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Managing long distance and localised learning in the Emilia Romagna life science cluster

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Abstract

The paper provides some empirical evidence of the effectiveness of the "open innovation" model in the life science cluster of Emilia Romagna (a region of Italy), comparing the network of R&D collaborative activities in public research organisations (PROs) and the network linked to R&D collaborative activities in private firms. By presenting the main results of a field research in the life science sector in Emilia Romagna, we are contributing to the recent debate focused on the crises of the old "close innovation" model and the rise of the "open innovation" model. Our survey consists of both primary data deriving from face to face interviews with researchers and entrepreneurs, and secondary data extracted from the Internet, the PubMed database, and from the European Patent Office. Our work is based on the analysis of a representative sample of 30 research groups in PROs, 2173 scientific articles published by the interviewed scientists, and a representative sample of 78 private firms.

Keywords: life science sector, learning at the boundaries, R&D, networks, open innovation model

1 Introduction

Innovation is increasingly seen as the result of an interactive process of knowledge generation and exploitation. However, while the advantages of collaborative relationships are widely accepted, the geography of innovation linkages is still a debated issue.

On the one hand, clustering processes of high-tech industries are largely diffused in several world regions, emphasising the advantages of spatial proximity for technological innovation. The studies on clusters and innovative milieux argue that the concentration of firms and supporting organisations in specific industries fosters innovation thanks to the advantages of spatial proximity, social embeddedness, interaction with local institutions, and knowledge spillover (Camagni, 1991; Cooke, 2002; Maskell and Malmberg, 1999; Porter, 1998; Storper 1997).

On the other hand, regions and clusters are nowadays part of complex productive architectures with mobile boundaries, which influence, and are in turn influenced by, the existence of global commodity chains (Gereffi et al. 2005; Guerrieri et al. 2001, Van Dijk and Sverrisson 2003). For firms embedded in regions and local industrial clusters, an important outcome of the globalisation processes is the possibility of deploying multiple innovation sources, which are located inside and outside the locale, implementing localised and long distance learning, through the access to external R&D cooperation with international actors (Moodysson, Coenen, and Asheim, 2006). As a result, the technological evolution of densely agglomerated areas appears in part to be organised through external linkages and distant R&D/technology collaborations (Giuliani et al., 2005, Markusen 1996, Belussi, Pilotti and Sedita, 2006).

By means of knowledge offshoring the role of spatial proximity seems to be diminished, while organisational proximity is enhanced by the formation of international business networks and small-born multinationals, within an open innovation model. Modern regions and local industrial clusters, in fact, combine patterns of localised learning with dynamics of external learning (due to the process of external knowledge scanning, absorbing, exploiting and exploring).

The aim of this study is to investigate the propensity to build research networks in the life science sector, comparing the geography of innovation linkages established by a sample of firms and Public Research Organisations (PROs) localised in the Italian Region of Emilia Romagna. Thus we contribute to the debate on the evolution patterns of regions and clusters in advanced countries, focusing, in particular, on the learning process for innovation shaped by the new challenges linked to the globalisation process. In order to explore the relative importance of these two important sources of learning, which constitute important drivers for innovative activities, we conducted during 2005 a survey on the Emilia Romagna life science sector, interviewing both private and public organisations devoted to innovation. We adopt a definition of life science sector that includes firms specialised in medical machinery, appliances, pharmaceuticals, and biotech, together with research groups specialised in biomedical and biotech research in public research organisations (hereafter PROs), namely Universities and interdisciplinary centres of several Faculties (Biology, Chemistry, Molecular Biology, Pharmacy, Physics, Engineering, Medicine, Veterinary, Pathology, and Biomedical Science). Results from the interviews, integrated with secondary data (European Patent Office – EPO and Pubmed) were elaborated statistically and through social networks tools.

The paper proceeds as follows. Section 2 describes the main research aims of our work and puts forward our working hypotheses. Section 3 provides a brief description of the theoretical background, which ties up with our hypotheses, tested in the empirical part of the paper (Section 4). Finally Section 5 is dedicated to the presentation and discussion of the results, while Section 6 proposes some concluding remarks and hints for further research.

2. Research field and questions

The life science sector emerged in the mid-1980s, as a new technological trajectory which combines medical, agrochemical, chemical, and pharmaceutical science (Tait et al, 1990). In life science firms, the organisation of R&D activities is based on the exploration of new scientific knowledge at the frontier of new scientific discovery. In this sector there is a low demarcation between science activities and technological activities, perceived as a technical application of the new scientific principles. The absorption of various heterogeneous knowledge deriving from new discoveries in science, and from their recombination in firms, is the main component of the innovative activity of the enterprises. The innovation activity introduced in firms is therefore strongly tied to R&D projects in basic research, and to the acquisition of new knowledge developed in public scientific institutions (Arrow, 1994), often typically organised within networks (Powell et al. 1996). Life science organisations produce and absorb knowledge in a continuous game of interactions, that produces a hybridisation of the possessed knowledge, and generates a cumulative process of acquisition of knowing and competences (Dasgupta and David, 1984; Winter, 1987; Antonelli, 1999; 2002). The availability of complementary knowledge and activities in product/technology experimentation and in commercial nets advocates the necessity of recombining different and distant (but equally necessary) competences, in many fields such as biological and medical knowledge, engineering and computer science knowledge, mechanical knowledge and knowledge tied to the use of new materials. In life science sectors the importance of institutions is of overwhelming significance for the advancement of science and technology (Cooke, 2002; Nelson and Levin, 1986; Nelson, 1992). Private companies benefit strongly from the possibility of using and accessing scientific sources of new knowledge.

