THE ROLE OF GEOGRAPHIC PROXIMITY FOR UNIVERSITY-INDUSTRY LINKAGES IN BRAZIL: AN EMPRICAL ANALYSIS

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ABSTRACT The aim of this paper is to analyse the role of geographic proximity in the occurrence of university-industry linkages. The main argument is that university-industry linkages are strongly localized, which suggests that geographic proximity between academic research and firms' research and development (R&D) facilities matters in fostering university-industry linkages. Interactions between university and industry in Brazil were analysed using data from the Census 2004 - Directory of Research Groups. Using this data it was possible to gather information on 2 108 academic research groups that interact with 3 068 firms. From the location of both firms and university research groups, it was possible to analyse the spatial pattern of university-industry linkages in Brazil, and the differences among knowledge areas. The results of the empirical analysis show that geographic proximity matters for the cooperation between firms and academic research groups. In addition, significant differences among knowledge areas imply different location patterns in university-industry linkages.

KEY WORDS: university-industry linkages; economic geography; innovation; geographic proximity. JEL Classification: O18; 031; R12

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1. INTRODUCTION

Innovation and technological change in firms depends upon the creation and the diffusion of new knowledge. As pointed out by Nelson (1959), knowledge can be seen as a non-rival asset and it plays a fundamental role as an input to firms' innovative efforts. Hence, one of the main sources for the creation and dissemination of new knowledge, the university, has played a widely recognised role to foster innovation in firms. In addition university-industry linkages have become an increasingly important factor for firms' innovative efforts.

Many authors, such as Jaffe (1989) and Audretsch and Feldman (1996), have identified the existence of co-localisation between universities and firms. This is because spatial concentration can stimulate the maintenance of frequent contacts between academic researchers and firms' research and development (R&D) staff. The geographic proximity allows face-to-face contacts and the building of specific channels of communication between firms and academic research.

Based on this assumption, the primary aim of this paper is to present an empirical investigation into the importance of localisation in the development of university-industry linkages. It has been suggested that proximity matters for the cooperation between academic research and firms' R&D activities. To explore this, data from the Census 2004 of the Brazilian National Council of Scientific and Technological Development (CNPq) Directory of Research Groups were used. This dataset collates information regarding the activities of research groups in Brazil. From this database, it was possible to gather information on 2 108 interactive research groups that interact with 3 068 firms. The location of research groups and firms allows analysis of the spatial pattern of university-industry linkages. Through the examination of these spatial patterns the role of geographic proximity in fostering the exchange of information and knowledge sharing between firms' R&D staff and academic researchers in the university can be determined.

This paper is organised in four main sections including this introductory section. The following section presents some brief conceptual remarks on the role of geographic proximity for university-industry linkages. Section 3 presents the methodology used, such as the main characteristics of the database and the construction of the control group for randomisation. The

Final section contains the results of the empirical analysis and some final remarks are presented.

2. BRIEF CONCEPTUAL REMARKS

The geographic concentration of producers and other agents can benefit from the presence of strong externalities, especially pecuniary knowledge externalities. The pecuniary knowledge externalities emerge from unintentional contacts and interactions among local agents with positive effects for the dissemination of new information, knowledge sharing and technological learning (Antonelli, 2008). In many cases, the diffusion of information and knowledge occurs within a complex social network, in which personal ties and informal contacts among local workers allow trust building and enable the diffusion of information and knowledge that foster local innovation.

There is intense debate on the importance of local knowledge spillovers and the main ways to measure them. Firms' R&D activities, skilled labour and academic research are among the major sources of local knowledge spillovers. Hence, academic research plays an important role for the generation of new knowledge and for disseminating this knowledge among local agents.

As stated by many authors, such as Klevorick *et al*. (1995), universities are a very important source of knowledge for the innovative efforts of firms, especially in industries in which new academic research findings are closely linked to industrial innovation. Nevertheless, in the case of developing countries such as Brazil, this role of the university must be deeply investigated, since the industrial structure of these economies has not shown the strong presence of firms in high-tech industries. In contrast with the role of academic research in developed economies, universities in developing countries could have different characteristics and distinct patterns of interactions with firms (Suzigan *et al*., 2009).

