

The Effect of Research Quality and Different Institutional Behaviour on the Relationship between Institutional and Geographic Distance in Scientific Publications

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The main goal of our research is to look in depth at the relationship between geographical and institutional distance in research collaborations: we ask whether such relationship is influenced by the importance and ambition of the research project and by the different behaviour of different institutions. We analyse a database including the publications done by the Italian biotech firms from 2003 to 2005; the institutions to which the authors of the publications belong are registered and classified in four categories (firms, universities, hospitals and research centres); their localization is registered too. We find that, considering the papers that receive few citations (which may be considered as results of project of limited scientific relevance or quality), the relationship between geographical and institutional distance is inverse; among more cited papers the relationship is direct. On another side, considering the behaviour of different institutions, we observe an inverse relationship between spatial and institutional distance for firms, universities and research centres, a direct relationship for hospitals.

Fields of Research: University-industry collaboration; Institutional distance; Spatial distance; Co-authorships; Knowledge flows; Scientific and Technological Policy.

1. Introduction

It is widely acknowledged that, in the modern knowledge-based economy, therefore particularly in science-based sectors, the innovation usually derives from collaboration of different agents, often located in different regions or countries and often belonging to different institutions (OECD, 1996). The patterns of collaboration across regions or countries, the ease given by modern information technology to distant collaborations and the persistent importance of vis-à-vis collaboration are themes widely investigated by the literature (Katz, 1994; Liang and Zhu, 2002; McKelvey, Alm and Riccaboni, 2003). On the other side, an abundant stream of literature exists on the difficulties deriving from collaborations between different institutions, particularly between university and industry, which have different research goals and incentive structure (Dasgupta and David, 1994; Frenken and Van Oort, 2004); anyway collaborations among different innovative institutions may bring benefits in terms of quality, because of the existence of complementarities (Bonaccorsi and Thoma, 2007; Iorio, Labory and Paci, 2012). Relatively less explored is the theme of the relationship between this two kinds of “distance”, the physical and institutional one, in research collaborations. Analysing this relationship is the main goal of our paper. A more articulated view about this issue may help to understand better how knowledge flows among innovative agents and to adopt better and more selective policy measures.

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We observe the phenomenon of research collaboration through the lens of co-authorship of scientific publications in the Italian biotech sector. This sector is particularly suitable for such kind of study, as it is characterized by a complex knowledge base, where the sources of expertise are widely dispersed and network relations are frequently used to access and to exchange this knowledge (Powell, Koput and Smith-Doerr, 1996).

Basing on a database including the publications done by the Italian biotech firms from 2003 to 2005, we build the network of co-authorships and we analyse it through the instruments of the regression analysis and of the social network analysis. The institutions of the authors of the publications are the nodes of the network. They are classified in four categories (firms, universities, research centres and hospitals) and their localization is registered too. We compare the national network of publications (the network generated by the publications done by authors all belonging to Italian institutions) with the international network of publications (the network generated by the publications done by authors belonging at least to one international institution), to verify if the inter-institutional collaborations assume different intensity in the two sub-networks. In this way we investigate the relationship between spatial and institutional distance. We sustain that, on a theoretical point of view, such relationship may be twofold. On one side, as both kinds of distance imply a cost, a trade-off may emerge: according to this view, international publications should be characterized by more homogeneous (on an institutional point of view) networks of publications. On the other side, highly specialised competencies are very dispersed, on a geographic and institutional point of view; therefore a firm that needs on-the-frontier knowledge activates an international and heterogeneous network of collaboration, while, if the required knowledge is more ordinary, a local and homogeneous network is activated.

We try to verify which direction of the relationship prevails. We test the hypothesis that this relationship may be influenced by the scientific relevance of the project that originated the paper (that we suppose may be measured by the citations received by the paper) and may be different for different kinds of institutions.

This paper adds a new contribution to the existing literature, as it looks deeper, beyond an aggregate analysis, into the issue of the relationship between institutional and geographic distance, assuming that the direction of such relationship is not univocal, but it depends on factors like the quality of the research and presents different signs for different institutions. Besides, the paper combines the use of analytical instruments usually used separately, like the regression analysis and the social network analysis.

The paper is structured in the following way: the second section presents: a review of the more relevant literature for our research; some hypotheses that may be formulated regarding the relationship between spatial and institutional distance; a brief illustration of the biotech sector and of the theme of scientific collaborations and consequent joint publications; in the third section a description of the data used for the empirical analysis can be found; the fourth session presents the results of the bivariate and multivariate analysis and of the social network analysis; a seventh section concludes the paper with some final considerations.

2. Literature Review

2.1 Spatial and Institutional Distance: A Literature Review

The specific focus of this paper is on the relationship between institutional and spatial distance in research collaborations: while an abundant theoretical and empirical literature analyses the effect of spatial distance on R&D collaboration, a more limited number of papers considers how this effect is mediated by other factors, like the institutional distance.