At present, life science sectors provide one of the most efficient and effective platforms for analysing the existence of interactions between a network of innovators, occurring through research co-operation between entrepreneurs and scientists. At the same time, in life science the issue of technological and scientific spillovers appears equally important, because they both take place among distant and localised relationships between firms and public research centres, or in networks of enterprises characterised by the presence of leading actors. The ubiquitous presence of networks appears to be not just a characterisation of life science firms, but also a constant element of the modern corporation (Gulati, Nohira, and Zaheeer, 2000).

The paper aims to explore the geography of the learning networks of PROs and firms, operating in the life science cluster in Emilia Romagna. It does so by studying the R&D cooperative relationships of PROs and firms, and the impact on their innovative performance.

The idea is to illustrate separately the networks of research collaborations which are originated by firms and by PROs, to validate the open innovation model at the private and the public level. Are the networks originated by firms different from the networks originated by PROs concerning the type of partners, their geographical location, and their impact on the innovative performance?

With this research, by adding some “fresh” results obtained from our empirical analysis, we intend to enrich the debate on innovation, testing:

a. the crises of the old “close innovation” model, and the rise of the “open innovation” model;
b. the overwhelming importance of distance learning in determining the innovative performance of firms and PROs;
c. the significance of localised learning for the continuous upgrading of the stock of knowledge possessed by firms and PROs;
d. the possible spatial mimetic convergence of PROs’ open science research networks and firms’ technological collaborations.

3. Theoretical background and working hypotheses

An extensive literature on strategic and innovation management suggests that firms can enhance their innovativeness and performance through external collaborations (Doz and Hamel, 1998; Gulati, 1999; Gulati et al., 2000; Hagedoorn, 1993, 1995; Hagedoorn and Schakenraad, 1992; Zaheer and Bell, 2005). There are several motives for the establishment of innovation collaboration. Firms may team up to spread the costs and risks associated with the innovation process (Arora and Gambardella, 1994; Gambardella, 1998), especially in industries characterised by increasing development investments, such as pharmaceuticals, telecommunications and aerospace. Collaboration between users and suppliers of new products and technologies can be aimed to establish technical standards and dominant designs. Pavitt (1984) argued that a relevant part of innovations adopted by the firms originates externally and involves their customers and suppliers, especially in the so-called supplier-dominated sectors. One of the most widely cited motives for collaboration is the acquisition of knowledge and capabilities from partner firms (Hagedoorn, 1993; Hamel, 1991; Mowery et al. 1996). The increasing complexity of products urges the mobilisation of heterogeneous technological competencies and emphasises the need for complementary resources that are not usually available to a single firm's technological asset, especially to small firms with limited financial, managerial and technical resources. Indeed, inter-firm collaborations are one of the possible means of access to essential knowledge held by other companies, which are difficult to imitate or to acquire on the market (McEvily and Marcus, 2005; Gulati, 1999).

However, while the advantages of collaborative relationships are widely accepted, the geography of innovation linkages is still a debated issue. Our analytical context explores contemporarily two distant (but interwoven) streams of literature: the clustering of life science activities in specific regions, where leading scientific institutions appear to play a catalytic role, and the existence in firms of the "open innovation" model, which supports both internal and external knowledge searching activities.

The clusterisation of life science activities

As argued by Cooke and Huggins (2004, p. 112), "high technology or knowledge-based clusters are one of the most visible manifestations of what Storper & Scott (1995) term the construction of place-specific economic culture and order". The increasing role of agglomeration processes highlights the fact that knowledge production and innovation do not arise in an abstract space. They are strongly rooted in specific local environments, which include also social and institutional components. Knowledge can be tied to a locality but it can also float across space. We do not live in a borderless world, because firms, labour forces, capital, and technological competences distinguish one place from another (Morgan, 2004). Evolutionary theories of economic and technological change have indeed replaced deterministic growth models with a broader view on the process of innovation as a non-linear process, involving many related activities (Carlsson, 1994; Smith 1994). Because knowledge is generated, transmitted, and shared more efficiently in close proximity, economic activity based on new knowledge has a high propensity to cluster in a geographic area. This is crucial for an industry such as biotechnology whose survival is based upon continuous innovation streams.

Crucially, differences in economic performance of national and sub-national (regional and/or local) innovation systems have shown that different local contexts offer disparate possibilities for knowledge creation (Lundvall, 1992; De la Mothe and Paquet, 1994). In general, localised industry-university collaborations have been claimed to be fruitful for both the actors involved in the relation

(Lundvall, 1992; Etkowitz, 1998). They have also been empirically investigated in the life science sectors (Niosi, 2003). Empirical research on knowledge and firms dynamics demonstrates a dual local-global logic of localisation and knowledge flows around nodes of excellence interconnected by global networks (Feldman , 2004; Coenen, Moodysson, and Asheim, 2004)

The emergence of life science clusters, or mega-clusters (Cooke, 2004), within the more ample category of high-tech systems (Saxenian, 1994) has been systematically reviewed in the literature. Some famous examples are the area of Cambridge and Oxford in England, San Diego (DeVol, R. Wong, Ki, Bedroussian, and Koepp , 2004), Boston and Minneapolis in the United States (Feldman, 2001), or the scientific park of Sophia Antipolis, in France (Longhi, 2002). Many authors have described in detail the existence of both intense local research-oriented interactions and external R&D collaborations. Benefits from networking, under the shape of alliances, are sustained by some scholars (Baum, Calabrese and Silverman, 2000), who tested the positive performance of Canadian biotech firms involved in alliances. Dahlander and McKelvey (2005) have provided a typology of external collaborations focusing on their occurrence and spatial distribution in a small cluster: the biotech firms of Gothenburg.