In addition to the importance of the university and the academic research for the firms' innovative activities, many authors, such as Jaffe (1989) and Audretsch and Feldman (1996) observed that geographic proximity and spatial concentration of firms and universities can be an important factor for knowledge sharing. In fact, these authors were trying to measure the importance of local knowledge spillovers, ever since the existence of spatially-mediated knowledge spillovers was identified. They also stated that academic research is one of the main ways in which local knowledge spillovers occurred.

In the same way, Varga (2000) considered the importance of spatial proximity between universities and firms for innovation, especially in high technology industries. He stated that geographic proximity of academic research institutions and industry is an important source of positive knowledge externalities. The author identified that personal networks of academic and industry researchers, university spin-off firms and graduate students are the main important channels for the diffusion of the new knowledge from the university to local firms. Thus, his study provides some empirical evidence of the role of agglomeration effects, by using a modified version of the Griliches' knowledge production function. His results show the positive effects of the spatial concentration on the transfer of academic knowledge to firms.

Breschi and Lissoni (2001) also pointed out the importance of the "knowledge externalities bounded in space", finding that firms that are operating near important knowledge sources tend to be more innovative than rival firms located elsewhere. They also emphasize the importance of increasing empirical research on local knowledge spillovers towards a better understanding of their nature and primary characteristics, and argue that "the concept of local knowledge spillover is no more than 'a black box', whose content remains ambiguous" (Breschi and Lissoni, 2009; p. 976). The authors, Breschi and Lissoni (2009) illustrate the role of these knowledge flows by verifying the contribution of the mobility of inventors and the network of researchers to the diffusion of knowledge across firms and within regions. However, their results show that the effect of spatial proximity on knowledge diffusion is not so strong, since the main channel for knowledge diffusion is the co-inventors network, which is not necessarily spatially concentrated. Hence, Breschi and Lissoni (2009) pointed out that social and cognitive proximity among agents could be as important as geographic concentration.

Other studies, such as D'Este and Iammarino (2010), indicate that, in general, the smaller the spatial distance between universities and firms, the greater the interactions among them. The main reason, according to the authors, is the reduction in costs involved with the exchange of information and knowledge sharing over smaller spatial distances. In addition, D'Este and Iammarino (2010) show that geographic proximity and research quality are positively associated to university-industry linkages, even though there are strong differences across knowledge areas. Similarly, Laursen *et al*. (2010) highlighted the importance of academic research quality and found evidence that geographic proximity tends to be particularly important when the cooperation with universities presents very good academic performance.

Therefore, there is a general assumption that geographic proximity can play an important role in fostering university-industry linkages, since it allows the building of specific channels of communication and local networks, which facilitate the dissemination of information and knowledge sharing.

3. METHODOLOGY

Characteristics of the Database

In order to evaluate the role of geographic proximity in university-industry linkages, data from the Census 2004 of the Brazilian National Council of Scientific and Technological Development (CNPq) Directory of Research Groups was used. A research group is defined by CNPq as "a group of researchers, students and technical support staff that is organised around the development of scientific research lines following a hierarchical rule based on expertise and technical-scientific competence" (CNPq Directory of Research Groups, 2004).

This is the broader database of research activities in Brazil and gathers information on the activities of Brazilian research groups, both in universities and public research organisations (PRO). The database is fed by the research group leader, who provides information regarding: human resources, such as researchers, students and technical staff; main research lines; knowledge specificities; academic production, measured by scientific publications, patents, and artistic production; industries linked with the research groups activities; and patterns of interaction between the research group and firms.

These data are the main source of information about the patterns of interaction between universities and firms in Brazil. For this reason, the database allows the examination of the main features of the relationships between academic research and the firm's R&D activities. However, there are two methodological limitations that should be pointed out: filling out the form that feeds the database is voluntary and the data are collected by self-declaration. Therefore, there is a high possibility that the interactions between research groups and firms are underestimated in the database, since not all the research group leaders complete the form with the correct information.

