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The role of the geographical proximity and the quality of academic research to university-industry linkages

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Abstract

This paper examines how the geographical proximity of university-industry linkages relates to the quality of an institution's research, local efforts in research and development (R&D), and characteristics of a region's production structure. The important role of universities for the firms' innovative efforts has been widely accepted in the literature. In particular, universities serve as a source of new scientific and technological knowledge and geographical proximity can facilitate an interactive learning process between universities and industry. To exam this point, database of the Brazilian Ministry of Science and Technology was used, such it collects and compiles information on the activities of research groups in Brazil and their interactions with firms.

Findings from this study show a positive correlation between the quality of research groups and the mean distance of interactions with firms. Top-tier research groups interact with both local firms (due to the convenience of being co-located) and more distant producers in need of cutting edge research and expertise to support advanced innovation. It is evident, then, that the costs of establishing long-distance university-industry relationships are overcome by the benefits offered by interacting with high capabilities research groups to solve complex and highly specific problems. Results also show that the increasing positive correlation between academic quality and interaction distance decreases with an increase in quality. This pattern was demonstrated by the quadratic parameter used in the empirical model and is particularly significant when top-tier research groups are involved. Thus, the mean distance of interactions tends to decrease when the interactions involve centres of academic excellence.

However, the importance of second-tier universities cannot be neglected. Results from the empirical model indicate a positive correlation between academic research quality and interaction distance, suggesting that second-tier universities tend to interact more frequently with local firms. Findings from this study indicate that second-tier universities are well-equipped to handle the simpler needs of local producers, which do not require cutting edge expertise or complex academic capabilities.

Findings from this study have important policy implications. Results emphasise the importance of creating and supporting top-tier centres of advanced research, since these centres are able to generate and exchange complex knowledge through university-industry linkages. It is also important to support research development in second-tier universities, as these universities attend to the specific needs of local businesses and help enhance their competitiveness. Finally, it is worth noting that industry R&D efforts greatly contribute to the development of university-industry linkages.

The role of the geographical proximity and the quality of academic research to university-industry linkages

Introduction

This study examines how the geographical proximity of university-industry linkages relates to the quality of an institution's research, local efforts in research and development (R&D), and characteristics of a region's production structure.

The important role of universities for the firms' innovative efforts has been widely accepted in the literature. In particular, universities serve as a source of new scientific and technological knowledge. Geographical proximity can facilitate an interactive learning process between universities and industry by allowing for frequent interaction and face-to-face contact, which speeds the local knowledge spillovers. However, it is also necessary to analyse the quality of the university's academic research because state-of-the-art scientific and technological expertise is required for the development of advanced industry innovations. This level of expertise is more commonly found at top-tier universities.

To exam this point, the Directory of Research Groups from the Lattes database of the Brazilian Ministry of Science and Technology was used. The Lattes database collects and compiles information on the activities of research groups in Brazil and their interactions with firms. By using these data, it was possible to identify factors influencing geographic distance in university-industry linkages, including the quality of academic research, local research efforts, and the characteristics of the local production structure. This study aims to contribute to the debate on the role of geographical proximity in university-industry interactions by providing an analysis of the issue in Brazil. Furthermore, the empirical model developed for this analysis introduces control variables that will help to identify the role of geographical proximity.

Following this introduction, the article is structured in four sections. Section 1 defines the main relevant concepts. Section 2 and 3 briefly describe the Lattes database and the empirical model, respectively. The main results are analysed and discussed in Section 4. The final section presents concluding remarks and some policy implications.

1. Geographical proximity in university-industry linkages and the quality of academic research

The role of universities in promoting industry innovation has been the object of many studies. These studies focused primarily on the importance of universities as new knowledge sources, supporting the development of firms' innovative efforts (Nelson, 1959; Klevorick *et al.*, 1995; Cohen *et al.*, 2002). A number of studies, such as that of Klevorick *et al.* (1995), demonstrated that universities are a very important source of firms' innovation, particularly in industries closer to science and technology base.

Recently, analyses of university-industry linkages have increasingly focused on the role of geographical proximity. Areas with dense spatial concentrations of universities and firms can bring important benefits to participating companies, both assisting with and promoting innovative efforts. Firms located in closer proximity to knowledge-generating centres are able to realise an important competitive advantage because of the benefits associated with increased potential for university interactions.