A first remark regarding the relationship between institutional and geographic distance may be found in Pavitt (1984) and DeSolla Price (1984), who assumed that collaborations between academic and non-academic organizations were more localised into space than collaborations between universities. Boschma (2005) explicitly states an inverse relationship between geographical and institutional proximity, as geographical proximity may compensate for the lack of institutional proximity and institutional proximity facilitates the interaction over long geographic distance. An important reference point for our study is the paper by Ponds, van Oort and Frenken (2007), as they analyse the role of geographical proximity for scientific research collaboration in science-based technologies between three kinds of institutions: academic organizations, firms and governmental/non-profit organizations. They observe the co-authorships in scientific publications, in eight technological fields, as registered in ISI-Web of Science from 1988 onwards. The spatial distance is calculated in great detail: it is the average travel time between the regions (defined at a NUTS-3 level) where the institutions are located. The consideration of institutional distance is less detailed: as reported above, three kinds of institutions are defined, and there is a distinction between collaborations among institutions of the same kind (no institutional distance) and of different kind (institutional distance). Their conclusion is that the collaborations involving different kinds of institutions are more localised than collaborations between the same kind of institutions: when institutional distance increases, spatial distance reduces.

The paper of McKelvey, Alm and Riccaboni (2003) is very interesting for us too, as the content of their study is similar as before and the sector they analyse is the same of our study, biotechnology; besides they consider a national case (Sweden). They find a trade-off between spatial and institutional distance: geographical co-location is more important for inter-institutional collaboration (firms with universities) than for collaboration among the same kind of institutions (firms with firms; universities with universities).

Other papers, even though not exactly focused on the theme of our interest, are relevant to our work, as they analyse the effect of spatial distance on collaborations through the interaction of other factors (kind of research, social distance, nature of the agents). Broström (2010), for example, explores if in university-industry interaction there is a relationship between the spatial distance and the kind of research involved in the project. He conducts a survey among the managers responsible for R&D in the engineering sector in Sweden and he finds that geographical proximity is important for short-term projects of a very applied nature, because the exchange of tacit knowledge is particularly relevant for this kind of research, while in long-term projects it is generally easier to work across geographical distance.

Autant-Bernard et al. (2007) analyse the role of geographical distance and of the “network effects” (the position and role in the network of collaboration) in affecting the probability to collaborate in R&D projects. The analysis is conducted among participants to 290 research projects submitted for the 6th EU Framework Program in micro and nanotechnologies. They distinguish among firms that are involved in many projects and firms involved in one single

project: analyzing only the “multi-project” firms, there is no evident influence of the spatial distance on the probability to collaborate, while there is a clear influence of the firm’s position within the network (number of direct and indirect partners; social distance between firms); if “single-project” firms are taken into account too, both geographical distance and social network effects matter, reinforcing the phenomenon of intra-national local clustering.

Even Scherngell and Barber (2009) find different effects of geographical distance on R&D collaboration in two different groups of agents: in this case the distinction is among private and public agents. Considering the collaboration among firms (industrial R&D networks), spatial distance seems to have an important effect on the probability to collaborate, while, analysing the public research R&D network (among universities and research organizations) the effects of geography are smaller. In both groups the technological distance is the most important factor. This analysis is conducted among the projects of the 5th EU Framework Programme.

Scherngell and Barber (2011) find that the spatial proximity increases the probability to collaborate between different organizations but other factors may act in the same way; such factors are: the thematic distance, the experience in projects of the same kind (the authors are analysing the projects of the 5th EU Framework Programme), the prior acquaintance and the centrality of the institution in the network of collaborations.

In many papers d’Amore and Iorio, with or without some co-authors, analysed the same database considered in the present paper, reaching several results. D’Amore et al. (2013), comparing observed collaborations with those observed by conditional randomization, find a trade-off between spatial and institutional distance if international and national dimensions are compared, while there is no statistical evidence of the trade-off comparing regional and extra-regional dimensions (inside the same country); they also consider the nature of the research (if basic or applied) and find that the trade-off holds in each kind of research; another result of this paper is that links become more homogeneous, on an institutional point of view, when more frequent collaborations are considered. D’Amore et al. (2012) look even more in depth to the relationship between the institutional and geographic distance, the nature of the research and the institutional homogeneity of the research groups. They find that the institutional-geographic trade-off holds for occasional collaborations, not for repeated ones. D’Amore and Iorio (2014) find confirm of the trade-off, even considering different indexes of institutional distance and even extending their analysis of Italian biotech firms publications in a period of sixteen years.

2.2 Expectations about the Relationship between Spatial and Institutional Distance

This paper has the aim to analyse the relationship between spatial and institutional distance in the research collaborations. The existing literature about these issues suggests the existence of two different effects: following Ponds, van Oort and Frenken (2007), it is possible to argue that both kinds of distance, spatial and institutional, imply a cost, that may be intended in direct monetary terms or in terms of “strength”; as agents try to minimise costs, there is a trade-off between the two kinds of distance: the more is the spatial distance, the less is the institutional distance and *vice versa*; therefore local networks should be more heterogeneous than international networks.

Indeed, another line of argument is possible, leading to an opposite conclusion: highly specialised competencies are very dispersed, on a geographic and institutional point of view: a firm that needs on-the-frontier knowledge activates an international and heterogeneous network of collaboration; if, on the contrary, the required knowledge is more ordinary, a local

and homogeneous network may be activated. If this argument is correct, local networks should be more homogeneous than international networks.