Nevertheless, the number of research groups that are filling out the form for the database is growing. In addition, there are an increasing number of studies that are using the Directory of Research Groups to examine the Brazilian university-industry linkages, such as Rapini *et al*. (2009), Suzigan *et al*. (2009) and Fernandes *et al*. (2010). In the 2004 Census, there were 19 470 research groups, encompassing 77 649 researchers from 375 different institutions in all the Brazilian regions. For the purposes of this paper, only the research groups that declared linkages with firms were selected. Table 1 shows the lists of variables selected for analysis.

Table 1. Main Information Collected.

Research group level	Name
	Leader
	State
	University/PRO
	Main knowledge area
	Specific knowledge area
Firm level	Name
	Fiscal Code (CNPJ)
	State of the unit that interacts
	Type of interaction
	ISIC (CNAE)

Source: CNPq Directory of Research Groups, (2004).

Data on the location of the research groups are available in the Directory, and data on the location of the firms were collected from the Brazilian

Treasury Department. Therefore it was possible to use information on the location of both the firm and the research group. Concerning the localisation of interactions between research group and firm, the location was included in three different aggregation levels: states, meso-region and micro-region. These levels of regional aggregation were created by the Brazilian Office of Statistics (IBGE), which defines micro-regions as a cluster of neighbour cities, and meso-regions as a wider geographic space that normally involves three or four micro-regions. In Brazil, there are 558 micro-regions and 137 meso-regions in its 27 states. In general terms, micro-regions can be associated with the EU NUTS3 regions, and meso-regions with EU NUTS2.

With regard to the interaction with firms, the research group leader may register up to three different types of interactions from a list of 14 options. Since the leader can select more than one type of linkage with the same firm, interactions may be counted more than once. Therefore, for the empirical analysis, the repetitions that included different types of relations were removed, to ensure that each pair “research group-firm” was counted only once. Each register of the database contains one research group and one interactive firm.

Data Description: Pattern of University-Industry Linkages in Brazil

In the 2004 database, 2 108 research groups from 217 different institutions indicated some type of linkages with firms. This shows that of all the research groups in the database (19 470), 10.8 percent declared to have some type of interaction. Taking the universities and public research organisations, 57.8 percent of all the institutions had research groups that presented some kind of linkages with firms (217 out of the 375 in the database). The declared interactions between research groups and firms totaled 8 817. After removing the duplications, 4 476 interactions were listed with information about the location of the pair “research group-firm”.

As for the distribution of the interactions with Brazilian universities and public research organisations, the top 10 institutions with the largest share of interactions accounted for 41 percent of the total linkages. The share of interactions by public research organisations was 12.2 percent. Observing the distribution of interaction among the 2 108 research groups, it was not possible to identify any substantial concentration. The single exception concerned one research group which declared maintaining linkages with 199 different firms, or 4.1 percent of the total.

Suzigan *et al*. (2009) have presented a comprehensive map of the university-industry linkages in Brazil. The main assumption of the authors is that the Brazilian national system of innovation is incomplete and immature, and this characteristic matters to the development of university-industry linkages. According to the authors, interactions between universities and firms in Brazil are characterised both by the transmission of typical codified knowledge, for example by rendering of services and training, and by the creation of bidirectional flows of information and knowledge, through collaborative R&D projects that involve researchers from the R&D facilities at the firm and researchers from the university.

In terms of firms that interact with research groups, it is not possible to identify a greater concentration. The three firms most often mentioned by the research groups were: Petrobras, the stated-owned oil Brazilian company and one of the Brazilian firms that presents huge innovative efforts; Embrapa, an agricultural research institute that is quite important in Brazil and interacts both with universities and with firms; and Cemig, a power utility company, the interactions of which are stimulated by public policy. Among the top 12 firms that had linkages with a university in Brazil, the main industries were energy, including oil and gas; pulp and paper; and mining. It is important to mention that there are some public policy measures in Brazil that stimulate the interaction of firms with universities. Some of these measures apply for all industries, while others are specific to certain industries. This is the case for the energy industry in Brazil, since public policy forces firms to spend a share of their revenue in R&D. This often culminates in the establishment of joint projects with universities or public research organisations.