Many researchers have empirically demonstrated the benefits associated with the co-location of university and firms. The pioneering works of Jaffe (1989), Jaffe *et al.* (1993) and Acs *et al.* (1992) identified a positive correlation between firms' innovative

activities, measured for example by patents, and academic research at a regional level. Results from these studies indicated the existence of knowledge spillovers at the local level. Audretsch and Feldman (1996) used data from innovative firms to demonstrate a positive correlation at the regional level between regions with high amount of innovative firms and increased R&D from both industry and university.

The benefits associated with geographical proximity between universities and firms can be summarised in three main points. First, firms located close to universities are more likely to benefit from the local knowledge spillovers of from academic research. This is because dissemination of knowledge can be facilitated by local communication networks between firms and university (Jaffe, 1989; Audretsch and Feldman, 1996; Mansfield and Lee, 1996; Anselin *et al.*, 1997; 2000; Varga, 2000). Second, geographical proximity allows local firms to participate in knowledge networks with academic researchers. In these cases, the local university can serve as a gateway for firms, facilitating development of the trust necessary for a company to become part of these knowledge sharing networks and epistemic communities (Laursen *et al.*, 2010). Finally, the close geographical proximity of firms and universities facilitates the interactive learning process. One of the intrinsic characteristics of academic research involves being at the cutting edge of knowledge, which demands the mastery of a broad, complex set of capabilities. The transfer of that knowledge to firms requires developing a relationship based on frequent personal interaction and face-to-face contact, thereby favouring firms located near centres of scientific and technological expertise (Arundel and Geuna, 2004; Abramovsky *et al.*, 2007; Fritsch and Slavtchev, 2007; Ponds *et al.*, 2007; Bekkers and Bodas-Freitas, 2008; D'Este and Iammarino, 2010; Bishop, 2011; D'Este *et al.*, 2012; Muscio, 2012).

The importance of the co-location of university and firms is mainly related to the tacit, specific, and complex character of knowledge involved in firms' innovative efforts and in their relation with university. Arundel and Geuna (2004) examined the role of geographical proximity on the different types of knowledge involved in university-industry linkages. They demonstrated that the exchange of tacit knowledge requires strong personal contact, making close geographical proximity between university and industry essential. Other authors, such as Schartinger *et al.* (2001) and Arza and Vazquez (2010), explored the main differences of the benefits of interaction among distinct industries and knowledge areas.

It is important to include the quality of the academic research of the university in this debate (Abramovsky *et al.*, 2007; D'Este and Iammarino, 2010; Laursen *et al.*, 2010; Bishop, 2011; D'Este *et al.*, 2012). The generation of more advanced or radical innovations requires a differentiated set of knowledge, which is more easily found at top-tier universities. Therefore, excellence in academic research may also be an important factor in firms' innovative activities.

The benefits associated with close geographical proximity between university and industry are more relevant to top-tier universities. First, proximity to top-tier universities allows local producers privileged access to knowledge spillovers from state-of-the-art research. Second, close proximity allows local firms to have access to extensive, complex knowledge networks. Finally, close geographical proximity facilitates the development of specific communication channels between firms' R&D staff and academic researchers working on cutting-edge projects. Therefore, it is expected that close proximity to top-tier research universities will result in greater opportunities for the exchange of tacit, specific, and complex knowledge with industry.

The literature includes numerous empirical studies demonstrating the role of the quality of academic research and geographical proximity in university-industry

linkages. Mansfield and Lee (1996) indicated that a firms' decision to interact with university is directly related to the quality of the institutions' research. Industry commonly looks for partnerships with the world's leading research universities in the fields of science and technology. Laursen *et al.* (2010) revealed that the co-location of university and industry may play out differently depending on the university's academic performance. The authors indicate that firms interact more frequently with top-tier universities than universities with lower academic performance, even when geographical proximity is not a significant factor.

In contrast, results presented by D'Este and Iammarino (2010) show that both geographical proximity and the quality of academic research positively impact the degree of university-industry collaboration. Distance from university was negatively correlated with industry interaction, indicating that geographical proximity is a factor in facilitating university-industry linkages. In addition, the quality of academic research was positively correlated with interaction frequency, suggesting that top-tier universities have more interactions with companies. Moreover, the authors observed a positive correlation between departments conducting top-quality research and geographic distance. However, D'Este and Iammarino (2010) note that top-tier departments tend to attract firms that are seeking the benefits associated with access to privileged knowledge and expertise, actively reducing the geographic distance.