The first effect is substantially based on an idea of at least partial substitutability of collaborators (considered like a sort of inputs in the production of new knowledge), therefore the costs of factors have a role in the choice process: we may therefore call it a “resource based” effect. The second effect is based on the idea that particularly high competencies are difficultly substitutable and they must be taken “wherever they are”: we may call it a “competence based” effect,

Our hypothesis is that the two effects coexist and that the predominance of one or the other effect may depend on some specific factors: we suppose that the quality and relevance of the scientific project may be one of such factors: if an important research project is activated, involving a strong monetary investment, the need to save resources is less important than finding the proper competencies: in this case the “strength” of the “resource based” effect is weaker than the “competence based” effect and an indirect relationship between spatial and institutional distance is observed; and on the contrary, if the project is less ambitious, the aim to save resources may be prevalent, the first effect may be predominant and a direct relationship between spatial and institutional distance is observed.

Moreover, we suppose that different institutions have different behaviour and attitudes in managing the balance between the two kinds of distance, therefore the relation between spatial and institutional distance may be different for different kinds of institutions.

In the empirical part of the paper we will try to test which of the two effects fits better our data. We first conduct our analysis at an aggregate level, considering all the publications and institutions together; then we disaggregate our data according to the factors indicated above: the citations received by the papers, as an indicator of the quality and relevance of the research projects; the kind of institution to which the authors of the paper belong.

As empirical tools of analysis, we utilise both the regression analysis and the social network analysis.

2.3 Research Collaboration and Joint publications in the Biotech Sector

The theme of the relationship between spatial and institutional distance in this paper is empirically tested in a specific context, the Italian biotech sector. This sector is particularly suitable for a study about research collaborations involving different institutions because it relies mostly on inter-organizational collaborations. As stated by Powell, Koput and Smith-Doerr (1996), in the biotech sector the locus of innovation will be found in networks rather than in individual firms. There are many organizations where it is possible to find the knowledge, the expertise useful for the firm: it is possible to find it in the universities, in the research centres, in the hospitals.

The new knowledge generated by these collaborations not only takes the form of industrial innovations, but it is often disclosed through the scientific publications: research collaborations often generate co-authored publications. Over two-thirds of even formal alliance partners in this field also appear as partners in scientific publications (Gittelman, 2005) and there is a close link between successful patents and scientific publications (Gittelman and Kogut, 2003; Murray and Stern, 2007).

Therefore, if the aim is to study the characteristics of the knowledge exchanges inside a technological field, considering that data on publications are usually of high quality and easy to access, it is possible to study the publications of the firms.

3. Data

3.1 Sources of Data

In order to build a database of scientific publications in the biotech sector we made an intersection of two databases: *i*) RP Biotech data base; *ii*) ISI Web of Science. They are briefly described in the following.

RP Biotech data base. It is a collection of potentially all the Italian firms belonging to the biotech sector, active until December 2005 (d'Amore and Vittoria 2008; d'Amore and Vittoria 2009). In this study we considered only the 306 life-science for profit firms.

ISI databases, especially the Science Citation Index®, and the web-based version Web of Science, is a detailed bibliometric database of journal articles and citations of worldwide research literature, that contains 14.000 international peer-reviewed scientific and technical journals.

We obtained information about publications of the selected firms across the period 2003-2005. The record of each publication in ISI-Web of knowledge reports, among other kinds of information, the name of the authors and the name of the institutions to which the authors are affiliated. We extracted all the publications where the name of at least one of the selected firms (Italian life-science for-profit biotech firms) appeared among the institutions of affiliation. Then we identified five categories of institutions (universities, research centres, hospitals, Italian life-science for-profit biotech firms, other firms) and established which category each institution belongs to. In the following, except the presentations of the graphs, the category are reduced to four, as all firms are considered together.

The analysed case is particularly interesting and particularly suitable to our purpose, as biotech in Italy at the beginning of 21st century was an emerging sector (d'Amore and Vittoria, 2008), where firms needed many research collaborations to expand their knowledge base, and where small firms with limited project coexisted with big firms involved in important research projects.

4. Empirical Results

4.1 Descriptive and Regression Analysis

Table 1 shows some relevant statistics about our sample of Italian biotech firms' publications. We report the total number of publications done by Italian biotech firms in the period 2003-2005, the number and percentage of publications deriving from institutional collaborations, the number of different institutions involved in such publications and the average number of institutions involved in each paper. It is remarkable the frequency of institutional cooperation, as in almost 9 papers on 10 the authors belong to more than one institution.¹

Table 1: Descriptive statistics about publications and involved institutions

Total publications	1053
Publications in collaboration	918 (87.18%)
Italian biotech firms	115
Other firms	114
Universities	218
Research centres	134
Hospitals	289
All institutions	900
Mean number of institutions per paper	3.43

In order to analyse the impact of spatial distance, we divided the papers in two categories: national papers (all the institutions to which the authors belong are Italian) and international papers (at least one of the institutions to which the authors belong is not Italian). In our analysis we exclude papers written not in collaboration (written by authors belonging only to Italian biotech firms), therefore we have 918 papers. Among these, 550 (60.57%) are national papers, 362 (39.43%) are international papers.