Other information available in the database concerns the distribution of interactions over the different knowledge areas. Many authors, such as Metcalfe (2003), pointed out that some knowledge areas, such as engineering, pharmacology, agronomy, computing and medicine, because of the nature of their scientific activities, tend to be closer to the problems of society and of firms. For this reason they often bridge the gap between academic activities and applied research within firms. Schartinger *et al*. (2002) also points out that different knowledge areas present distinct patterns of interactions, which is evident in the different types of mechanisms involved in linkages between firms and universities.

In the case of university-industry linkages in Brazil, the importance of Engineering and Agricultural Sciences is verified, as these are the areas with the largest number of interactions with firms (Table 2).

Table 2. Number of Interactions in each Knowledge Field.

Knowledge areas	**Interactions**	**%**
Engineering	1 869	41.8
Agrarian Science	946	21.1
Healthy Sciences and Biology	699	15.6
Natural and Earth Sciences	568	12.7
Human and Social Sciences	394	8.8
Total	**4 476**	**100.0**

Source: CNPq Directory of Research Groups, (2004).

These data show the important role played by these two knowledge areas in fostering firms' innovation in Brazil, which can be seen by the huge number of interactions with firms. Some of these interactions are characterised by more routinised activities and codified knowledge, such as laboratorial tests and essays or the supply of specialised inputs. However, there are a large number of interactions that are based on joint research projects between university researchers and firms' R&D staff, which involve a higher level of tacit knowledge sharing.

Thus, to evaluate the intensity of knowledge flows between firms and universities, the main types of relationship between the academic research groups and firms must be examined. When filling out the form, the research group leader is required to specify the type of interaction made with each firm. The leader can thus select up to three types of interactions out of the 14 types presented.

Table 3 shows all the different types of interaction that the research group leaders pointed out in the 2004 Census. Some of these interactions involve unilateral knowledge flows, moving from the research group toward the firm or vice versa, as is the case of technology transfer and product development.

On the other hand, there are other types of interaction such as joint research projects, which have a typically bilateral nature, in which there are stronger tacit, specific and complex knowledge sharing.

Table 3. Types of Interaction Between University and Industry.

			Knowledge flow direction	
Type of interaction	***Total***	***%***	***Firm***	***Research group***
Short-term R&D collaborative projects	2 422	27.5	x	x
Technology transfer	1 472	16.7	x	
Long-term R&D collaborative projects	1 206	13.7	x	x
Consultancy	680	7.7	x	
Training	510	5.8	x	
Material supply	385	4.4		x
Non-rotinized engineering	324	3.7	x	
Software development	254	2.9	x	
Technology transfer	220	2.5		x
Training	181	2.1		x
Software development	102	1.2		x
Non-rotinized engineering	97	1.1		x
Material supply	44	0.5	x	
Other	513	5.8		
NA	407	4.6		
Total	8 817	100.0		

Source: CNPq Directory of Research Groups (2004).

The most common type of interaction is the "Short-term R&D cooperative projects," which corresponds to 2 422 interactions or 27.5 percent. The second most common is "Technology transfer to the firm", with 1 472 interactions, and the third is "Long-term R&D cooperative projects," 1 206 interactions. These results show that a considerable share of interactions take place via joint research projects, which require the transfer of complex information and knowledge sharing in both directions..

4. RESULTS ON THE LOCAL DIMENSION

The use of data from the Directory of Research Groups allowed examination of the importance that geographic proximity has for the university-industry linkages in Brazil. An empirical test was built in order to study the differences in distance and the propensity to interact in different knowledge areas.

Regional Distribution of Firms and University

A preliminary analysis of university-industry linkages in Brazil shows that there is a strong regional concentration of research groups and firms in the Brazilian Southern regions. Taking interactions as the unit of analysis, it was clear that out of all the research groups that declared maintaining linkages with firms, more than half of the interactions occurred with research groups from three Southern Brazilian states: São Paulo, Minas Gerais and Rio Grande do Sul. If other states are added in the same region (Rio de Janeiro, Paraná and Santa Catarina), it turns out that they account for 78 percent of the interactions (Table 4).