The importance of second-tier universities to supporting local firms in innovation efforts cannot be underestimated (D'Este and Iammarino, 2010). According to Mansfield and Lee (1996), many firms seek the assistance of local universities in identifying solutions to their problems. For this type of interaction, close geographical proximity is a key factor in connecting second-tier universities with industry because second-tier universities are sought out almost exclusively by local firms.

Industry interactions with second-tier universities usually involve finding solutions for simpler problems, such as identifying small incremental changes to industrial products or processes. Therefore, local second-tier universities have a relative (or even absolute) advantage over internationally recognized research universities (Mansfield and Lee, 1996). Similarly, Laursen *et al.* (2010) show that firms with fewer internal capabilities, and then lower absorptive capacity, tend to interact more locally. These authors present an empirical analysis indicating that firms with lower levels of investment in R&D are more likely to interact with universities in their geographical region. Companies investing more heavily in R&D tend to collaborate with more distant universities. Similar findings were obtained by D'Este and Iammarino (2010) who demonstrated that there is a greater positive and increasing correlation between geographic distance and research quality for engineering departments than for general science departments. The authors highlight that geographical distance tends to decrease when firms' interactions occur with top-tier academic departments.

In sum, the literature indicates that geographical proximity and the quality of academic research are important factors in facilitating the exchange of knowledge between firms' R&D teams and academic researchers. This study adds to the literature by analysing empirical data on the relationship between geographical proximity and university-industry linkages in Brazil.

2. Data description and methodology

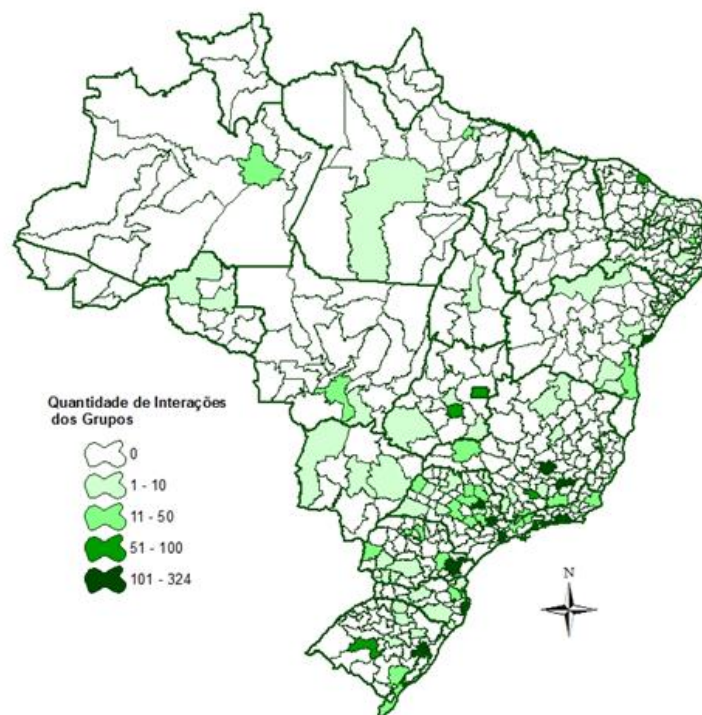
2.1. Database of interactive research groups

This analysis of the role of geographical proximity in university-industry linkages in Brazil was based on the 2008 CNPq Lattes database from the Directory of

Research Groups in Brazil¹. This database provides a broad set of information on the activities of research groups in Brazil, including their interactions with firms. The database includes 1,462 interactive research groups across 142 Brazilian universities. These groups were recorded as having 3,559 public interactions with 2,784 firms. The majority of research groups (1,066 groups, 73%) only interacted with industry once or twice, although a small number of groups interacted with industry frequently.

Data extracted from the Lattes database allowed for the identification of all recorded university-industry linkages and the geographical locations of participants. Figures 1 and 2 show the geographical locations of the Brazilian research groups and firms, respectively. The representation is shown at the micro-regional level².

Figure 1 – Distribution of interactions between research groups and industry within each micro-region in Brazil.