We assume that in international papers the physical distance among the authors is larger. It is possible that this is not always true: the distance between two distant regions of Italy may be larger than between two locations near the national borders. But this distinction lets to simplify the analysis and we calculated on a random sample that it is, on average, largely true. Besides, a collaboration across the borders implies other kinds of distance, like cultural and linguistic ones, that are absent in national collaboration (we remember that in Italy only a few and little minorities do not have Italian as their main language², while, except a little region in Switzerland, in no other country Italian is spoken).

The first step of our analysis consists in calculating, for national and international papers, the average number of institutions to which the authors of the papers are affiliated: the average is 3.51 for national papers and 4.21 for international papers. Therefore the international networks of research are wider.

Then we consider the variety of institutions involved in the publications. We assume that the institutional distance is measured by the variety of institutions to which the authors of the paper are affiliated: if the authors belong to n institutions, the institutional distance is larger than in the case the authors belong to less than n institutions³.

In our analysis we consider four kinds of institutions (firms, universities, research centres and hospitals) and we calculate how many kinds of institutions the authors of the papers belong to. Among national papers, the authors belong, on average, to 2.34 kinds of institutions; among international papers to 2.35 institutions.

From this results we should conclude that, when spatial distance increases, the number of involved institutions increases too, but there is no variation in the institutional distance. But this conclusion is not fully convincing: as an higher number of institutions increases the probability to have an high variety of institutions (in fact the number of institutions and the number of kinds of institutions involved in each paper are highly and significantly correlated: 0.521, significant at 99%) we need to verify the relationships between spatial distance and the variety of institutions also *ceteris paribus*, that is controlling for the number of institutions. The proper question is: *given the number of institutions*, do international papers have an higher or lower variety of institutions?

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We need therefore a multivariate analysis, where the institutional distance among the authors of the paper (measured by how many kinds of institutions are involved in the paper) depends on the spatial distance among the institutions (measured by their national or international nature), controlling for the number of involved institutions. In the basic model, assuming the single paper as unit of analysis, we have therefore as dependent variable the number of kinds of institutions to which the authors of the paper are affiliated (we call this variable KINDINST); a dummy variable assuming value 1 if the paper is “international” and value 0 if the paper is “national” is the independent variable (INTERNAT) and the number of institutions to which the authors of the paper are affiliated (NUMINST) is the control variable.

Dummy variables for years and firms may be added: the world of scientific research and publication is rapidly and continuously changing, therefore even a quite limited period may imply systematic changes that could be controlled through year dummy variables; on the other side, the unit of analysis is the single publication and each publication is connected to an Italian biotech firm (at least one author belongs to an Italian biotech firm), but each Italian biotech firm may be connected to one or more publications; as the behaviour about publications of different firms may be systematically different, firm dummy variables may be useful in controlling for these differences.

As the dependent variable can assume only four integer values, from 1 to 4, the ordered probit is the more suitable technique.

In Table 2 we show the results and the relevant statistics of the ordered probit regression of the restricted model (without dummy variables) and of the extended one (including dummy variables).

Table 2: Determinants of the number of kinds of institutions involved in the co-authorship of a publication - ordered probit

Independent Variables	Coefficients (Standard errors)	
INTERNAT	-0.2111319*** (0.0783275)	-0.1234008 (0.0954058)
NUMINST	0.337165*** (0.0211192)	0.386217 *** (0.0256089)
Year dummy variables	Excluded	Included
Firm dummy variables	Excluded	Included
Statistics		
Number of observations	918	918
Log Likelihood	-828.53096	-694.16601
LR Chi2	(2) 290.16	(114) 558.89
Prob>Chi2	0.0000	0.0000
Pseudo R² (McFadden)	0.1490	0.2870

Dependent variable: KINDINST

***Significant at 99%

Standard errors in brackets

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The coefficient of INTERNAT is negative. This means that, given the number of institutions involved in each paper, in international papers, on average, less typologies of institutions are involved than in national papers: when spatial distance increases, institutional distance decreases. But this coefficient, significant at 99% in the restricted model, in the extended model is not significantly different from zero.

We also observe that the relationship between NUMINST and KINDINST is positive and significant in this multivariate analysis too. The inclusion of firm dummy variables largely increases the goodness of fit of the model, while the increase given by years dummy variables is weak.

The results we obtained, both bivariate and multivariate, show that, even if there are some signals of a negative relationship between spatial and institutional distance, there is no convincing statistical evidence in this sense. As regards the two effects identified in the theoretical section of the paper, one implying a negative relationship between spatial and institutional distance, the other implying a positive relationship, these results are consistent with the coexistence of the two effects, up to the point that the net effect is not clear.

If the two effects coexist, we also assumed in the theoretical section that their strength may be different with different scientific relevance and quality of the research projects. Among the low quality papers the negative relationship between spatial and institutional distance should prevail, while a positive relationship should prevail among high quality papers.