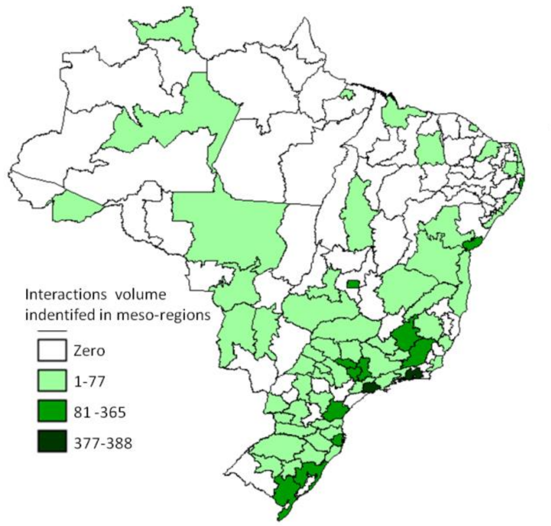
Table 4. Geographic Distribution of the University-Industry Linkages in Brazilian States.

	Location of the research groups			Location of the firms		
Ranking	State	n.	%	State	n.	%
1	São Paulo	1 227	27.4	São Paulo	1 307	29.2
2	Minas Gerais	607	13.5	Rio Grande do Sul	484	10.8
3	Rio Grande do Sul	549	12.3	Minas Gerais	469	10.5
4	Rio de Janeiro	424	9.5	Rio de Janeiro	454	10.1
5	Paraná	385	8.6	Paraná	358	8.0
6	Santa Catarina	303	6.8	Santa Catarina	293	6.5
7-27	Other	756	21.9	Other	212	24.9
	Total	4 476	100.0	Total	4 476	100.0

Source: CNPq Directory of Research Groups (2004).

This result is strongly linked with the regional distribution of income in Brazil, since these states account for a high share of the Brazilian gross domestic product (GDP) (70.3%). Other indicators of innovation, such as deposit of patents, innovative firms or scientific publications, are even more concentrated in these states. Conversely, the share of the total interaction of the other states is fairly low. The other 21 states together, only account for 21.9 percent of the total interactions of research groups. This confirms, for the Brazilian experience, the statement from Audretsch and Feldman (1996) that innovation is more concentrated in space than economic activity.

This spatial concentration is also seen in micro-regions. The top 20 micro-regions encompass 75.1 percent of interactions (i.e. 3 361 interactions). Figure 1 clearly illustrates this concentration, highlighting the high regional concentration of the university-industry linkages in Brazil, especially in the Southern regions.



Source: CNPq Directory of Research Groups (2004).

Figure 1. Regional Distribution of University-Industry Linkages in Brazil.

From the standpoint of the firms that interact with research groups, the circumstances are similar to those shown in Table 4. Likewise, most of the interactive research groups could be found in the same six states, with small changes in the positions. This means that the Southern concentration remains unchanged. In the micro-regions level, the concentration is only narrowly lower than for research groups; the share of the top 20 most interactive micro-regions is 63.8 percent (2 857) of all the interactions.

The Role of Geographic Proximity for University-Industry Linkages

In order to analyse the role of geographic proximity in fostering university-industry linkages, data from the Directory of Research Groups were ordered by the location of the interactive research groups and the firms.

Upon examination of the interactions between research groups and firms, it is evident that a huge share of the interactions (71.3%) take place within the same state. However, as stated by authors such as Breschi and Lissoni (2001), states are not the correct unit of analysis to examine the role of geographic proximity and its benefits. This is because the state unit is too large to foster the dissemination of information and knowledge sharing. Thus, it is not possible to assume that academic researchers and firms' R&D staff in a given state are more likely to have face-to-face contacts and to build local networks. Therefore, at the state level, diffusion of information and knowledge sharing do not occur in relation to geographic proximity. In the same way, Beaudry and Schiffauerova (2009) reinforce this problem, since the results of several empirical tests applied to larger areas turned out to be far less significant than those of lower geographic areas.

In order to overcome this problem, three different aggregation levels were used (states, meso-regions and micro-regions) to analyse the role of geographic proximity in university-industry linkages of less aggregated geographic levels. In addition, in the smaller spatial unit, the micro-regions, an analysis based on geographic distance was added.