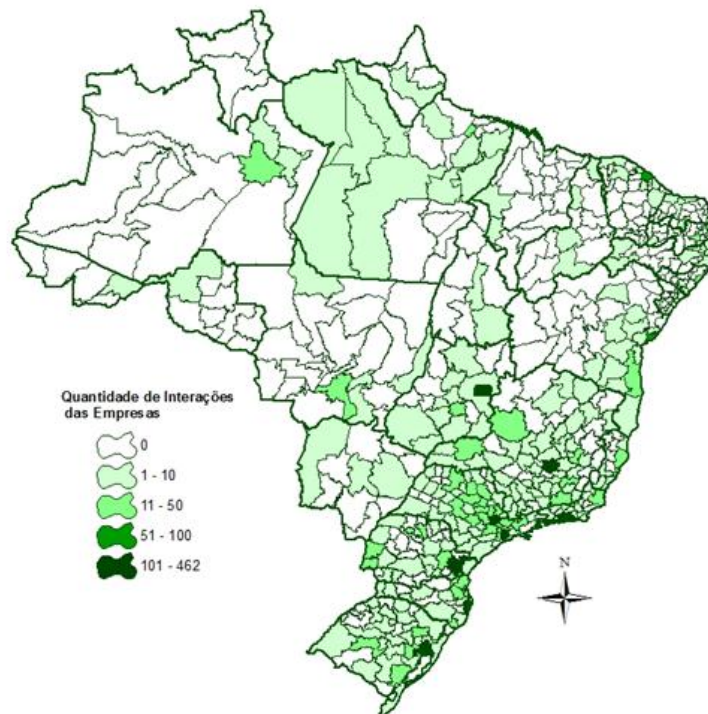


Source: Original work, ArcGIS.

¹ CNPq is the Brazilian Council for Scientific and Technological Development is an institution of Brazilian Federal Government under the Ministry of Science and Technology, dedicating to the promotion of scientific and technological research. Other studies (e.g., Rapini et al., 2009 ; Suzigan et al., 2009 ; Fernandes et al., 2010) have used the same database to analyse university-industry linkages in Brazil.

² The Brazilian Statistical Office (IBGE – Brazilian Institute of Geography and Statistics) defines 558 micro-regions in Brazil for statistical analysis. The Brazilian micro-regions are equivalent to the European Union NUTS3.

Figure 2 – Distribution of the number of industries interacting with research groups in each micro-region in Brazil.



Source: Original work, ArcGIS.

A marked spatial concentration of interactive research groups is evident when examining the geographical distribution of research groups' interactions. Only 100 micro-regions have one or more research groups interacting with firms. The 11 micro-regions with at least 100 interactions each account for a total of 2,287 interactions. This is 64% of the total university-industry linkages in Brazil. The spatial distribution of interactive firms with research groups shows a less dramatic spatial concentration, with 274 micro-regions having at least one interactive firm with research groups. However, only nine micro-regions have more than 100 interactive firms, accounting for a total of 1,845 interactions or 52% of the total number of university-industry linkages in Brazil³.

At the regional level, the highest concentrations of interactions occur in the south and southeast regions of Brazil⁴. This distribution results from two factors. First, the spatial distribution of university-industry linkages overlaps with the spatial distribution of academic activities in Brazil. Second, the overlap between the spatial distributions of universities and industry is due to their co-location, which accounts for 44% of the total university-industry linkages in the country. The second factor suggests the importance of geographical proximity to the development of university-industry linkages. 59% of the interactions between university and industry occur between groups within 100 km of each other. Additionally, the number of interactions decreases with

³ This spatial concentration of university-industry linkages could be seen in other countries. For example, Autant-Bernard (2007) showed the strong spatial concentration of economic activity in Europe and its relation to the localised knowledge spillovers.

⁴ The micro-regions having 100 or more interactive research groups and 100 or more interactive firms simultaneously are Rio de Janeiro, Porto Alegre, São Paulo, Florianópolis, Recife, Curitiba, Belo Horizonte, and Campinas.

distance and 24% of interactions occur between organisations located at least 300 km apart, while only 10% of interactions involve distances greater than or equal to 800 km. This demonstrates the important role that geographical proximity plays in the development and maintenance of university-industry linkages.

2.2. Measuring the quality of academic research

The quality of academic research is one factor used to assess how the role of geographical proximity may change in the development of university-industry linkages. To analyse the role of research quality, it was necessary to develop a procedure for consistently measuring the quality of university-level research. A grade was assigned to the postgraduate programs associated with research groups (based on their affiliation and research subject area) and was used as an indicator of research quality⁵. Postgraduate programs (and their research groups) producing higher-quality research, greater impacts, and better academic performance receive higher grades than groups associated with lower performance. The grade scale ranges from 1 to 7. Table 1 shows the distribution of research groups and university-industry linkages according to quality⁶.

Table 1 – Distribution of research groups and interactions according to quality.