Relevance and quality may be measured by the citation received by the publications. Therefore a group of regressions could be run, among differently cited papers. If the hypothesis formulated above is correct, the sign of the coefficient of the variable indicating the spatial nature of the co-authorships (INTERNAT) should increase when the number of citations increases; it should be negative among little cited papers, positive among highly cited papers.

As the number of citations received by a paper tends naturally to increase over time, a good way to conduct this analysis is to take into consideration the papers published in the same year, grouping them according to the number of citations received (the database, including the number of citations, has been built during 2006).

In Table 3 we show the results of the regressions run among the papers published in 2004. We have the results of four regressions: the first one among all the papers published in 2004; the second one among papers which had received no citations; the third one among the papers that had received one, two or three citations; the fourth group includes the papers that had received at least four citations (the number of citations is chosen in order that the three sub-groups are of similar consistency).

The results are consistent with the expectations: when the number of citations increases, the coefficient of INTERNAT is progressively increasing, turning from a negative to a positive sign. More precisely, testing the complete models, with year and firm dummy variables, the sign of the variable INTERNAT is negative and significant at 99% among the never cited papers, greater but still negative and not significant at 95% among the little cited papers, positive and significant at 95% among the most cited papers.

The results, not shown here, are similar if the same kind of regressions are run among the papers published in 2003 or among those published in 2005⁴: the coefficient of INTERNAT

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shows the same increasing value, turning from negative among the never cited papers to positive among the more cited papers.

We can synthesize the results we obtained in the following way.

The international papers involve more institutions than national papers, but there is no significant difference in the variety of institutions, that we assume as a measure of the institutional distance. When the relationship between the variety of institutions and the geographical nature of the paper is verified in a multivariate context, no clear evidence emerge about it: when spatial distance increase, it can not be excluded that there is, on average, no variation in the institutional distance. It is possible that the two effects identified in section 2.2 (the “resource based” and the “competence based” effect), leading to opposite results (respectively: indirect and direct relationship between spatial and institutional distance), coexist.

These conclusions hold considering all the papers together. But, if we distinguish the publications according to the number of received citations (that is an indicator of relevance and quality) we see that among little cited papers, when spatial distance increases, the institutional distance decreases; among highly cited papers the opposite holds: spatial and institutional distance move in the same direction. It is therefore possible to conclude that the two effects coexist but, when the quality and relevance of the scientific projects increases, the strength of the “resource based” effect decreases and the strength of the “competence based” effect increases ⁵.

**Table 3: Determinants of the number of kinds of institutions involved in the co-
authorship - papers published in 2004 grouped by number of citations – ordered probit**

	All papers published in 2004	Papers published in 2004 with 0 citations	Papers published in 2004 with 1, 2 or 3 citations	Papers published in 2004 with 4 or more citations
Independent Variables	Coefficients (Standard errors)			
INTERNAT	-0.2393038 (0.1851845)	-1.345745*** (0.517334)	-0.2752135 (0.4997519)	0.8314411** (0.3851284)
NUMINST	0.4058566*** (0.0554129)	1.134806*** (0.2207921)	0.4736707*** (0.1728966)	0.4534034 (0.1053319)
Firm dummy variables	Included	Included	Included	Included
Statistics				
Number of observations	295	112	86	97
Log Likelihood	-180.76667	-44.213856	-31.078813	-57.833268
(df) LR Chi2	(77) 215.81	(48) 134.02	(47) 83.95	(39) 81.61
Prob>Chi2	0.0000	0.0000	0.0000	0.0001
Pseudo R² (McFadden)	0.3738	0.6025	0.5746	0.4137

Dependent variable: KINDINST

***Significant at 99%; **Significant at 95%

4.2. Results of the Social Network Analysis

In order to explore more in depth the spatial and institutional distance in the scientific collaboration among universities, research centres, hospitals, Italian life-science for-profit biotech firms and other firms, we decided to look at the structure and properties of their co-authorship relations.

Generally, Social Network Analysis (SNA) focuses on studying relationships among individuals or groups of individuals which represent the nodes of the network.

Methods for Social Network Analysis applied to co-authorship data give the possibility to examine the knowledge flow throughout a scientific community. These techniques have been used by many authors to investigate the co-authorship networks in different scientific disciplines. Barabasi et al. (2002) and Newman (2004) analysed the structural features and collaboration patterns of knowledge diffusion among researchers in biology, mathematics and physics. Moody (2004) examined a structurally cohesive core in collaboration networks by testing some models for the sociological co-authorship networks. Goyal, Van der Leij and Moraga-Gonzales (2006) investigated the evolution and the properties of co-authorship relations among economists. De Stefano, Giordano and Vitale (2011) analysed how the use of different adjacency matrices can produce a major insight into the author role and position in co-authorship networks in different scientific disciplines.