Both the literature on innovation systems (Lundvall 1992; Nelson 1993; Cooke 2001) and the triple helix model (Etzkowitz and Leydesdorff, 1997) have stressed the importance of close interactions among heterogeneous actors, such as large firms and SMEs, venture capitalists and local high-tech firms, producers, end users, local firms and universities or other public and private research institutions. Networks in biotech are considered as the appropriate new organisational form to deal with exploitation and exploration issues (Gilsing and Nooteboom, 2006). Asheim and Gertler (2005) have stressed that even in sectors characterised by the presence of a scientific (analytical) knowledge base, like in biotech, where knowledge tends to be highly codified, there is not less, but more spatial concentration. Spatial concentration appears to be linked to large companies, forefront institutions, leading universities, and localised human capital, like star scientists (Zucker and Darby, 1998).

Only few studies take into account the spatial distribution of R&D collaborations. Some authors have suggested that among co-located partners localised research collaborations should be more frequent and effective. Indeed, for the success of research collaborations, given the complexity of the innovation process, direct contacts between partners would be required (Pisano et al. 1988). The main idea behind this assertion is that spatial proximity enables the transfer of tacit knowledge and facilitates the exploitation of knowledge spillovers (Maskell 2001; Malmberg and Maskell, 2005). In contrast, other authors have emphasised the importance of research external linkages with geographically distant partners, claiming that, in high-tech industries, innovation requires knowledge that is both “global best” and “diverse” (Dahalander and McKelvey, 2005). In this latter view, since the search for partners is highly selective and targeted on specific strategic or complementary competences of potential partners, innovation networks are often on an international or even global scale, especially in knowledge-based industries such as ICT and biotechnology (Powell 1998; McKelvey et al. 2003). On the same line of reasoning Casper and Murray (2004), question the issue if biotech clusters develop superior capabilities to commercialise science. In fact, they argue, whether or not their marketplace is bounded depends on their social network-like setting for their interaction. Many firms indeed are clustered but they draw on the resources of a global marketplace. However, the importance of co-location for innovation is not undermined. In a different research project, focused on the analysis of Swedish biotech firms, McKelvey, Alm and Riccaboni, (2003) found both a local, a national, and a global pattern of R&D collaboration. Studying the pattern of co-publication among some scientists in Medicon Valley, which is used as an illustrative case, Coenen, Moodysson, and Asheim (2004) have underlined another aspect, which represents an intermediate logical position. Functional proximity (accessibility) is often underpinned by relational proximity (closeness in term of relations, references and knowledge), fostering interactions within the same epistemic community, but the role of spatial proximity should not be neglected.

The "open innovation" model

West and Gallagher (2006, p. 82), following Chesbrough (2003), defined open innovation as an activity of firms devoted to *"(…) systematically encouraging and exploring a wide range of internal and external sources of innovation opportunities, consciously integrating that exploration with firm capabilities and resources, and broadly exploiting those opportunities through multiple channels"* Few companies can afford to develop novel technologies internally . Open innovation processes combine internal and external ideas into architectures and systems. It can be understood as the antithesis of the traditional vertical integration model where internal R&D activities lead to internally developed technologies and products. Open innovation involves the use of purposive inflows and outflows of knowledge to accelerate internal innovation, and expand the markets for external use. Chesbrough claimed that also modern firms have dropped the "do-it-all-yourself" approach. Companies import ideas from outside, and let their own innovations enter the wider marketplace through licensing and spin-offs. The theoretical caveat in the "open innovation" model, where a network of external actors is participating in the collective innovation process, is to identify whether these external sources are potentially substitutes or rather complementary to internally organised R&D efforts.

Indeed, some scholars considered in-house R&D as a prerequisite for an effective use of external ties, since it is expected to increase firm's absorptive capacity and attractiveness for potential partners (Cohen & Levinthal, 1990; Dahlander and McKelvey, 2005). Others have maintained that external ties are themselves an appropriate *locus* for innovation, therefore undervaluing the role of internal R&D activities (Powell et al., 1996).

In the close innovation model, small firms, which are often not able to afford large investments in R&D, occupy an inferior position. In contrast, small firms in an "open innovation" perspective are less at a disadvantage, because they may utilise a network of fruitful knowledge-based relationships with other organisations (Lipparini and Lorenzoni, 1996; Lipparini, 1995; Lipparini and Sobrero, 1994; Boari and Lipparini, 1999). Again, firm size in the emergent "open innovation" model is no longer an obstacle. Relational and co-ordination capabilities of firms (Lorenzoni and Lipparini, 1999), and research labs, allow the establishing of a positive spiral of learning.

Some recent studies attempted to capture the dynamics of the open innovation model at firm level. Laursen and Salter (2006) investigated the search strategies at firm level in UK manufacturing firms finding: a) a positive relation between firm openness and innovative performance, and b) a substitution effect between internal R&D and openness.

As admitted by Chesbrough, the "open innovation" model follows a long-term tradition of innovation studies, and stands on the shoulders of many previous contributors. Richardson in a seminal paper set down the criteria on the basis of which, in the industrial organisation, an extensive cooperation emerges in the market. Activities are carried out by organisations with *"appropriate capabilities, or, in other words, with appropriate knowledge, experience and skills"* (Richardson, 1972: 888). The emergence of a complex network of cooperation is explained by the need to combine closely complementary but dissimilar activities (from R&D to marketing) that in certain circumstances cannot be allocated either straightforwardly to the market (because of the existing complementarities with firm assets), or to the firm itself (because it lacks the required capabilities).