Quality Grade	Research groups		Interactions	
	Number	%	Number	%
2	2	0.1	3	0.1
3	227	15.5	472	13.3
4	500	34.2	1,145	32.2
5	479	32.8	1,143	32.1
6	196	13.4	452	12.7
7	58	4.0	344	9.7
Total	1,462	100.0	3,559	100.0

Source: CNPq Lattes database from the Directory of Research Groups, 2008; and CAPES, 2010.

Note: The grades shown here were rounded to the nearest whole number.

Intermediate grades show the highest relative frequencies. Grades 4 and 5 each correspond to approximately one third of interactions⁷, accounting for approximately 67% of the total interactions.

3. Empirical model of the importance of geographical proximity

Analysing the importance of geographical proximity in university-industry linkages involves measuring the effects of factors that influence the creation and maintenance of cooperative relations between universities and firms. Three primary factors were considered in this study: the quality of academic research, the role of local

⁵ The grade is assigned by Coordination for the Improvement of Higher Education Personnel (CAPES - Coordenação de Aperfeiçoamento de Pessoal de Nível Superior), the most extensive academic quality assessment in Brazil. In the same way as other countries, the evaluation is based on the impact of the research and the formation of young researchers.

⁶ In cases where research groups are linked to more than one postgraduate program, the mean grade assigned by CAPES was used.

⁷ This analysis excludes interactive research groups that are not linked to a postgraduate program.

industry and academic R&D efforts, and characteristics of the local production structure. The impact of these factors on the geographical dimension of university-industry linkages is assessed by the following empirical model:

$$DistInt = f(Quality; R\&D; Regional\ Structure)$$

The dependent variable is the geographical distance between the interactive research group and firm (*DistInt*). *DistInt* was measured (in kilometres) as the shortest linear distance between the firm and the research group. In the database, locations are given at the municipality level, precluding precise georeferencing. Distances were measured between the geographic centre of the municipalities in which the research group and firm were located.

Independent variables were measured as follows. The quality of academic research was measured by the grade assigned to the research group's postgraduate program. Local industry and academics R&D was assessed independently because of the different ways that each may relate to geographical proximity. Because firm may grow its R&D through spillovers of local knowledge, two spatially lagged variables were included: industrial R&D spillover and academic R&D spillover. Regional structure was measured using an index of specialisation/diversification and regional population density.

The empirical model was therefore defined as:

$$LN(Dist) = Quali + Quali^2 + R\&DInd + WR\&DInd + R\&DUniv + WR\&DUniv + SD + LN(Dens) + LN(NPrg) + LN(NInt)$$

Table 2 gives a description of the variables and their respective proxies used in the model.

Table 2 – Description of variables.

Variable	Description	Source
<i>Dist</i>	Logarithmic distance (in kilometres) between the municipality centres of research groups and companies.	Original work from data compiled from NEREUS*.
<i>Quali</i>	Mean grade assigned by CAPES to the subject area postgraduate programs of the research groups involved.	CAPES, 2010.
<i>R&DInd</i>	Number of industry employees with an advanced degree per 10,000 residents of the municipality in which the industry is located.	RAIS, 2009 and IBGE, 2010.
<i>WR&DInd</i>	Spatial lag for <i>R&DInd</i> using a Queen Weights Matrix.	Original work.
<i>R&DUniv</i>	Number of active, full-time PhD professors per 10,000 inhabitants of the municipality in which the university is located.	INEP 2009 and IBGE 2010.
<i>WR&DUniv</i>	Spatial lag for <i>R&DUniv</i> using a Queen Weights Matrix.	Original work.
<i>SD</i>	Krugman's index of specialisation (see Crescenzi <i>et al.</i> , 2007).	Original work using data from RAIS, 2009.
<i>Dens</i>	Population density in the industry's micro-region.	IBGE, 2000.
<i>NPrG</i>	Number of postgraduate programs in the research groups' affiliated university.	CAPES, 2010.
<i>NInt</i>	Number of research groups interactions.	CNPq, 2008.
<i>NNE</i>	<i>Dummy</i> for Brazil's north and northeast regions.	CNPq, 2008 and IBGE.
<i>Area</i>	<i>Dummy</i> for knowledge areas.	CNPq, 2008.
<i>Type</i>	<i>Dummy</i> for interaction types.	CNPq, 2008.

Source: Original work

As previously described, the quality of academic research (*Quali*) was estimated by the CAPES grade assigned to a research group's postgraduate program. Additionally, the model includes a *Quali* quadratic variable to assess whether an increase in the distance involved in interactions had a negative effect on research quality (D'Este and Iammarino, 2010). To test for a relationship between geographical distance and research quality, two sub-samples of research groups with different quality grades were selected. These sub-samples included 472 interactions with grade 3 groups and 452 interactions with grade 6 groups.

