1984; Hoffman and Franke, 1986).

Considering this standpoint, in this paper, correspondence analysis was applied to the contingency table of scientific fields and sectoral industries in order to create an index for cognitive proximity. From the coordinates obtained through the correspondence analysis, vectors can be drawn for each scientific field and sectoral industry pair; and cognitive proximity can then be interpreted in terms of the coordinates. Therefore, cognitive proximity is defined by the cosine index, which is calculated by the inner product of each scientific field and sectoral industry pair. Thus, the cognitive proximity index can be interpreted as the association between a scientific field and an industry. Values closer to 1 represent vectors in the same direction, which means a positive association between the scientific field and the sectoral industry. Such categories are likely to occur together because the frequency is higher than expected under independence.

Values closer to -1 represent vectors in opposite directions, representing a strong negative association. Finally, values closer to zero, orthogonal vectors of around 90 degrees, correspond to what is expected to be independence between the scientific field and the sectoral industry. The similarity measure reflects the patterns of collaboration between research groups and firms, in which higher values indicate greater cognitive proximity (Table 1).

From this representation, it is possible to note, for example, that the Agricultural Sciences and Veterinary scientific fields exhibit similar patterns and magnitudes for cognitive proximity. Both are cognitively close to industries such as the Public Administration, Agriculture, Food Processing, Non-durable goods, and Retail Trade industries and cognitively distant from the Electric and Gas, Electronic Equipment, Mining, Metal and transportation products and Transportation and Urban Infrastructure industries. Similarly, the Civil Engineering and Mechanical Engineering scientific fields are cognitively closer to the Mining, Metal and Transportation products, and Transportation and Urban Infrastructure industries and distant from the Agriculture, Retail Trade and KIBS industries.

Table 1 – Measure of cognitive proximity according scientific field and industry

Industry/Scientific Field	Agricultural Science (A)	Civil Engineering (B)	Electrical Engineering (C)	Mechanical Engineering (D)	Veterinary (E)	Chemical Engineering (F)
Public Administration (1)	0.651	-0.092	-0.927	-0.351	0.807	0.738
Agriculture (2)	1.0	-0.833	-0.289	-0.949	0.966	-0.062
Food processing (3)	0.836	-0.365	-0.787	-0.597	0.939	0.522
Non-durable goods (4)	0.595	-0.021	-0.952	-0.283	0.762	0.785
Retail Trade (5)	0.965	-0.636	-0.556	-0.817	0.999	0.232
Eletric and Gas (6)	-0.515	-0.076	0.977	0.189	-0.696	-0.841
Electronic equipment (7)	-0.375	-0.23	0.998	0.034	-0.576	-0.915
Mining (8)	-0.775	0.998	-0.351	0.945	0.656	0.656
Chemicals (9)	0.118	0.477	-0.979	0.229	0.341	0.989
KIBS (10)	0.134	-0.682	0.896	-0.466	-0.095	-0.995
Metal and transportation products (11)	-0.607	0.955	-0.56	0.843	-0.41	0.813
Transportation and urban infrastructure (12)	-0.942	0.962	-0.016	1.0	-0.842	0.364

Source: authors' own elaboration.