Nelson and Winter (1982) modelled the firm's decision to search for new technologies outside its own organisation. Cohen and Levinthal (1990) discussed the "two face" role of R&D activity: in order to develop their capabilities, firms invest both in new knowledge creation and in "absorbing capabilities". The literature has broadly documented that innovative dynamics are not held within organisational borders or single firms' research units. A relevant part of innovations adopted by the firms originates externally and involves their customers and suppliers, especially in the so-called supplier-dominated sectors (Pavitt, 1984).

Eric von Hippel (1988) has identified several sources of useful external knowledge for firms: suppliers and customers, competitors, universities and research centres. This is, in substance, the model at work in Italian industrial districts (Belussi, Gottardi and Rullani, 2003) where firms increase their internal knowledge by developing numerous channels capable to absorb (Belussi, Pilotti and Sedita 2006) information (meetings, participation in fairs), codified technical knowledge (acquisition of patents, reverse engineering, R&D innovative outputs provided by local universities), or know-how (consultants, strategic alliances with knowledgeable suppliers).

For Wernerfelt (1984) and Teece, Pisano, and Shuen (1997), successful firms are those which invest in "strategic resources", not just in R&D or in new technology, but in human capital, know-how, managerial organisation, marketing, after-sales services, and in efficient relations with suppliers and sub-contractors. Coombs and Metcalfe (2000; 2002), have also argued that the process of innovation is becoming more distributed across firm boundaries than in the past. Co-operating with external actors (research labs or institutions) is an opportunity to multiply the learning occasions, mostly in knowledge-intensive sectors. The Triple Helix model (Etzkowitz and Leydesdorff, 1997) has deeply stressed the importance of interactions between universities, firms and government in the process of evolution of innovation systems.

Many scholars have underlined the importance of network ties for fostering innovation (Zaheer and Bell, 2005). On one hand, because R&D assets are characterised by decreasing returns, after a certain threshold, firms are pushed to collaborate and to exploit synergies with external partners. This reduces the costs and risks associated with the innovation process (Arora and Gambardella, 1994; Gambardella, 1998; Lipparini, 1998; Gargiulo and Mariotti, 1999). On the other hand, the increasing complexity of products urges the mobilisation of heterogeneous technological competencies and emphasises the need for complementary resources that are not usually available to a single firm's technological asset, especially to small firms with limited financial, managerial and technical resources. Indeed, inter-firm collaborations are one of the possible means of access to essential knowledge held by other companies, which are difficult to imitate or to acquire on the market (McEvily and Marcus, 2005; Gulati, 1999).

The "open innovation" model, as a process of achieving new knowledge in firms, should not be limited to R&D alliances, but must include also the participation of firm's employees in social networks, such as the local communities of practice (Lave and Wenger, 1991; Brown and Duguid, 1991; Wenger, 1998).

The meta-level of analysis, which adopts the perspective of the region or the local industrial cluster, is often neglected in the literature. Our contribution aims to fill this gap by analysing the Emilia Romagna life science cluster and the feasibility of an open innovation model to support the functioning of local R&D activities.

The identification of some testable hypothesis

The paper provides new insights on the relative importance of long distance learning as opposed to localised learning through R&D cooperative networks in the industrial and science system, and assesses the relationship between networking and innovative performance of both firms and PROs. By doing so the paper sheds light on the issue of whether the research networks originated by firms differ from the networks originated by PROs concerning the type of partners, their geographical location, and their impact on innovative performance.

Specifically, the research design adopted in the study aims to provide new empirical evidence on the following issues detailed in three working hypotheses:

e. to what extent do firms and PROs rely on distance learning to foster their innovative performance?

f. What is the role of localised learning for the continuous upgrading of the stock of knowledge possessed by firms and PROs?

g. Is there a spatial mimetic convergence of PROs open science research networks and firms technological collaborations or, conversely, do the industrial and science systems show divergent patterns in the geography of innovation linkages?

4. Data collection, sampling procedure and measures

This research is based on an empirical survey on the life science sector in Emilia Romagna, organised with a field study, and a consequent statistical elaboration of the constructed database. We consider both primary data from face to face interviews with researchers and entrepreneurs, and secondary data from the Internet, the European Patent Office, and the PubMed database. We have investigated the innovation strategies of 78 firms and 30 PROs operating in the life science sector out of a constructed Emilia Romagna universe of 513 firms and 135 research/groups in PROs.

4.1 The sample of firms in the Emilia Romagna life science sector

Our research work started with the identification of the regional life science cluster from the existing databases (we used the CERVED archive, provided by the Italian Chamber of Commerce for the registered firms – not only legally founded but also operative, and we updated this archive through other sources: websites inspection, interviews with regional experts and the use of firm associations archives, like Consobiomed, the association of small firms of the biomedical district of Mirandola). We selected 3 large productive segments:

- firms belonging to the biomedical sector, and that produce medical appliances and disposables for diagnosis and therapeutic aims;
- firms in pharmaceutical and biotech sectors, even if the latter is little developed both in Italy and in the Emilia Romagna region;
- firms that have developed specific ICT applications in the field of distance telemedicine[1].

In turn, the biomedical sector was subdivided into 4 sub-areas, as shown in Tab. 1: diagnostics, therapeutics (complex machinery), disposables, and other electro-medical (or parts) or non-therapeutic machinery (other apparatus and appliances)[2].

Tab. 1: Sectoral classification of life science firms: universe and sample of selected firms

Manufacturing firms of the Emilia Romagna life science cluster	Revised Cerved population		Sampled firms (productive and commercial)	
	Firms	Employees	Firms	Employees

[1] We derived this archive from the firms that have participated in the programmes of research support for innovation launched in Emilia Romagna in recent years (PRIT and PRAI), see Belussi and Di Bernardo (2005).
[2] See Appendix A for a short description of the sub-sectors of activity of the enterprises inserted in the sample.