Before representing the data as a co-authorship network, we used an affiliation matrix \mathbf{Z} of size $(n \times m)$, where the rows represent the set of institutions and the columns represent the set of publications written by the authors affiliated to the institutions. In this matrix the generic element $z(i, j)$ ($i = 1, \dots, n; j = 1, \dots, m$) equals 1 if the paper j was written by the author affiliated to the institution i and 0 otherwise. From the affiliation matrix \mathbf{Z} we derived an adjacency matrix \mathbf{A} ($n \times n$):

$$\mathbf{A} = \mathbf{Z}\mathbf{Z}^T .$$

\mathbf{A} is an undirected weighted adjacency matrix. The value of the element $a(i, j)$ represents the number of co-authored papers for institutions i and j . If two institutions have no publication in common, the entries are equal to 0. The diagonal elements represent the total number of publications for each institution and were removed from the matrix \mathbf{A} . If we are interested in taking into account only the presence and absence of ties we have to transform the matrix \mathbf{A} in an undirected binary adjacency matrix by setting all entries greater than zero to "1". Because the information about frequency of collaboration is lost by considering the binary adjacency matrix, we decided to focus further analysis on weighted adjacency matrix.

In addition to relational information, we associated two categorical attributes with each node: institutional type (universities, research centres, hospitals, Italian life-science biotech firms, other firms) and geographical location (Italy, Europe, Extra-Europe).

In order to evaluate if the behaviour of the actors toward the institutional distance is different when geographical scale changes, inside the whole network of co-authorships we considered three sub-networks on a geographical basis. The first network is the national network which includes only Italian institutions (derived from publications written only by Italians). The second one is the international network which represents collaboration among institutions of the papers written by at least one international author. The "pure" international network is the

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network obtained from the international network by eliminating links among institutions belonging to the same nation.

The following figures (Figure 1, Figure 2, Figure 3) show the graphs of the three networks. Different shapes represent the different kinds of institutions (while in the previous analysis we considered four categories of institutions, in the graphs below there are five categories, because the Italian biotech firms are distinguished from the other firms), different colours represent different localizations (in the graphs there is the distinction between Italian, European and Extra-European institutions, but in all the analysis we only considered the dichotomization Italy-abroad).

Figure 1: National network

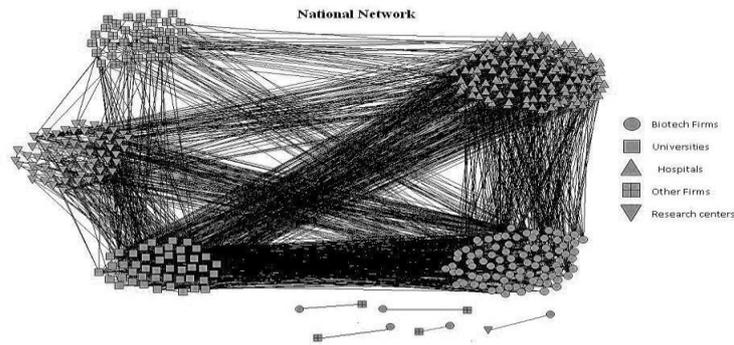


Figure 2: International network

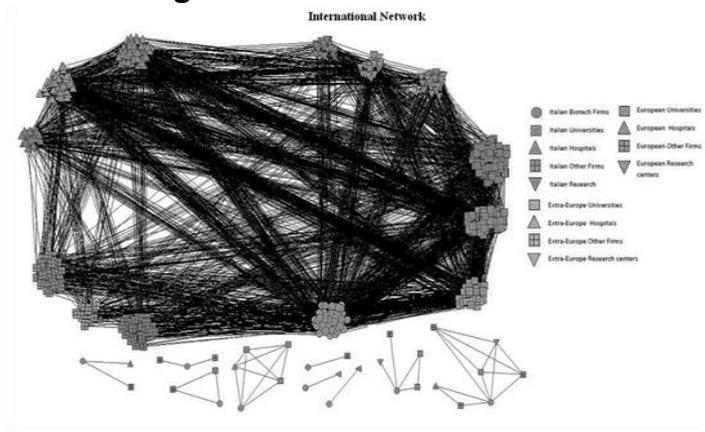
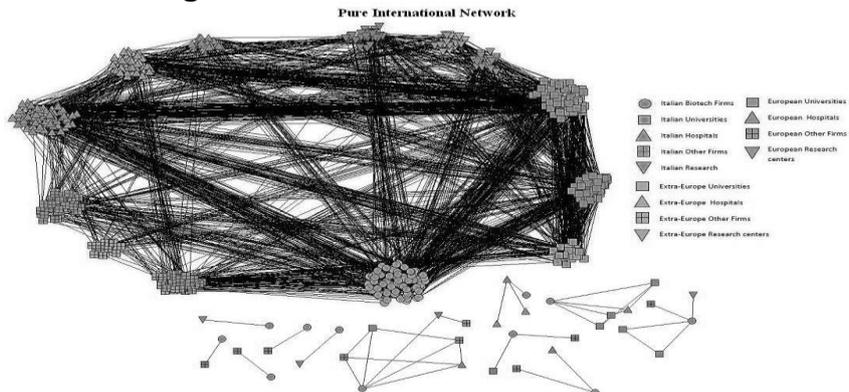


Figure 3: Pure international network



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Table 4 shows the basic statistics describing the structural characteristics for the three networks. In the case of valued network the density is calculated as the total of all values divided by the number of possible ties. Respectively for the national network, the international network and the pure international network the density values are 0.034, 0.019 and 0.012. Analysing the connectivity of the actors, we observed that in the national network there are several components, one large of 369 nodes and 5 sub-groups of 2 nodes which have no connection to the largest group.