The influence of research quality on the distance between organisations involved in university-industry linkages for each of the grade groups. Research groups with lower academic performance tend to interact with firms in closer proximity. This can be seen in the higher number of local interactions for grade 3 research groups. However, there are two points of intersection between the cumulative distribution curves. A higher proportion of interactions occur with lower grade research groups for distances of up to 900 km. This pattern is seen again with distances greater than 2,400 km. It is therefore reasonable to assume some effect of proximity on research groups with higher academic performance. This assumption supports the inclusion of a quadratic variable in the model.

Efforts on industrial R&D (*R&DInd*) were measured by the number of employees in manufacturing activities with advanced degrees in the municipality where the firm was located. This proxy was selected to compensate for a lack of data on R&D expenditures at the necessary geographic scale in Brazil. Similarly, academic investment in R&D (*R&DUniv*) was measured by the number of active, full-time PhD

professors per 10,000 residents. Regional production structure was assessed using two proxies. The Krugman's index (*SD*) measures the relative level of diversification in a region, and *Dens* indicates the population density of a micro-region as a measure of urban agglomeration. Control variables include the size of the university with which research groups were affiliated (*NPrg*), the total number of interactions of individual research groups (*NInt*), and dummy variables for Brazil's North and Northeast (*NNE*) regions, for different knowledge areas (*Area*) and for interaction types (*Type*). Table 3 displays descriptive statistics for these variables.

Table 3 – Descriptive statistics of continuous variables

	Mean	Standard Deviation	Minimum	Maximum
Distance	257.2	490.6	0	3,308.3
Quality	4.7	1.1	2.0	7.0
Academic R&D	7.0	10.5	0	95.8
Industrial R&D	41.7	44.6	0	606.9
Krugman's index	0.7	0.2	0.4	1.8
Population density	1,287.8	1,766.6	0.6	5,441.4

Source: Original work.

Interactions occur at an average distance of 257.2 km. However, the standard deviation is very high because 44% of the interactions occur between organisations located in the same municipality (i.e., zero distance). There are also long-distance interactions between organisations located in municipalities that are up to 3,308 km apart. The mean academic research quality of participating research groups was 4.7 (standard deviation = 1.1).

The analysis of *R&DUniv* indicates high dispersion. The largest number of interactions occurs in municipalities with no evident investment in *R&DUniv*. In other words, these municipalities do not have professors with doctorate degrees. Thus, the mean of *R&DUniv* is 7 active professors per 10,000 inhabitants (standard deviation = 10.5). The mean for *R&DInd* is 41.7 employees with an advanced degree in each municipality.

Krugman's index values range from 0.4 to 1.8, indicating the presence of regions with both a diversified production structure (values close to zero) and a specialised production structure, as compared to the other municipalities. The population density is also highly variable between the micro-regions where interactions occur. Population density varies between 0.6 and 5,441 inhabitants per km².

4. Results

After defining all variables and their proxies, the coefficients for each variable were estimated using a Tobit model. The regression results are presented in Table 4.

Table 6 – Estimation of coefficients using a Tobit model.

Quality (<i>Quali</i>)	1.730(0.573)***
Quality ² (<i>Quali</i> ²)	-0.15(0.058)***
Number of programs (NPrg)	-0.02(0.110)
Group's number of interactions (<i>NInt</i>)	0.702(0.081)***
Industry's number of interactions (<i>NInt</i>)	0.651(0.108)***
Academic R&D (<i>R&DUniv</i>)	-0.17(0.011)***
Industrial R&D (<i>R&DInd</i>)	0.005(0.001)***
Spatial lag <i>R&DUniv</i> (<i>wR&DUniv</i>)	0.038(0.027)
Spatial lag <i>R&DInd</i> (<i>wR&DInd</i>)	0.012(0.003)***
Krugman's index (<i>SD</i>)	2.485(0.457)***
Population density	-0.17(0.065)***
Dummy for region <i>NNE</i> (North-Northeast)	0.029(0.239)
Dummies for knowledge areas	Yes
Dummies for interaction types	Yes
Constant	-6.11(1.498)***
Number of observations = 3559	
2003 uncensored observations	1556 left-censored observations
LR chi2(21) = 935.08	Prob > chi2 = 0.0000
Log likelihood = -6764.0112	Pseudo R2 = 0.0647

*** p < 0.1%; ** p < 5%; * p < 10%; standard deviation in brackets

Source: Original work.