	N	%	N	%	N	%	N	%
Diagnostics	12	2.34	31	0.27	5	6,4	28	0,62
Therapy and rehabilitation	106	20.66	3,306	28.42	11	14,1	2,535	56.73
Disposables	157	30.60	1,917	16.48	28	35,9	892	19.97
Other appliances	211	41.13	1,947	16,74	21	27.0	680	15.21
Pharmaceutical and biotech	14	2.73	4,264	36.65	3	3,8	165	3.69
Computer science applied to medicine	13	2.53	169	1.45	10	12,8	169	3.78
Total	513	100.0	11,643	100.0	78	100.0	4,469	100.0

Source: our elaboration on Cerved data, website and interviews made with sector experts.

The Emilia Romagna life science cluster appears quite significant – about 500 firms and about 11,600 employees (data refer to all productive and commercial firms). The main sectors are, respectively, therapeutic and rehabilitation, other appliances, and pharmaceutical and biotech. Our sample follows this ranking, but two large pharmaceutical firms, initially included in the survey, were subsequently excluded, because either their R&D research laboratories were located outside Italy or the information was insufficiently completed. Firms were sampled with simple random sampling techniques. We assigned the firms to each sub-sector using the information obtained directly during the interview, or using the Cerved archive (which describes the firm activity in detail).

In comparison with the extracted sample we received few refusals, thus the sample of interviewed firms corresponds strongly to the original sample[3]. Our semi-structured interviews were done directly by the research group financed by the Emilia Romagna Region (Fiorenza Belussi, Tito Casali, Massimo Gastaldon, Alessia Sammarra), in the period March-September 2005. The interview was mainly organised with the entrepreneur, owner of the firm, or with the manager delegated by him to deal with this type of activity. Interviews lasted 1-2 hours and they were focused on the history of the firm, product, innovation capability, R&D investments, patents, markets, number of competitors, recent trends of growth, external R&D cooperation, and the relationships with the regional supporting institutions. The whole results of this work are published in Belussi (2005).

From a spatial point of view, the interviewed enterprises (Tab. 2) are above all concentrated in the province of Modena (42 cases corresponding to 53.8% of the firms, and 84% of employees), where we find the Italian biomedical industrial district of Mirandola[4], which counts about 80 firms and 5,000 employees (quite small if compared with Medicon valley between Lund and Copenhagen with 1,000 firms and 34,000 employees, see Medicon Valley, 2003). The other important area is Bologna (22 firms interviewed). The regional cluster contains a clear-cut industrial district, and a mosaic of niches of dispersed producers mainly localised along the Modena-Bologna axis, where also numerous regional clinical institutions and universities are situated. There are, then, some important university centres and medical clinics in Ferrara and Parma).

Tab. 2: Localisation of the life science firms in Emilia Romagna: the sample

								Total
	Bologna	Modena	Parma	Piacenza	Reggio Emilia	Ferrara	Mantova	Sample

[3] We excluded firms involved only in assistance services, because they are not firms endowed with innovation and technological capabilities.

[4] The district enterprises are located in a small bunch of municipalities, which show high contiguity, like Camposanto, Cavezzo, Concordia, Finale Emiliano, Medolla, Mirandola, S. Felice, S. Possidonio and S. Prospero.

Diagnostics		2	0	0	0	0	3	0	5
Therapy and rehabilitation		4	7	0	0	0	0	0	11
Non durable materials		2	24	0	0	0	0	2	28
Other equipments		9	8	2	0	1	1	0	21
Pharmaceutical and biotech firms		1	2	0	0	0	0	0	3
Enterprises of computer science applied to telemedicine		4	1	1	2	2	0	0	10
Total	Firms (%)	22 (28.2)	42 (53.8)	3 (3.8)	2 (2.6)	3 (3.8)	4 (5.2)	2 (2.6)	78 (100)
	Employees (%)	393 (8.8)	3,759 (84)	56 (1.3)	8 (0.2)	83 (1.8)	70 (1.6)	100 (2.2)	4,469 (100)

4.2 The sample of research labs in the Emilia Romagna life science sector

Let us now discuss the method used for sampling the centres/groups of research belonging to the Emilia Romagna PROs. We construct the population starting from the recent virtual lab organised by Prof. Calzolari on biotech. We also add the centres included in the census by Aster (the regional agency for innovation and training of the Emilia Romagna Region). So, we reach a total number of 135 research units (see Tab. 3), mainly located in public universities[5].

Tab. 3: Localisation of centres/groups of research belonging to public structures in Emilia Romagna involved in the life science sector: population and sample

								Total	
	Bologna	Modena	Parma	Piacenza	Reggio Emilia	Ferrara	Mantova	Sample	Population
Biochemical and molecular biology						1		1	17
Biology									12
Chemistry	2	1						4	15
Pharmacy		1				3		4	7
Physics									1
Engineering		2						2	2
Interdisciplinary centres		1						1	2
Medicine	11	1	2			1		15	53
Morphology and animal production		2						2	2
Animal Pathology	1							1	6
Biomedical Medicine									18
Total	18	4	2			6		**30**	**135**

Source: our elaboration on information extracted from the interviews made with members of the labs.

These centres/research groups are related to the Faculties supporting biotech, molecular biology, biochemical, and biomedical research[6]. We selected a sample of 30 centres/groups of research, and

[5] See Appendix B for a short description of the sub-sectors of activity of the research labs inserted in the sample.