An important measure of the role of geographic proximity is the number of interactions within the same region, i.e., the linkages between firms and research groups of the same region. As indicated by authors such as Zucker and Darby (1996) and Audretsch and Feldman (2004), the spatial proximity of the main sources of knowledge facilitate the access to differentiated knowledge flows and reduce the time involved in firms' learning processes. The examination of the co-located linkages shows that 49.1 percent of total interactions are of research groups and firms located in the same meso-region and 44.1 percent in the same micro-region (Table 5).

Table 5. Co-Localisation of Firms and Interactive Research Groups.

Geographic level (N = 4 476)	No.	Share (%)
Same State	**3 206**	**71.6**
Same meso-region	**2 196**	**49.1**
Same micro-region	**1 974**	**44.1**

Source: CNPq Directory of Research Groups, 2004.

This result shows the importance of geographic proximity for the interaction between academic research and the firms' innovative efforts. The main reason for the co-location of university and industry is that the knowledge flows generated by academic activities remain local and local firms can benefit from the geographic proximity. Furthermore, the co-location facilitates the establishment of joint projects between academic research and firms' R&D. Hence, the high number of interactions that occur in the same micro-region show the role of geographic concentration of both universities and firms, in which the local pool of capabilities, the local networks of professionals and face-to-face contacts are important factors to stimulate the diffusion of information and knowledge sharing between universities and firms.

It is worth observing that the results above, which show that university-industry linkages in Brazil are highly co-located, may have been heavily influenced by the spatial distribution of economic activity, since in Brazil the main economic and innovative indicators are strongly concentrated in Southern states. Hence, the geographic concentration of the university-industry linkages could be a result of a previous geographic concentration of economic activity. Many authors, such as Jaffe *et al*. (1993), stated that pre-existing location factors can influence the measurement of local knowledge spillovers, and the same statement can be applied to university-industry linkages. Therefore, it is necessary to control pre-existing location factors, in order to verify if, despite the geographic concentration of economic activity, university-industry linkages remain geographically concentrated. Without this kind of control, the co-localisation between research groups and firms could be related solely to the fact that research groups are close to firms, but not to the presence of externalities associated with the geographic proximity.

For this reason, the analysis of the localisation patterns of university-industry linkages requires the use of some methodological tools that can separate the importance of geographic proximity and the pre-existing concentration of agents. To do this, in the same way as Jaffe *et al*. (1993), a random control sample was built, in which previous location factors could be removed. The comparison between the database and the control group allows the analysis of the importance of geographic proximity for university-industry linkages, in spite of other location factors.

The construction of the control group is quite simple. It is presumed that the choice made by the firm to interact with the university is related to its specific needs in a certain knowledge area. Thus, the firm will search a research group that masters this knowledge and is able to help with the solution to its problem. A total of 77 sub-areas of knowledge were identified based on the Brazilian classification. Assuming the decision to interact is made by the firm, the control group was built by taking each firm of the original database and associating it with a new research group randomly selected among the groups of the same sub-area of knowledge. Thus, any chance that geographic proximity could influence the firm's decision to interact with the university was removed.

Through the randomisation, in the control group, the geographic proximity has no influence on the decision of the firm to interact, and firms can choose any research group in any part of the country, despite the existence of benefits related to the closeness to the university. Therefore, each interaction between a research group and a firm would have the same probability of occurring with any research group in that knowledge area, taking into account the unequal distribution of research groups in that field. If after randomisation the proportion of co-located interactions differs with statistical significance, it is possible to conclude that there is a non-random process underlying the location of university-industry linkages, and geographic proximity may play an important role for the interactions between research groups and firms.

One potential problem regarding the randomisation procedure is that some of the 77 knowledge sub-areas only had a small number of research groups. For example, in the database, 34 sub-areas presented less than 25 of the interactions in Brazil. In those cases, the random set of research groups is small and the probability that the original pair firm-research group is selected to the control group increases. This problem can introduce a bias toward co-localisation. However, this problem is not so important since interactions in those 34 sub-areas were responsible for a only 6 percent of the database. It would be possible to also use the type of interaction in the randomisation, since there could be a relationship between the distance and the type of interaction. However, this would impose a new restriction for building a control, since firms could interact with research groups in more than a one way. For example, a research group could engage in a joint research project with one firm and provide training to another one; or another group that has an agreement to transfer technology to a company acts via a consultancy contract with other firms.