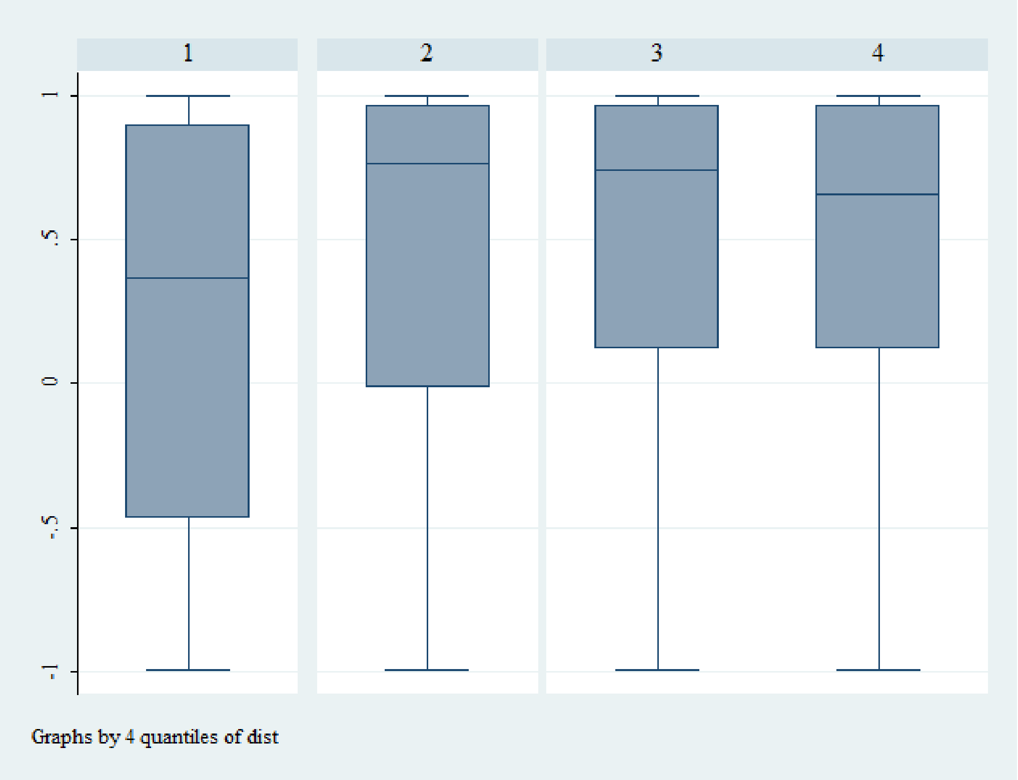
The measure for cognitive proximity should be independent of geographical distance. Therefore, together determining the frequency of collaborations as a proxy for cognitive proximity and geographic distance could cause problems of simultaneity and endogeneity. In order to prevent this problem, correspondence analysis was applied only to the co-located collaborations, by considering the first two quartiles, i.e., between zero and the median (82.4 kilometres). Considering this collaboration to measure the cognitive proximity, the proxy became independent from geographical distance because both measures are not determined simultaneously.

3.4. Geographical distance and cognitive proximity

The frequency of collaboration of a scientific field and an industry was used to create the cognitive proximity index. In order to relate cognitive proximity and geographical distance, four groups sorted by the geographical proximity were formed from the quartiles of the geographical distance. The cognitive proximity index average for each quartile shows that collaborations are more geographically distant when cognitive proximity increases. This descriptive result indicates that cognitive proximity between two collaborating actors allows them to interact at greater geographical distance. This means that, in order to collaborate with more geographically distant research groups, firms should be more cognitively close to their partner.

Box plots can also be used to visually represent the relation between geographical distance and cognitive proximity. Each distribution of collaborations for the four groups shows the differences in the distributions among groups, indicating that local collaborations are associated with lower cognitive proximity (Figure 3).

Figure 3: Cognitive proximity according research groups



Source: authors' own elaboration.

4. Econometric analysis

An econometric model was estimated to analyse the relations between geographical distance and cognitive proximity in the university-industry collaboration. Measures of both geographical distance and cognitive proximity were used. The dependent variable is geographical distance (*DistGeo*), and the most important independent variable is cognitive proximity (*ProxCog*). By defining these two main variables, it was possible to assess how the cognitive proximity affects the geographical distance of the collaborations and to provide new empirical evidence on this issue.