[6] We choose the criterion of belonging to faculty, for the problem of data aggregation, because many departments are founded by different faculties, and have various names.

a senior member was interviewed: typically an Associate or a Full Professor. The interviews were done in the same period of 2005. Interviews lasted about one hour. They were focused on collecting information about: a) the estimation of the total available R&D funds for the year 2004, b) the research conducted, c) the number of patents obtained by the centre personnel, d) the size of the centre, e) the self-evaluation of the excellence of the research conducted, and f) the existence of external links for the realisation of cooperative research. Later, we used the PubMed data to check the publishing activity of the interviewed researcher (we analysed only 29 cases because one interviewed person was a technician without any research record). Not all information collected was used in the presented statistical analysis.

4.3 Some descriptive results: the importance of being connected

Following Dahlander and McKelvey (2005), we gathered relational data on the occurrence and spatial distribution of research collaborations among the sampled firms and PROs. Specifically, respondents were asked to list the number of research collaborations they have established with other organisations in the period 2000-04 and to indicate the geographical location of each partner.[7].

We focussed specifically on the geographical extension of the R&D collaborative relationships.

The research questions to which we have tried to provide an answer were respectively: is the metaphor of the "open innovation" model a workable hypothesis for the description of the innovation model of the Emilia Romagna life science firms? Is the occurrence of external research collaborations a diffused phenomenon? Are life science firms using extensively external innovation sources? Are firms more involved in locally (regionally) based R&D relationships or do they tend to build global R&D linkages? In order to explore our analysis the following variables were utilised, both related to measures of performance (output indicators) and to the input of innovative activity (R&D, innovations sources, and existence and localisation of external R&D linkages).

We computed several relational variables which measure the number of research links established by the respondents. With respect to the partners involved, we classified research links in four categories: (i) firm-to-firm (N_F2F), (ii) firm-to-PRO (N_F2P), (iii) PRO-to-PRO (N_P2P), and (iv) PRO-to-firms (N_P2F) relationships. With respect to the geographical location of partners, we classified research links in three categories: (i) regional (N_REG), national (N_NAT) and foreign (N_FOR) relationships.

We computed attribute variables measuring the innovative performance of firms, using the number of patents registered in the period 2000-2004 (N_PATENTS) as a proxy. Other firms' variables included the amount of investments in R&D allocated by the firm during the year 2004 (RD_EXP), the number of employees (expressed in logarithms) as the measure of size (SIZE), and the number of years from foundation as age. We also calculated the number of publications (N_PUBINT)[8] as a measure of PROs, innovativeness and the total funds and costs for research activities as a proxy of internal innovative investments (TF). In our explorative analysis we also

[7] The software used to analyse relational date is Ucinet 6 (Borgatti et al., 2002).

[8] This information is derived from an accurate screening of PubMed, which is to our knowledge the most complete collection of biomedical articles. It allows access to more than 11 million citations of scientific journals and links to the full-text articles. This powerful life science database has been created and daily updated by the National Centre for Biotechnology Information (NCBI), a division of the National Library of Medicine (NLM), belonging to the National Institute of Health (NIH), USA. NCBI is updating the archive about all international research in molecular biology, biochemistry and genetics to provide information to the community of researchers and doctors. N_PUBINT is the number of international publications of the interviewed researcher of the single research laboratory in the sample signed in during the period 2000 to 2004.

calculated for firms and PROs the correlation between some of the main indicators of innovation intensity, such as networking activities[9], innovative effort and absorptive capacity[10] (RD_EXP; RD_SHARE – for firms, and TF – for research lab), innovative performance - number of patents (N_PATENTS)[11] and number of publications (N_PUBINT).

All variables entered in the analysis are listed and briefly described in Tab. 4.

In our study the networking activities indicator N_REL corresponds to the total number of external collaborative relationships established for research purposes by each PRO and firm. This indicator is used to asses the impact of external research relationships on the firm's and PRO's capability to exploit innovations and on their future returns (both in terms of performance and funds delivery).

Tab. 4: Variables description, year of analysis: 2004

Phenomenon	Variable	Description
Occurrence	OPEN	Openness indicator (dummy – YES/NO)
Networking	N_REL	Number of external relationships
	N_SOURCE	Number of external sources of knowledge for innovation
Type of relation	N_F2F	Number of firm-to-firm relations
	N_F2P	Number of firm-to-PRO relations
	N_P2P	Number of PRO-to-PRO relations
	N_P2F	Number of PRO-to-firm relations
Spatial distribution	N_REG	Number of relations within the region (Emilia Romagna)
	N_NAT	Number of national relations (within Italy)
	N_FOR	Number of foreign relations (outside Italy)
Internal innovation efforts and absorptive capacity	RD_SHARE	Share of R&D employees (R&D employees/#employees)
	RD_EXP	R&D expenditure – log
	TF	Public and private research funds+labour costs
	N_PATENTS	Number of patents owned by the firm
	N_PUBINT	Number of international publications since 2000

4.3.1 The role of external research relationships in the sample of firms

First we considered the role of external relationships in shaping the networks of research collaborations originated by firms.

[9] We aim to use some proxies to reflect the networking activities of firms and PROs: the number of direct collaborations enacted by each single firm or PRO (firm-to-firm, firm-to-PRO, PRO-to-PRO); and the number of external sources of knowledge for innovation.

[10] Innovative and absorptive capacity is represented by two proxies (RD and TF). The information on the amount of research and development investments (RD) is derived from the European Patent Office Database. We decided to integrate this information with the entrepreneurs' declarations, to avoid the risk of not considering the patents not signed by the firm, but by the individual researcher regularly employed by the firm. Total funds (TF) is the sum of research funds (public and private) plus labour costs.