In a preliminary examination of the results, the importance of the co-localisation could be seen by the share of interactions that took place in the same region. Table 6 presents the interactions between firms and research groups of the same state, the same meso-regions and the same micro-regions, both in the database and in the control group by knowledge areas.

Table 6. Comparison: Database and the Control Groups.

		Same state (%)		Same meso-region (%)		Same micro-region (%)	
Group	N	Interact	Control	Interact.	Control	Interact.	Control
All interactions	**4 476**	**71.6**	**21.5**	**49.1**	**8.4**	**44.1**	**7.6**
Engineering	1 869	72.0	22.7	47.9	9.0	43.5	8.1
Agricultural Sciences	946	69.3	18.7	37.2	2.7	28.9	1.9
Healthy Sciences & Medicine	699	72.2	21.7	54.8	9.2	50.5	8.0
Natural and Earth Sciences	568	69.4	15.5	53.2	7.0	49.3	6.5
Human and Social Sciences	394	77.7	30.5	67.0	19.8	64.7	19.0

Source: CNPq Directory of Research Groups, (2004).

A simple comparison between them shows that local interactions were more than three times higher in the database than in the control groups in every spatial aggregation level and for every knowledge area. This clearly shows that university-industry linkages are quite localised, which suggests the important role played by geographic proximity. This result is similar to what Jaffe *et al*. (1993) found in the analysis of patent citations in the U.S., using the same method of randomisation. At the micro-region level, where the benefits of the geographic proximity are more powerful, the co-localised interactions are up to five times higher, which strengthens the conclusion that geographic proximity matters.

Furthermore, by looking at the distinct knowledge areas, it is possible to see different co-localisation patterns. In the case of Agricultural Sciences, interactions are less co-localised than the average, even though localisation remains quite important since a huge share of interactions occurs in the same region, and almost 30 percent of all interactions take place in the same micro-region, ten times more than in the control group. On the other hand, Human and Social Sciences tend to be more spatially concentrated, since 64.7 percent of all interactions take place in the same micro-region.

Moreover, it is possible to analyse the difference regarding distance, in kilometers (km), between the location of research groups and firms. This was done both for the whole database and for the control group for each knowledge area. For both groups (database and control group), the distance from the centroid of the research group's to the firm's micro-regions was added. In the case of interactions within the same micro-region, a null distance was assumed. Table 7 shows the main results.

Table 7. Interactions Distance (in km).

Knowledge areas	N	Database Distance	Control group Distance	Geographic average distance+	Distance difference between areas#
All Interactions	4 476	294	936	1 502	-
Engineering	1 869	284	828	-	-10.2
Agricultural Sciences	946	323	1 047	-	28.5
Healthy Sciences and Biology	699	305	985	-	10.4
Natural and Earth Sciences	568	335	1,111	-	40.9
Human and Social Sciences	394	197	845	-	-97.6

Source: CNPq Directory of Research Groups – 2004.
+ This value was measured by the average value of a matrix with all distances between the 558 Brazilian micro-regions. It's important to point that the maximum distance between two micro-regions is 4 504 km.
 # The Engineering and Nature and Earth Sciences groups distance differences to the average of all groups presented no significance in the Wilcoxon rank-sum test with p-value of 0.6722 and 0.3262, respectively. The Healthy Sciences and Biology presented a p-value of 0.0236 and the others 0.000.

The average geographic distance between all the Brazilian micro-regions is very high, around 1 500 km. After creating the control group, in which the geographic distribution of all interactive research groups is considered, it was possible to observe a substantial decrease in distance to 936 km. In addition, in the examination of each knowledge area, the control group distance varies from 845 km in Human Sciences to 1 111 in Natural and Earth Sciences. In the same way as the share of co-localised interactions presented above, the distance of the interactions between research groups and firms of the control group is more than three times as high in comparison with the whole database. The difference between these averages is more than 600 km, which confirms that geographic proximity matters for the university-industry linkages, even when pre-existing location factors are controlled for. The average interaction distance measured in the whole database was 294 km while in the control group the average was 936 km. A Mann-Whitney U test (Wilcoxon rank-sum) revealed that these values were distinct at a 0.1 percent statistically significant level – it is important to note that it was not possible to apply a T-test because both Shapiro-Wilk and Skewness-Kurtosis tests rejected the normality both of the database and the control group. This led to the conclusion that geographic proximity plays a very important role in the university-industry linkages, as shown by the descriptive analysis.

