Is cognitive proximity a driver of geographical distance of university-industry collaboration? A comprehensive analysis

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Abstract

The role of geographical proximity in fostering innovation is widely recognized, and local flows of information and knowledge sharing play a very important role in interactive learning. However, geographical proximity can be supplemented by other forms of non-spatial proximity shaped by, for example, cognitive proximity among actors. In this way, the aim of this paper is to examine the relations between geographical and cognitive proximity in university-industry collaborations in Brazil. 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 shape their interactions. Main results show that cognitive proximity is a substitute for geographical proximity because shared capabilities and expertise between university and the collaborating firm stimulate long distant collaboration. Moreover, findings also add a new driver, cognitive proximity, which affects long-distance university-industry collaboration.

Based on this assumption, this paper aims to contribute to the debate on the different dimensions of proximities and university-industry collaboration, by presenting new empirical evidence on the relations between cognitive and geographical proximities. This subject is applied to a developing country, in which the university has been playing an increasing role in fostering innovation. It is also applied to university-industry collaborations, and findings allow adding evidence regarding a new driver of the geographical distance of collaborating firms and academic research groups, that is the cognitive proximity between the two partners. Finally, a new index to measure cognitive proximity is proposed, by using correspondence analysis techniques.

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

JEL Codes: R58; O18

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1. Introduction

The role of geographical proximity in fostering innovation is widely recognized, and 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, geographical proximity should not be considered 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 that are 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 (Nooteboom 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 in Brazil. Universities have played an increasing role in fostering innovation, and collaboration between universities and firms is one of the most important channels to transfer new academic knowledge to industrial R&D. As in developed countries, academic research is playing an increasing role in fostering innovation in Brazil (da Motta e Albuquerque 2007; Suzigan et al. 2009; Fernandes et al. 2010). However, unlike in developed countries, Engineering and Agrarian Sciences are the most important areas in which technology transfer occurs (Suzigan et al. 2009). Among the firms that collaborate more with universities are low- and medium-tech industries, such as mining, oil and gas, and high-tech industries, such as biotechnology (Chaves et al. 2012). Regional distribution of university-industry linkages are strongly unequal; there is a strong concentration in the Southern part of the country (Garcia et al. 2015). In this paper, 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.

There is still room for further research on this topic. Although there are several contributions on the relations between spatial and non-spatial forms of proximity, there is still no empirical evidence on this issue applied to university-industry collaborations. Moreover, previous research has only been applied to developed countries. In this way, this paper aims to contribute to the debate on the different dimensions of proximities and university-industry collaborations by presenting new empirical evidence on the relations between two dimensions of proximity, cognitive and geographical proximities. This subject is applied to university-industry collaborations, and the findings of this study add new empirical evidence regarding a new driver of the geographical distance of collaborating firms and academic research groups, that is, the cognitive proximity between the two partners. In addition, this subject is applied to a developing country, in which the university has been playing an increasing role in fostering innovation in firms (da Motta e Albuquerque 2007; Suzigan et al. 2009). Finally, the last contribution is a new index to measure cognitive proximity through the use of correspondence analysis techniques.

To achieve this aim, the paper is organized 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. Geographical and cognitive proximity and university-industry collaborations

2.1. Spatial and non-spatial proximity

The main assumption regarding the importance of geographical proximity is that it facilitates knowledge sharing and, thereby, interactive learning and innovation. Several scholars state that geographical proximity plays an important role in 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 the geography of innovation, and its context-specific nature renders it "spatially sticky" (Gertler 2003). Geographical proximity facilitates both planned and serendipitous face-to-face interactions and therefore, fosters knowledge sharing and innovation through 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. However, geographical proximity alone cannot generate synergies and complementarities, and it is not enough to encourage interactive learning among local actors (Boschma 2005; Aguiléra, Lethiais, and Rallet 2012; Broekel 2015). Spatial dimension can be supplemented by other forms of non-spatial proximity that are shaped by organizational, social, institutional and technological linkages (Paci, Marrocu, and Usai 2014).

Based on this assumption, different dimensions of non-spatial proximity can be put forward. In this way, is it possible to examine whether geographical proximity still plays a role in interactive learning and innovation because other dimensions of proximity can also fulfil this role (Boschma 2005; Knoben and Oerlemans 2006). 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.

One of the mentioned dimensions of non-spatial proximity is cognitive proximity, and its role 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 this accumulation relies on the capacity of a firm to learn with this new knowledge. The tacit and idiosyncratic nature of a firm's knowledge base implies that effective knowledge transfer requires the absorptive capacity to identify, interpret and exploit new knowledge (W. 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 will be not able to bridge the knowledge gap, and collaboration requires a minimum level of cognitive proximity between two actors. Cognitive proximity, similar to technological proximity (Breschi, Lissoni, and Malerba 2003; Krafft, Quatraro, and Saviotti 2014), 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).