[11] N_PATENTS measures the number of patents owned by the single firm in the sample; the information comes from face to face interviews with entrepreneurs, controlled with the European Patent Office. Earlier studies have suggested, and assumed, that patents are a fairly good indicator of the inventive output of the research department of a firm and a measure of the "output" or "success" of R&D (Bound, Cummins, Griliches, Hall and Jaffe, 1982; Hausman, Hall and Griliches, 1984), although they have only been able to prove a simultaneity in the year-to-year movements of patents and R&D, which appear to be dominated by a contemporaneous relationship (Hall, Griliches and Hausman, 1986).

Considering all types of relationships (N_REL), tab. 5 informs us of the occurrence of the external learning phenomenon, showing that out of the 78 firms interviewed, 45 (58% of all sampled firms) have established external ties, motivated by the desire to implement shared R&D activities, reaching a total number of 170 collaborations. The model of "open innovation" thus appears to be a dominant feature of the Emilia Romagna life science firms.

If we investigate the typology of collaboration, and we thus discriminate between private firm-to-firm collaborations and semi-public firm-to PROs linkages, it emerges that the firm-to-PRO modality covers the majority of detected ties (153 ties registered by 44 firms, corresponding to 56% of the sample). Only 8 firms corresponding to 10% of the sample have established research collaborations with other enterprises, involving a total number of 17 ties out of 170. So there is a strong diversity (in terms of frequency) depending on the type of actors involved. It appears evident here that firm-to-firm relationships (N_F2F) have an absolutely marginal diffusion. This result is quite remarkable, and in contrast with the given emphasis provided by the literature to the ample existence of interfirm (firm-to-firm) collaborations[12]. In the Emilia Romagna case, the public actor dominates the local model of open innovation. As we shall see below, this underlines the importance of the role played by regional institutions in providing the necessary knowledge inputs to local life science based firms.

In terms of spatial distribution, Tab. 5 shows some interesting variations across the two sets of relationships analysed. Firm-to-firm collaborations, considering the 17 firms involved, occur primarily with European enterprises (41%), followed by national (29%) and extra-European ties (18%). Collaborations with enterprises localised in the Emilia Romagna region are indeed less frequently organised (12%). Therefore, firm-to-firm relationships are more likely to occur with distant partners. In contrast, the spatial distribution of firm-to-PRO collaborations offers a different picture. Firms in the sample have established half of their external ties with regional PROs (50%), followed by ties with national (31%), European (16%) and extra-European (3%) PROs. Therefore, firm-to-PRO relationships are more likely to occur with local partners.

The availability of numerous proximate PROs suggests that firms may prefer a local co-located partner because regional PROs are more accessible (in terms of sharing common language, identity, and openness of knowledge exchange). However, all things considered, spatially bounded (regional) relationships do not dominate over global (national and international) relationships.

4.3.2 The role of external research relationships in the sample of research labs

In this section we investigate the behaviour of the interviewed PROs, when it comes to innovation through networking. Tab. 6 shows the diffusion of external research collaborations among the sampled PROs in the Emilia Romagna life science sector and the distribution in terms of typology and spatial location of external partners.

In terms of occurrence, we found that 87% of the research labs interviewed have established collaborations with external partners. In our sample, thus, PROs have a higher propensity than firms to be engaged in research relationships. With whom do PROs mainly collaborate? While before the majority of firms do collaborate with PROs, here the majority of PROs collaborate with other PROs. So, in this case, the most diffuse modality is the PRO-to-PRO collaboration. Out of the registered 194 ties, 148 are with PROs and 46 with firms. In terms of spatial distribution, there is a fair amount of similarity across the two sets of collaborations analysed. Both PRO-to-PRO and PRO-to-firm relationships are more frequent with regional (respectively 43% and 41%) and national partners (respectively 34% and 35%). In general, research collaborations with European (15% and 7%) and non-European (8% and 17%) partners are less likely to occur, showing that research

[12] See for instance the research findings reported by Dahlander and McKelvey (2005) for the Gothenburg population of biotech enterprises where the authors found that 43% of the firms were involved in firm-to-firm relations, measured through formal arrangements.

organisations in our sample have a low propensity (and/or ability) to be engaged in international research networks. Like in the case of firms, spatially bounded (regional) relationships do not dominate over global (national and international) relationships. This reminds us of the important role of external learning also for local institutions.

Fig 1 and 2 map the geography of research collaborations for the two types of organisations: firms and PROs R&D networks. Some actors are weakly inter-connected at regional level and only few of them show an elevated number of ties. The geography of science collaborations related to the PRO networks shows a striking symmetry with the technological networks activated by firms. One would have expected that science collaborations would be less spatially clustered than technological collaborations, as emerged in the US case discussed by Gittelman (2006). The spatial mimetic convergence of PROs open science research networks and firms technological collaborations appears perhaps to blur a "pick and place" mechanism which is in place where there no longer appears to emerge a clear ranking of hierarchical relations with central actors.

4.4 Relation of networking and innovativeness

Several studies have provided empirical evidence on the positive correlation between collaborative ties and company performance measures. Most studies have dealt with firm-to-firm relationships, while inter-organisational relations between PROs and private companies are less investigated (Stuart and Podolny 1999; Powell et al. 1999; Ahuja 2000). In order to integrate these previous studies, we conducted a correlation analysis between the relational variables and the innovative performance of both PROs and firms.

In order to provide some empirical evidence able to suggest the existence of an "open innovation" model, we processed our data to investigate the correlation between external relationships, innovativeness, and in-house R&D efforts. Tab. 7 shows a positive correlation between the variable used to measure performance (N_PATENTS) and the selected variables indicating the presence of in-house research and external innovation sources (N_REL, N_SOURCE, RD_EXP). As a preliminary comment, we can claim that the patenting activity of firms is positively related to the existence of an open innovation model, which is the result of the combination of a) the internal efforts of innovation and absorptive capacity, b) the scope of innovation search (sources of innovation used[13]), and c) intensity of R&D networking.