Other independent variables were added to the model, especially those related to the main characteristics of the collaborating firms and research groups. Previous research has shown that the characteristics of both collaborating firms and research groups affect the geographical distance of the collaborations (D'Este and Iammarino, 2010; Laursen et al., 2011; Muscio, 2013; De Fuentes and Dutrénit, 2014; Garcia et al., 2015). In this way, regarding the characteristics of the collaborating firms, two variables were added: the absorptive capacity of the firm (*AbsorCF*), measured as the share of employees with a higher education, and firm size (*SizeF*), and measured as the number of employees in logarithmic form. The characteristics of the research groups include the quality of academic research (*Quali*), measured as the number of published papers per researcher, the size of the research group (*SizeG*), measured as the number of researchers in each research group, and (*TimeG*) related to the research group's lifetime. Control variables for locational factors and for the type of collaboration were also added. Table 2 presents the description of the main variables. Descriptive statistics are presented in the Table 3. The empirical model was defined as follows.

$$DistGeo = \Pr oxCog + AbsorvCF + SizeF + \mathrm{Quali} + SizeG + TimeG + Controls$$

Table 2 – Description of the variables

Variable	Description	Source
DistGeo	Distance in kilometres in a straight line from the georeferenced coordinates (latitude and longitude) of the zip code (ZIP) for the firm and the research group (logarithmic form)	Original work
ProxCog	Cognitive proximity calculated by the Correspondence Analysis	Original work
Quali	Number of articles per researcher (2009-2010)	CNPq, 2010
AbsorCF	Share of employees of the firm with a higher education degree (undergraduate or higher)	RAIS, 2008
SizeG	Number of researchers in the research group	CNPq, 2010
TimeG	Research group lifetime (years)	CNPq, 2010
SizeF	Logarithm of the number of employees in the firm	RAIS, 2008
AgglomLev	Urban population density in the micro-region in which the firm is located	IBGE, 2000
K-index	Krugman's specialisation index for the micro-region in which the firm is located	Original work, using RAIS, 2008
R&D_LG	Number of active, full-time PhD professors per 10,000 inhabitants of the municipality in which the firm is located	INEP, 2009 and IBGE, 2010
R&D_LF	Number of R&D researchers per 10,000 workers of the municipality in which the firm is located	RAIS, 2008
Financ	Dummy for public or private financial support	CNPq, 2010
MacroF	Dummy for firm's Brazilian macro region	CNPq, 2010; IBGE
MacroG	Dummy for research group's Brazilian macro region	CNPq, 2010; IBGE
Metro	Dummy for metropolitan region	
CollType	Dummies for different types of collaboration***	CNPq, 2010

Source: authors' original work.

Table 3: Descriptive statistics (N=4,337)

Variable	Min	First quartile	Median	Third quartile	Max	Mean	SD
DistGeo	0	6.9	82.4	366.3	3344.6	316.5	544.0
ProxCog	-1.0	-0.1	0.7	0.96	1.0	0.4	0.7
AbsorCF	0	0.0	0.2	0.5	1.0	0.3	0.3
SizeF	0	2.0	4.3	0.1	11.8	4.0	2.6
	0	7.0	73.0	440.0	139047.0	664.4	3381.9
Quali	0	4.6	10.1	19.1	144.5	14.1	14.3
SizeG	0	5.0	8.0	12.0	54	9.6	6.2
TimeG	0	4.0	9.0	16.0	78.0	11.3	9.9
AgglomLev	0.3	67.5	337.5	1112.6	5796.0	1207.1	1786.7
K-index	0.4	0.6	0.7	0.9	1.9	0.7	0.2
R&D_LG	0	478.0	663.4	941.8	1839.3	736.5	368.5
R&D_LF	0	2.1	40.3	59.8	312.3	46.3	51.0
Financ	0	0	0	1.0	1.0	0.5	0.5
Metro	0	0	1.0	1.0	1.0	0.6	0.5

Source: authors' original work.

5. Results and discussion: empirical evidence on the relation between cognitive proximity and geographical distance

Main results from the estimated model by robust OLS are presented in Table 4. The empirical model relates geographical distance to cognitive proximity and other main variables, such as the characteristics of the firms, the characteristics of the research groups and controls (models 2 and 3).