Relations among the non-spatial 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, Boschma, and Frenken 2015; Broekel 2015; Cantner, Hinzmann, and Wolf 2017). 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. This evidence can be seen both in R&D collaboration projects between firms (Aguiléra, Lethiais, and Rallet 2012; Marek et al. 2016) and in scientific collaborations (Capello and Caragliu 2016; Heringa, Hessels, and van der Zouwen 2016).

Empirical studies have also examined whether cognitive and other non-spatial forms of proximity can be a substitute for geographical proximity (Huber 2012; Mattes 2012; Hansen 2014; Fitjar, Huber, and Rodríguez-pose 2015; Capello and Caragliu 2016). The results obtained in a study from Canadian infection and immunity research networks show that both institutional and geographical proximities are very important for supporting collaboration. In addition, institutional proximity can compensate for a 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, Marrocu, and Usai 2014). Substitution effects, in which non-spatial proximity substitutes for geographical proximity as a tool for interaction, were empirically found between cognitive and geographical proximities in collaborative innovation projects in the Danish clean tech industry (Hansen 2014). Regarding scientific collaboration, network proximity also alleviates the impeding effects of geographical distance on collaboration (Bergé 2016). For high spatial distances, cognitive proximity has been a very important tool for scientific cooperation between researchers from distant different regions (Capello and Caragliu 2016).

In addition, studies on industrial clusters have shown the importance of non-local relations of local producers, which is supported by the presence of cognitive proximity among actors (Vale and Caldeira 2007; Amisse, Leroux, and Muller 2012) or intermediated by technological gatekeepers (Morrison 2008; Hervas-Oliver and Albors-Garrigos 2014). However, other studies show that relations between geographical and cognitive proximities could be complementary in nature because interactions characterized by both geographical and cognitive proximities are more likely to be realized than linkages characterized by only geographical proximity (Broekel and Boschma 2011; Amisse, Leroux, and Muller 2012; Herrmann, Taks, and Moors 2012).

Cognitive proximity can also be created and strengthened by temporary geographical proximity. The increasing mobility of people has reduced the constraints of collaboration at long geographical distances because interactions can be fulfilled temporarily through travel and distant online meetings (Andre Torre and Rallet 2005), and supported by the emergence of communities of practice, epistemic communities or forums of professionals (Knoben and Oerlemans 2006; Maskell, Bathelt, and Malmberg 2006; André Torre 2008; Andre Torre 2014). These communities' participants are able to exchange information and share knowledge even at long distances, and it can be a good, albeit imperfect, substitute for the mechanisms of geographical proximity.

2.2. Geographical proximity in university-industry collaboration

Similar 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 are 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, particularly when these problems are closer to the technological frontier (Nelson 1959; Klevorick et al. 1995; W. M. Cohen, Nelson, and Walsh 2002). Analyses of university-industry collaborations have devoted increased attention to the role of geographical proximity between academic researchers 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 bound spillovers from academic research to industrial innovation (Jaffe 1989; Audretsch and Feldman 1996; Mansfield and Lee 1996; Anselin, Varga, and Acs 1997; Arundel and Geuna 2004; Laursen, Reichstein, and Salter 2011; D'Este and Iammarino 2010; Garcia, Araujo, and Mascarini 2013).

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, Reichstein, and Salter 2011; Muscio 2013; Garcia et al. 2015; De Fuentes and Dutrénit 2016). 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 a firm's 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, Reichstein, and Salter 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 because top research groups can master a broad and complex set of capabilities that can help firms solve their innovative problems, particularly 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 factors that encourage firms to search for geographically distant universities for collaboration. However, no study has considered the role of non-spatial dimensions of proximity as factors that affect firms' decision to collaborate with geographically distant universities. This paper provides new empirical evidence on how cognitive proximity affects the geographical distance of university-industry collaborations.

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.