Results from the empirical model indicate that the quality of a research group (*Quali*) positively impacts the geographical distance associated with interactions. The mean distance between the university and the firm is greater when first-tier research groups are involved. This result holds true even when the high number of co-located interactions is accounted for. These results suggest that firms are willing to interact with more distant top-tier researchers to support innovative efforts, to help in the solution of problems related to internal production processes, and to foster the development of new products and processes. It can be assumed that firms target top-tier research groups for collaborative efforts because they believe them to be more capable of handling complex problems.

In contrast, second-tier research groups more commonly interact with local producers whose demands they better are capable of handling. However, second-tier researchers may lack the capabilities and expertise to justify developing relationships with distant firms. Therefore, as suggested by Mansfield and Lee (1996), the importance of lower-performing local universities cannot be ignored. Local universities are better positioned to collaborate with local firms on simpler problems that do not require access to cutting edge knowledge or expertise.

It is worth noting that results from the quadratic research quality variable (*Quali*²) are negative and significant, indicating that the effect of research quality on

geographical distance does not increase linearly, as was suggested in the analysis of Graph 2. Thus, an increase in research quality has a greater relative effect on the distance associated with second-tier research group interactions than with top-tier research group interactions. Research quality has a significant, increasing effect on the interaction distance between firms and top-tier research groups. However, this effect is reduced when research groups with better academic performance and higher impact are involved.

Similar findings are described by D'Este and Iammarino (2010) in the analysis of university-industry collaboration networks in the United Kingdom. The non-linear relationship between research quality and distance may be related to the fact that research quality positively affects the distance of interactions. However, in the case of centres of academic excellence, interactions become more geographically localised. Because interactions with top-tier research groups tend to be more localised, it is possible to conclude that close geographical proximity is important to the exchange of tacit, specific, and complex knowledge⁸. Thus, firms that require more complex solutions and cutting edge expertise try to locate themselves close to centres of research excellence. This proximity facilitates the exchange of knowledge through aforementioned mechanisms, including frequent interaction and personal face-to-face contact.

Investment in R&D (*R&DInd*) on the part of industry has a positive and significant coefficient, indicating that firms with more extensive *R&DInd* efforts tend to interact with more distant universities. This may indicate that firms making greater investments in R&D have greater absorptive and internal capabilities for effectively defining their needs and seeking optimal solutions to their problems⁹. Therefore, firms with higher absorptive capability are able to interact with more geographically distant universities in their search for collaborative opportunities. However, producers with lower absorptive capability may find it difficult to locate research groups prepared to address their needs and, consequently, may end up interacting primarily with local universities (Cohen and Levinthal, 1990). This idea was already put forward by Laursen *et al.* (2010), which showed that firms with less absorptive capability tend to experience less complex problems in their production and innovation processes. Lower-performing local universities are usually capable of handling these problems, removing any justification for seeking collaboration with distant research groups.

Academic R&D (*R&DUniv*) has a significant and negative effect on geographical distance. In other words, the more a university invests in R&D, the more localised interactions with firms become. In regions with top-tier universities, most interactions with firms occur within short distances. The main reason for this localised interaction is that top-tier research groups are usually capable of addressing the needs of firms in support their innovative efforts. Therefore, firms do not need to search elsewhere for collaboration. This is demonstrated by the high number of co-located university-industry interactions. The results presented here corroborate the findings of Laursen *et al.* (2010), which indicate that given similar levels of research quality, firms opt to interact with local universities. These findings highlight the importance of geographical co-location and proximity in the development of university-industry linkages.

⁸ It is important to note that this result corroborates the work of Arundel & Geuna (2004), who observed that geographical proximity is a key factor for the development of university-industry linkages involving tacit, complex knowledge.

⁹ According to Nelson & Winter (1982), one stage of the industry innovation process is a search for partnerships, which depend largely on the firms' routines and internal capabilities.

Results from this study also demonstrated the importance of spatial effects. Larger industry R&D efforts in neighbouring municipalities (*WR&DInd*) tend to be related to interactions with greater distances, indicating the importance of spatial spillovers. The same effect does not hold true for academic R&D efforts in neighbouring municipalities (*WR&DUniv*). It was not possible to identify the effects of spatial spill-overs of academic research on either neighbouring municipalities or on the distance associated with interactions.