This means that there are some Italian biotech firms which wrote papers only with one institution and did not create their collaboration network. In the international network we notice 10 different components: one very large component of 636 nodes, 3 components of 2 nodes, 3 sub-groups of 3 nodes, 2 sub-groups of 5 nodes and 1 component of seven nodes. For the pure international network, respect to the international network, we observed that, by eliminating links among institutions of the same nationality, we derive other two components with 2 nodes, 2 sub-groups of 3 nodes, 1 sub-group of 4 nodes.

In order to analyse the position of the single institutions in terms of their popularity and relational activity, their ability to influence or control communication and the capacity of a node to be reached, we calculated respectively three measures of centrality: degree centrality, betweenness centrality and closeness centrality. We noticed that in the national network the central role belongs to three universities (Milan, Bologna and Rome). In the international network three different kinds of institutions (the hospital San Raffaele in Milan; the University of Turin; the firm Sigma Tau) show the highest values of degree, betweenness and closeness centrality. In the pure international network the most central roles are played by the hospital San Raffaele in Milan, the firms Sigma Tau and Bracco Imaging and the Leiden, Leuven and Munich. Since technically closeness centrality cannot be computed if the network is not connected, this centrality measure was calculated for the main component of the network.

Table 4: Main statistics for the three networks

	Number of nodes	Number of edges	Density (St. Dev)	Number of components
National Network	379	3694	0,034 (0,26)	6
International Network	668	6158	0,019 (0,2)	10
Pure International Network	668	3784	0,012 (0,16)	12

In order to investigate our specific issue -the relationship between spatial and institutional distance- we need to analyse if the national network is more or less homogeneous, on the point of view of co-authorship relations among different institutions, than the international networks. In this part of analysis the institutional distance will be seen as the heterogeneity of relations among different institutions in the networks under analysis.

In order to measure which network (national or international) has more homogeneous linkages, we focus on the E-I index proposed by Krackhardt and Stern (1988). This index

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measures the relative homophily of a group while comparing the numbers of ties within groups and between groups and it is defined by:

$$\mathbf{E-I\ index = (E-I) / (E+I)}$$

Where **E** (External) is the number of external ties (ties between nodes belonging to different groups) and **I** (Internal) is the number of internal ties (ties between nodes belonging to the same group). The E-I index can be applied at three levels: the entire population, each group, and each individual. It ranges from -1 (all ties are internal, **E=0**) to +1 (all ties are external, **I=0**).

In our case the groups are the four kinds of institutions. A co-authorship relation between two firms indicates a collaboration within the same group, therefore it is an internal link; a co-authorship relation between a firm and a university is a collaboration between two different groups, therefore it is an external link. The value of E-I index is a measure of the mean propensity of each institutional actor to collaborate with a “different” actor rather than with a similar one.

As we decided not to lose the information about the number of publications two institutions wrote together, we proposed to calculate the E-I index taking weights of ties into account. In this case the values of **E** (External) and **I** (Internal) are obtained by summing the tie strengths instead of the number of respective ties. In our opinion it is important to save the values on the edges while calculating the E-I index, because they influence the final result and interpretation of this index. Table 5 shows the values of the E-I index for the three valued networks.

If, according to the prevalence of the “resource based” effect, in the international collaborations the institutional distance decreases, the links are more homogeneous than in the national networks, therefore the E-I index should be smaller in the international network than in the national one. The opposite according to the prevalence of the “competence based” effect.

We observe a small decrease in the value of the index moving from the national to the international network (comparing national and pure international network the difference is even smaller). This result is consistent with the prevalence of the “resource based” effect, which states that more spatial distance results in less institutional distance and *vice versa*.

Table 5: E-I index for the three valued networks

	E-I index
National network	0.486
International network	0.435
Pure international network	0.465

If we want to compare this analysis with that developed in section 4.1, we have to observe that data are investigated from a different point of view. In the previous analysis the institutional distance has been seen as the variety of institutions co-authoring a paper; here we focus on the relations among different institutions in their co-authorship network and the institutional distance is seen as the heterogeneity of linkages.

A weakness of the analysis based on the E-I index is the lack of multivariate considerations. Nevertheless, through the network analysis, it is possible to observe, in a quite easy and synthetic way, an important aspect: the relationship between spatial and institutional distance in collaboration networks of different kinds of institutions. For this purpose we calculated the value of the E-I index for each institution, then we calculated the mean value for each kind of institution: results are shown in Table 6.

Table 6: E-I index for each kind of institution

	National network	International network	Pure international network
Firms	0.789	0.448	0.384
Universities	0.353	0.236	0.215
Research centres	0.831	0.707	0.698
Hospitals	0.083	0.185	0.250

We observe that firms, universities and research centres have a lower E-I index in the international networks than in the national network. It means that, when physical distance increases, the collaborations become more homogeneous, that is the institutional distance reduces. On the contrary, for hospitals we notice an higher E-I index in the international network. It means that, when spatial distance increases, the collaborations become more heterogeneous and the institutional distance increases too.