Another important factor that may influence the distance of university-industry linkages is the knowledge area. Many authors, such as Metcalfe (2003), point out the different roles played by knowledge areas in the firms' innovative efforts, which implies different patterns of interactions with firms. In addition, Schartinger *et al*. (2002) points out that the firm's industry affects the collaboration with university. Since industries are differently distributed in space, they directly impact the average geographic distance of university-industry linkages. For example, industries more concentrated in large urban centres are normally closer to universities.

Table 7 presents the main patterns of interaction, in particular the last column indicates the difference for each knowledge area compared to the average of the whole database. There are significant differences among groups. Interactions between firms and research groups in Agricultural Sciences are 28 km farther than the average. On the other hand, interactions in Human and Social Sciences are almost 100 km closer than the average. It can be verified, therefore, that in some knowledge areas, such as Human and Social Sciences, interactions are more co-localised than others, such as Agricultural Sciences.

These differences could be associated with the spatial distribution of economic activities. The pattern of interaction in Agricultural Sciences, which is more dispersed in space, could reflect the dispersion of agricultural activities. Conversely, in Humanities, linkages to university are more local, probably linked to urban areas.

5. FINAL REMARKS

Universities are frequently presented in the literature as an important source of information and knowledge to firms' innovative efforts. Hence, geographic proximity between universities and firms can foster university-industry linkages, since face-to-face contacts and local knowledge networks are important ways of interaction.

Based on this assumption, this paper tries to shed further light on the role of geographic proximity for university-industry linkages. Data from the Brazilian Directory of Research Groups were used, as it has a comprehensive database on the research groups' activities in Brazil. The analysis shows a strong regional concentration of interactions in the Southern states of the country, and the top 20 micro-regions encompass slightly higher than three quarters of all the interactions. In terms of geographic proximity, a large share of co-localised interactions can be observed, since 44 percent of all the interactions occur between universities and firms in the same micro-region.

However, the geographic proximity, measured by the co-localized interactions, could be a result of the pre-existence of location patterns, since there is a huge geographic concentration of university-industry linkages in Brazil. In order to control these location pre-existent patterns, an empirical test was used with a control group, in the same way as Jaffe *et al*. (1993). The results show that, after controlling the pre-existing geographic concentrations of interactive academic research groups, geographic proximity remains an important factor for the university-industry linkages. In addition, geographic proximity plays a different role in each knowledge area in Brazil. For some knowledge areas, such as Human and Social Sciences, interactions occur more frequently in closer geographic areas; in others, such as Agricultural Sciences, linkages to university are more distant.

The main contribution of this paper is that there isn't a random geographic distribution of the interactions between research groups and firms, which allows us to conclude that university-industry linkages are strongly localized. This conclusion, based on the Brazilian experience, is in agreement with previous work, such as Jaffe (1989) and Audretsch and Feldman (1996), which identified the existence of co-localisation between university and firms. In addition, results show that there is a remarkable difference among the distinct knowledge areas.

The findings from this study also have important policy implications. The results emphasise the importance of universities in fostering firms' innovative efforts at the local level. In this way, policy measures should be designed in order to strengthen academic research at regional level, since local firms can benefit themselves from the local universities' activities. In this way, local research groups play a very important role not only by the creation of local capabilities, but also in the support of local firms' innovative efforts.

Even though the results show the importance of geographic proximity, there are some open questions that require further investigation. One being; what is the impact of the quality of the university on the role of geographic proximity? This question requires further investigation because the university's performance can affect the pattern of interactions between firms and universities (D'Este and Iammarino 2010; Laursen *et al*., 2010). Finally the type of collaboration between university and firms also requires further investigation (Schartinger *et al*., 2002).

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