Table 4 – Results

	VARIABLES	1	2	3	4	5
Distance	ProxCog		0.256***	0.118	0.153***	0.055
			(0.051)	(0.084)	(0.045)	(0.073)
Firm	AbsorvC	0.282**	0.333***	0.139	0.318***	0.184
		(0.118)	(0.117)	(0.129)	(0.117)	(0.123)
	SizeF	0.050***	0.044***	0.045***	0.046***	0.046***
		(0.013)	(0.013)	(0.013)	(0.013)	(0.013)
Group	Quali	0.015***	0.014***	0.015***	0.015***	0.016***
		(0.002)	(0.002)	(0.003)	(0.002)	(0.003)
	SizeG	0.027***	0.0254***	0.0251***	0.0261***	0.0256***
		(0.005)	(0.00539)	(0.00538)	(0.00540)	(0.00539)
	TimeG	0.0015	0.0010	0.0015	0.0013	0.0015
		(0.003)	(0.003)	(0.003)	(0.003)	(0.003)
Interactions	ProxCog*AbsorvCF			0.576***		0.501***
				(0.160)		(0.146)
	ProxCog*Quali			-0.004		-0.004
				(0.004)		(0.003)
Controls	AgglomLev	0.000158***	0.000154***	0.000153***	0.000154***	0.000153***
		(2.63e-05)	(2.61e-05)	(2.61e-05)	(2.62e-05)	(2.61e-05)
	K-index	0.755***	0.754***	0.770***	0.758***	0.772***
		(0.177)	(0.177)	(0.176)	(0.177)	(0.177)
	R&D_LF	-0.000131	-9.72e-05	-9.50e-05	-0.000121	-0.000122
		(0.000139)	(0.000139)	(0.000138)	(0.000138)	(0.000137)
	R&D_LG	-0.0102***	-0.0102***	-0.0102***	-0.0102***	-0.0103***
		(0.000737)	(0.000732)	(0.000732)	(0.000735)	(0.000734)
	Financ	Yes	Yes	Yes	Yes	Yes
	Macro_F	Yes	Yes	Yes	Yes	Yes
	Macro_G	Yes	Yes	Yes	Yes	Yes
	Metro	Yes	Yes	Yes	Yes	Yes
	CollType	Yes	Yes	Yes	Yes	Yes
	Constant	3.344***	3.251***	3.292***	3.293***	3.319***
		(0.230)	(0.230)	(0.231)	(0.230)	(0.231)
	Observations	4,337	4,337	4,337	4,337	4,337
	R-squared	0.136	0.141	0.144	0.138	0.141
	Robust standard errors in parentheses					
	*** p<0.01, ** p<0.05, * p<0.1					

Source: authors' original work.

The most important empirical result is the relation between the two analysed dimensions of proximity, geographical distance and cognitive proximity. The results show that cognitive proximity (*ProxCog*) is positively correlated to the geographical distance of the two partners. This indicates that higher cognitive proximity between the collaborating firm and the research group tends to stimulate higher geographical distance collaboration. This means that shared capabilities and expertise between the partners facilitate long-distance interactions, and cognitive proximity can be a substitute for the geographical proximity in fostering interactive learning between the two actors.

The ability of firms to collaborate with more geographically distant research groups is associated with the cognitive proximity between the firm and its partner. In this way, cognitive proximity can facilitate communication among actors, which can decrease the importance and benefits of the co-location of the actors, and can substitute for geographical proximity. In addition, cognitive proximity can reduce the costs of interactions over long geographical distances because actors can also solve communication problems using online communication. Temporary geographical proximity may also be an important factor related to cognitive proximity between research groups and collaborating firms, since temporary meetings between actors are easier and more productive when common communication channels exist. In this way, high cognitive proximity renders firms less dependent on co-location with their collaborating academic partner, since the actors share the same knowledge base.