3.3. The measurement of cognitive proximity

Measuring cognitive proximity is not a simple 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 a specific pattern of knowledge accumulation. Therefore, cognitive proximity can facilitate knowledge sharing because actors with similar knowledge bases and similar levels of absorptive capacity are more able to create specific channels for interaction. Cognitive proximity is greater when the actors' knowledge bases are more similar (Nooteboom 2000; Krafft, Quatraro, and Saviotti 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 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 different measures of cognitive or technological proximity. Jaffe (1986; 1989) proposed an empirical measure for technological proximity in terms of 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 uncentered correlation of the vectors, and two technologies are considered close if they are regularly used in combination with the same third technology (Jaffe 1986; Jaffe 1989; Colombelli, Krafft, and Quatraro 2014). Similar approaches were used by considering the index to measure the proximity or relatedness between two technologies (Breschi, Lissoni, and Malerba 2003; Krafft, Quatraro, and Saviotti 2014). It is also possible to explore patterns of knowledge interactions by analysing matrices of interaction according to the share of interactions for each pair of economic sectors and fields of science (Schartinger et al. 2002).

The dataset used in this paper covers two different dimensions comprising 6 categories of research groups' scientific fields and 12 sectoral industries grouped by the firms' SIC (Standard Industrial Classification). 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. 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.

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 categories to be graphically represented 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 decomposition value 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 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 approximately 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).

Insert 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.

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. 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. 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, 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.

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 the collaborating firms and the research groups affect the geographical distance of the collaborations (D'Este and Iammarino 2010; Laursen, Reichstein, and Salter 2011; Muscio 2013; Garcia et al. 2015; De Fuentes and Dutrénit 2016). 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*), 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 the research group's lifetime (*TimeG*). Control variables for locational factors and for the type of collaboration were also added. Table 2 presents the description of the main variables and Table 3 presents the descriptive statistics.

Insert Table 2

Insert Table 3

The empirical model was defined as follows.

$$DistGeo_{i,g,f} = \beta_1 ProxCog_{ig,f} + \beta_2 AbsorvC_f + \beta_3 Size_f + \beta_4 Quali_g + \beta_5 Size_g + \beta_6 Time_g$$
$$+ \beta_7 AgglomLev_f + \beta_8 Kindex_f + \beta_9 R\&D_f + \beta_{10} Macro_f + \beta_{11} Metro_f$$
$$+ \beta_{12} R\&D_g + \beta_{13} Macro_g + \beta_{14} Financ_i + \beta_{15} CollType_i + \varepsilon$$

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 variables, such as the characteristics of the firms, the characteristics of the research groups and controls (models 2 and 3).

Insert Table 4

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 collaborations. This means that shared capabilities and expertise between the partners facilitate long-distance interactions, and cognitive proximity can be a substitute for geographical proximity in fostering interactive learning between 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 between actors, which can decrease the importance and benefits of the co-location of actors, and can be a 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 non-spatial dimensions of proximity. The main effect of the cognitive proximity between two actors is to facilitate communication and knowledge sharing, which stimulates interactions and fosters interactive learning (Nooteboom 2000; Boschma 2005; Aguiléra, Lethiais, and Rallet 2012; Krafft, Quatraro, and Saviotti 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 2014) 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). In addition, an investigation of 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; Amisse, Leroux, and Muller 2012).

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 a concern regarding the main drivers of the geographical distance of university-industry collaborations (D'Este and Iammarino 2010; Laursen, Reichstein, and Salter 2011; Muscio 2013; Garcia et al. 2015; De Fuentes and Dutrénit 2016). 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 collaborations between firms and universities. Collaborating firms and research groups with high cognitive proximity are able to share similar capabilities and expertise, which allows them to collaborate across larger geographical distances.

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, which was determined using data on employment classification in each sectoral industry (models 4 and 5)[1]. This alternative proxy is a completely exogenous measure of cognitive proximity, which allows its use as a robustness check. The main results remained 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, Reichstein, and Salter 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

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[1] Brazilian professional occupations were obtained from the CBO (Brazilian Classification of Occupations), which is similar to the O*NET Classification.

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.

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, Quatraro, and Saviotti 2014; Broekel 2015). The second interactive variable is between cognitive proximity and the quality of the research group (*ProxCog*Quali*), which is used to assess the relations between cognitive proximity and the quality of the research performed by research groups (Laursen, Reichstein, and Salter 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 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 for geographical proximity because the existence of similar capabilities and common channels of communication can stimulate interaction at long distances (Broekel and Boschma 2011; Paci, Marrocu, and Usai 2014; Balland, Boschma, and Frenken 2015; Capello and Caragliu 2016).

In this paper, these assumptions were applied to university-industry collaborations to analyse the relation between geographical and cognitive proximities in a developing country such as Brazil. 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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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 & transportation products (11)	-0.607	0.955	-0.56	0.843	-0.41	0.813
Transportat. & urban infrastruc. (12)	-0.942	0.962	-0.016	1.0	-0.842	0.364

Source: own elaboration based on Brazilian Ministry of Science and Technology.

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' own elaboration.

Table 4. Results - robust OLS estimation

	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' own elaboration.