Concerning local production structure, the Krugman's index of specialisation (*SD*) has a positive and significant coefficient, indicating that firms located in more diversified regions tend to interact more locally. This positive relationship can largely be explained by the presence of increased academic resources in more diversified regions. This pattern emphasises the importance of urban agglomeration, which allows for the concentration of diversified industry and top-tier universities, generating cross-fertilisation effects and strengthening university-industry linkages. These processes are the central point of the Storper and Venables' (2004) arguments, who highlight the importance of concentrating agents to facilitate frequent, personal interaction. This result may also suggest that firms located in specialised regions may have considerable difficulty finding opportunities to collaborate on complex problems with top researchers. In such cases, firms may be forced to seek out collaboration with research groups located in more distant regions.

Population density (*Dens*), measured by the degree of agglomeration, was another parameter used to measure the effects of production structure. The analysis of *Dens* also suggests that a higher population density tends to be associated with more localised university-industry linkages. Additionally, in accordance with Storper and Venables' (2004) results, this finding demonstrates the importance of developing specific communication channels to speed the transmission of new knowledge in diversified and complex production structures.

The influence of university size was not significant, and therefore, this study did not find any distance effect of affiliation with a large university or a small academic research centre. University size (*Nprg*) was measured by the number of postgraduate programs at an institution. However, the coefficient of a research group's number of interactions (*NInt*) was positive and significant, indicating that research groups with higher numbers of interactions tend to work with more distantly located firms. This positive correlation may be explained by a more established research groups' ability to interact with more distant firms.

Final remarks and policy implications

The role of geographical proximity in facilitating collaboration between universities and industry is widely recognised in the literature. Close spatial proximity allows for frequent interaction and face-to-face contact, which strengthens knowledge sharing between academia and industry. A number of studies discuss the role of research quality in interaction distance because cutting edge research groups with advanced scientific expertise are better able to address industry's more complex needs. These top-tier research groups are able to contribute to companies' more advanced innovative efforts, generating radical inventions. The co-location of university and firms may be a key factor in the development and maintenance of university-industry linkages.

Findings from this study show a positive correlation between the quality of research groups and the mean distance of interactions with firms. Top-tier research groups interact with both local firms (due to the convenience of being co-located) and

more distant producers in need of cutting edge research and expertise to support advanced innovation. It is evident, then, that the costs of establishing long-distance university-industry relationships are overcome by the benefits offered by interacting with high capabilities research groups to solve complex and highly specific problems.

Results from this study also show that the increasing positive correlation between academic quality and interaction distance decreases with an increase in quality. This pattern was demonstrated by the quadratic parameter used in the empirical model and is particularly significant when top-tier research groups are involved. Thus, the mean distance of interactions tends to decrease when the interactions involve centres of academic excellence. This relationship may indicate that close geographical proximity becomes especially important when a university-industry linkages involves tacit, specific, and complex knowledge (which require cutting-edge expertise) because close proximity facilitates the sharing of such knowledge. Thus, it can be assumed that firms requiring cutting edge knowledge and expertise to support advanced innovative efforts seek to co-locate with centres of academic excellence. This close proximity facilitates the development of mechanisms for collaboration, including frequent interaction and face-to-face contact.

However, the importance of second-tier universities cannot be neglected. Results from the empirical model indicate a positive correlation between academic research quality and interaction distance, suggesting that second-tier universities tend to interact more frequently with local firms. Findings from this study indicate that second-tier universities are well-equipped to handle the simpler needs of local producers, which do not require cutting edge expertise or complex academic capabilities.

An interesting finding concerns the positive correlation between industrial R&D efforts and interaction distance. This positive relationship indicates that firms investing more heavily in research are more capable of locating and engaging collaboration with the necessary capabilities to solve industry problems, regardless of geographical location. This may be an indicator that firms with more developed R&D efforts have higher absorptive capability, making them more capable to establish and utilise sophisticated processes to find solutions for their innovation needs. The empirical model also shows that firms located in regions with diversified production structures tend to interact more locally because they can find more diversified, complex academic collaborators within a shorter distance.

Findings from this study have important policy implications. Results emphasise the importance of creating and supporting top-tier centres of advanced research. These centres are able to generate and exchange complex knowledge through university-industry linkages. This knowledge helps firms solve problems related to their innovative activities, especially when dealing with more advanced, radical innovation. It is also important to support research development in second-tier universities, as these universities attend to the specific needs of local businesses and help enhance their competitiveness. Finally, it is worth noting that industry R&D efforts greatly contribute to the development of university-industry linkages.

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