Therefore the direction of the relationship between spatial and institutional distance is different for different kinds of institutions. This may be due to the fact that different institutions have different objectives and attitudes.

Universities and research centres often base their research networks on personal knowledge: on a local basis it is easy to contact people belonging to different institutions; in a broader spatial context, it is common to meet people belonging to universities in conferences et *similia*, while it is more difficult to meet people belonging to other institutions.

Italian biotech firms are often sections of multinational companies: the collaboration with the headquarter and the other sections, both located abroad, is more frequent than the collaboration with other Italian firms; therefore the homogeneous collaborations are more frequent on an international than on a national scale.

For hospitals, it particularly holds a “competence based” effect: having the solution of practical health problems as their main goal, they find the competencies “wherever they are” and “whoever they belong to”.

5. Conclusions

In this paper we analyse the co-authoring networks in the scientific publications of the firms belonging to the Italian biotech sector, in order to understand the relation existing between spatial and institutional distance.

Two effects are identified: according to a “resource based” theory, as both kinds of distance are a cost, a trade-off among them exists, therefore when spatial distance increases, institutional distance decreases. According to a “competence based” theory, it is possible to suppose that highly specialised competencies are very dispersed, on a geographic and institutional point of view, therefore a firm that needs on-the-frontier knowledge activates an international and heterogeneous network of collaboration; if the required knowledge is more ordinary, a local and homogeneous network is activated; according to this “resource based” view, an increase in spatial distance goes together with an increase in institutional distance.

We suppose that the two effects coexist. Using the regression analysis and the social network analysis, particularly through the E-I index, we conclude that both analyses do not evidence a univocal relationship between spatial and institutional distance: this result is consistent with the coexistence of the two effects described above.

Moreover, we suppose that the prevalence of one or the other effect depends on factor like the research quality and the institutional behaviour: analysing disaggregated data, according to the quality/relevance of publications (measured by the citations received by each paper) and to the “institutional” level, we obtain more articulated results, consistent with our hypothesis. In fact, we observe that the direction of the relationship between the two kinds of distance changes when the quality/relevance of publications increases: among little cited papers, when spatial distance increases, institutional distance decreases; among more cited papers the opposite holds; this does not contradict the coexistence of the two effects, but it is possible to assume that they have different strength according to the quality/relevance of the papers. The institutional-level analysis shows a different behaviour for different institutions: for hospitals, when spatial distance increases, institutional distance increases too; for firms, universities and research centres the opposite holds.

On a methodological point of view, this paper shows the utility to treat a research issue with different analytical tools and under different perspectives, that may allow to capture different aspects of the problems. Under the point of view of new contents, this kind of analysis may shed more light on the way knowledge flows in an innovative sector and should be taken into consideration by the policy maker that aims to promote research collaboration between different institutions: a careful consideration of the role played by different kinds of distance and of the behaviour of different institutions in managing the proximity issue may be useful in designing proper policy measures in a field that is so important for the competitiveness in the contemporary knowledge-based economy.

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This paper comes from a strict collaboration between the authors. Anyway, sections 2.1, 2.3, 3 and the first part of 4.1 (until Table 2 and its comments: page 9, first and second paragraph) have been written by Rosamaria d'Amore; sections 2.2 and the second part of 4.1 (after Table 2 and its comments: page 9 from third paragraph) by Roberto Iorio; section 4.2 by Agnieszka Stawinoga; introduction and conclusion have been jointly written.

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Endnotes

¹ A more detailed description of the biotech sector, of the data and more statistical information may be found in d'Amore, Iorio and Stawinoga (2010); the present paper may be considered a further step of the research project begun with that paper, so that the two papers share some descriptive parts.

² The greatest linguistic minority is represented by almost half of the inhabitants of the province of Bozen, who are German speaking.

³ If a paper is written by six authors, two of them belonging to the firm Rossi S.P.A, two to the University of Milan, one to the University of Turin and the other author to the University of Rome, the number of institution involved is four and there are two kinds of institutions (firm and university). If another paper is written by five authors, one of them belonging to the firm Bianchi S.P.A., two to the University of Naples and two to the Hospital of Florence, the number of institutions involved is three and there are three kinds of institutions (firm, university, hospital). We assume that the institutional distance is greater in the second paper, as the variety of institutions is greater (even if their number is smaller; neither the number of authors has an influence on the institutional distance).

⁴ Considering the papers published in 2003, the coefficient of INTERNAT is negative among never cited papers; greater but still negative among papers with 1 to 3 citations; positive among papers with 4 or more citations; these coefficients are never significant at 90%.

Considering the papers published in 2005, the coefficient of INTERNAT is negative and significant at 90% among never cited papers; greater but still negative and not significant at 90% among papers with 1 to 3 citations; positive but not significant at 90% among papers with 4 or more citations.

⁵ The results of a probit analysis should be interpreted in terms of probability: coefficients measure the probability that, given an increase in the independent variable, the dependent variable increases or decreases. We avoid this terminology for the sake of language simplicity.

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