This result converges on the theoretical literature on the dimensions of proximity. The main effect of the cognitive proximity between two actors is to facilitate communication and knowledge sharing, which stimulate interactions and foster interactive learning (Nooteboom, 2000; Boschma, 2005; Krafft et al., 2014; Broekel, 2015). Similarly, previous studies show that cognitive proximity can substitute for geographical proximity because it can facilitate communication between two agents and then foster collaboration. This can be seen in the analysis of the collaborative innovation projects in the Danish clean tech industry (Hansen, 2015) and in the benefits of network effects for scientific collaboration (Bergé, 2016). Similar results on geographical and institutional proximities were also obtained by an investigation of the Canadian infection and immunity research networks (Lander, 2015). Otherwise, an investigation on local networks of firms shows that, when actors are located in the same region, cognitive proximity can strengthen firms' local networks (Broekel and Boschma, 2011).

By contrast, low cognitive proximity between firms and research groups increases the importance of local collaborations, as indicated by the lower average distance of their collaborations. This indicates that low cognitive distance among partners can demand that they meet constantly, which hinders the establishment of a geographically distant collaboration. In this way, the findings of this paper, applied to university-industry collaboration, are convergent with previous empirical studies because the results show that cognitive proximity can act as a substitute for geographical proximity.

Taking a specific look at the collaborations between firms and universities, there is an interesting debate regarding the main drivers of the geographical distance of the university-industry collaboration (D'Este and Iammarino, 2010; Laursen et al., 2011; Muscio, 2013; De Fuentes and Dutrénit, 2014; Garcia et al., 2015). The main results of previous studies show that the characteristics of both firms and universities are important drivers of the geographical distance of university-industry collaborations. On this subject, the findings of this paper show that cognitive proximity is another factor that affects the geographical distance of collaboration between firms and universities. Collaborating firms and research groups with high cognitive proximity are able to share similar capabilities and expertise, which allow them to collaborate across larger geographical distances.

In order to strengthen the results, another proxy for cognitive proximity was used as a robustness check. This alternative measure for cognitive proximity consisted of the composition of the labour force, using data on employment classification in each sectoral industry (models 4 and 5). This alternative proxy is a completely exogenous measure of cognitive proximity, which allows its use as a robustness check. The main results remain the same.

Regarding the characteristics of collaborating firms, both the absorptive capacity (*AbsorvCF*) and size of the firm (*SizeF*) positively affect the geographical distance of collaborations, in line with previous studies (D'Este and Iammarino, 2010; Muscio, 2013; Garcia et al., 2015). Firms with higher absorptive capacity are able to collaborate not only with more academic research groups but also with academic research groups at greater geographical distances (Garcia et al., 2015). These firms tend to face more complex innovation problems, and they are able to search for a broader set of research groups that can help them solve these problems. Sometimes, they find local research groups, but often, the academic capabilities that they need can be found only in geographically distant universities. In this way, firms with higher absorptive capacity are less dependent on the co-location of research groups in finding academic partners. Regarding the firm size, larger firms have broader capabilities for searching geographically distant universities and coordinating distant collaborations.

In regard to the characteristics of the research groups, both the quality of the research (*Quali*) and the size of the research group (*SizeG*) have positive and significant coefficients, which also confirms results of previous studies (Laursen et al., 2011; Garcia et al., 2015). Research groups that produce high quality research can increase the geographical distance of the collaborations, which indicates that firms are willing to collaborate with more distant high quality research groups to support their innovation efforts. In fact, firms may search for high-quality universities as collaborating partners because they think that such research groups have greater and more advanced capabilities for handling complex innovation problems. By contrast, low performance research groups engage in more local collaborations, since their capabilities are more likely to address only the innovation problems of local firms. Furthermore, the size of research groups positively affects the geographical distance of collaborations, indicating that research groups with more researchers are able to engage in collaborations are greater geographical distances. In addition, larger research groups have a broader structure, which provides them with greater and more diversified academic capabilities to solve more complex innovation problems.

In order to measure the possible relations between cognitive proximity and the main capabilities of the collaborating firms, two interactive variables were also added to the model (model 3). The first was the interaction between cognitive proximity and absorptive capacity (*ProxCog*AbsorCF*). Previous empirical studies show the importance of cognitive proximity and the main capabilities of firms, as measured by absorptive capacity (Krafft et al., 2014; Broekel, 2015). The second interactive variable is that between cognitive proximity and the quality of research group (*ProxCog*Quali*) in order to assess the relations between cognitive proximity and the quality of the research performed by research groups (Laursen et al., 2011; Garcia et al., 2015).

The results show that the interaction term between cognitive proximity and absorptive capacity (*ProxCog*AbsorCF*) positively affects the geographical distance of university-industry collaborations. This result shows the existence of combined effects of the cognitive proximity and the absorptive capacity that increases geographic distance of collaborations. This result reinforces the positive effects of cognitive proximity in the geographical distance of collaborations because this effect is preserved when high cognitive proximity is combined with the high absorptive capacity of the collaboration firm. Therefore, an increase in the cognitive proximity or in the absorptive capacity symmetrically fosters firms' abilities to collaborate with geographically distant universities. Furthermore, the other interaction term between cognitive proximity and of the quality of the research performed by the research group (*ProxCog*Quali*) presents no significance. In this way, the quality of research group is important by itself, and its importance is not related to the importance of the cognitive proximity.

6. Final remarks and policy implications

An important assumption in the literature on the geography of innovation is that geographical proximity plays an important role in fostering interactive learning among actors because it can stimulate frequent interactions and face-to-face contact (Glaeser et al., 1992; Gertler, 2003; Storper and Venables, 2004). However, recent studies have shown that geographical proximity is not a sufficient condition because the interactive learning requires complementarities among actors' capabilities and the existence of specific channels of communication among them. Other forms of non-spatial proximity can be important tools to stimulate interactions between two partners (Gilly and Torre, 2000; Boschma, 2005; Broekel, 2015). One of these non-spatial forms of proximity is cognitive proximity, which can substitute geographical proximity because the existence of similar capabilities and common channels of communication can stimulate interaction at long distances (Broekel and Boschma, 2011; Paci et al., 2014; Balland et al., 2015).

In this paper, these assumptions were applied to university-industry collaboration in order to analyse the relation between geographical and cognitive proximity. In order to relate these two types of proximity, a measure of cognitive proximity was created by using correspondence analysis to relate the knowledge area of the research groups and the industrial sector of the collaborating firms. Therefore, the cognitive proximity index is a new contribution of the paper because previous studies have measured cognitive or technological proximity using only one dimension.

Regarding the relation between the two types of proximity, the main results show that geographical proximity can largely substitute for geographical proximity because, when two actors are cognitively close, they tend to interact at larger geographical distances. In this way, the existence of similar capabilities and shared expertise between the collaborating firm and the academic partner can stimulate them to collaborate even at high geographical distances. This result represents new empirical evidence on the relation between geographical and other non-spatial forms of proximity, especially between geographical and cognitive proximity. The main results converge with previous theoretical and empirical results that cognitive proximity can substitute for geographical proximity in fostering collaboration between two actors.

Taking a specific look at university-industry linkages, the findings of this paper show that cognitive proximity between the collaborating firm and the academic partner affect the geographical distance of collaborations. Previous studies have shown that firms often prefer to collaborate with close university partners. However, they also show that the characteristics of the firms, such as absorptive capacity, and universities, such as the quality of academic research, are factors that can stimulate firms to interact with geographically distant universities. The findings of this paper add that cognitive proximity can be another factor that stimulates firms to collaborate with distant universities.

Finally, these findings offer policy implications. First, the results highlight the importance of universities for innovation. In this way, policy makers should design policies that stimulate and strengthen university-industry linkages. Second, the results show the importance of geographical proximity to foster interactive learning between the collaborating firm and the academic partner. Policies should thus provide mechanisms that allow the collaborating firm to take benefits from the externalities that arise from the geographic concentration of agents. Third, the findings show that cognitive proximity and high absorptive capacity can stimulate firms to collaborate with geographically distant universities. In this way, policies that stimulate university-industry linkages should include mechanisms to strengthen the absorptive capacity of firms by stimulating them to increase their highly qualified industrial researchers. Thereby, collaborating firms will be able to become cognitively closer to their academic partners, which will facilitate collaboration.

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