Considering the behaviour of PROs (Tab. 8), the productivity of scientists is positively correlated to the PRO R&D networking (N_REL), and to the variable measuring the amount of invested resources in research activity (TF log). Interestingly, the size of the research centre seems to be positively correlated with the number of publications of the interviewed scientists.

Tab. 9 indicates the results of the correlation analysis at the firm level, between all the relational indicators and the performance indicator. The total number of external research relations (N_REL) of firms shows a significant correlation at the 0.05 level (2-tailed) with the number of patents owned by the firm, supporting the hypothesis that innovativeness is positively correlated with the firm's capacity to engage in multiple external relationships. In terms of type of actors involved, both relationships with PROs and firms research organisations is significant, and positively correlated with firms' innovativeness. In terms of geographical location, only the relationships established with foreign partners are significant and positively related to firm's innovativeness.

[13] See Appendix C.

Tab. 5 Occurrence and spatial distribution of relations of all sampled firms (n = 78)

Variable	Occurrence in firms		TOT Ties	Spatial distribution (ties)							
	Yes	No		Reg		Nat		Euro		Extra-Euro	
				a.v.	%	a.v.	%	a.v.	%	a.v.	%
N_REL	45/78=58%	33/78=42%	170	78	46	53	31	31	18	8	5
N_F2F	8/78=10%	70/78=90%	17	2	12	5	29	7	41	3	18
N_F2P	44/78=56%	34/78=44%	153	76	50	48	31	24	16	5	3

Tab. 6 Occurrence and spatial distribution of relations of all sampled PROs (n = 30)

Variable	Occurrence		TOT	Spatial distribution							
	Yes	No		Reg		Nat		Euro		Extra-Euro	
				a.v.	%	a.v.	%	a.v.	%	a.v.	%
N_REL	26/30=87%	4/30=13%	194	82	42%	67	35%	25	13%	20	10%
N_P2P	23/30=77%	7/30=23%	148	63	43%	51	34%	22	15%	12	8%
N_P2F	18/30=60%	12/30=40%	46	19	41%	16	35%	3	7%	8	17%

Tab. 10 shows the results of the correlation analysis at the PRO level, between the relational indicators and the PROs innovativeness, which is measured in terms of the number of publications of the interviewed scientist. The total number of external research collaborations (N_REL) shows a statistically significant (at the 0.05 level – 2-tailed) and positive correlation with the number of international publications authored or co-authored by the researcher employed in the institute. This result indicates that the number of publications increases with the number of external relationships. Interestingly, concerning the spatial dimension of the relational indicators, only the number of research collaborations with foreign partners is statistically significant at the 0.05 level (2-tailed) and positively correlated with the number of international publications (the other relations show a very low correlation). This result suggests that foreign collaborations, although marginal in terms of frequency, are very important for PROs' innovativeness and performance.

Tab. 7: Descriptive statistics, year of analysis: 2004

Variable	N	Mean	Std.Dev.	Min	Max	1.	2.	3.	5.	6.
1. N_PATENTS	78	2.10	4.30	0	22					
2. N_REL	78	2.18	3.21	0	19	0.273*				
3. N_SOURCE	78	4.67	3.25	0	16	0.309*	0.341**			
5. RD_EXP (log)	78	7.68	6.03	0	15.12	0.261*	.346**	0.434***		
6. SIZE (log)	78	2.88	1.46	0	6.68	0.508***	0.213†	0.277*	0.270*	
7. AGE	78	16.04	12.20	1	73	0.374**	0.109	0.096	0.008	0.344**

† *p* < .10; **p* < .05; ** *p* < .01; ****p* < .001

Note: The R&D expenditure varies from 0 to 3,700,000 €, the mean value being 290,437 €. The size of the firm varies from 1 to 800 employees, the mean value being 57.29 employees.

Tab. 8 PRO analysis: descriptive statistics and simple correlations, year of analysis: 2004

Variable	N	Mean	Std.Dev.	Min	Max	1.	2.	3.	4.
1. N_PUBINT	29	20.27	17.20	1	59				
2. N_REL	30	6.47	6.44	0	30	.397*			
3. TF (log)	29	13.89	1.08	12.21	16.16	.452*	.027		
4. SIZE (log)	29	2.80	0.97	1.10	7.98	.409*	.073	.941***	

† *p* < .10; **p* < .05; ** *p* < .01; ****p* < .001

Table 9 Pearson's correlation and significance level, N=78

	No. of external research collaborations	Type of collaborations		Spatial distribution		
		F2F	**F2PRO**	**Regional**	**National**	**Foreign**
No. of patents	.273*	.262*	.231*	.168	.167	.340**

† $p < .10$; *$p < .05$; ** $p < .01$; ***$p < .001$

Tab. 10: Pearson's correlation and significance value, N=29

		No. of external research collaborations	Type of collaboration		Spatial distribution		
			PRO2PRO	**PRO2F**	**Regional**	**National**	**Foreign**
N. of publications		.397*	.338†	.356†	.230	.354†	.370*

† $p < .10$; *$p < .05$; ** $p < .01$; ***$p < .001$

5. Concluding remarks and further research

The paper addressed three emergent issues extracted from economic and business literature. The first is related to the existence of the so-called "open innovation" model among a representative selected sample of firms in Emilia Romagna belonging to the life science cluster. The second regards the spatial characterisation (localised if regional, and external or global if national and international) of existing forms of learning, measured as R&D cooperative relationships, investigated in a spatially bounded system. The third tries to assess the positive relationship between external R&D networking, in-house R&D investment, and the innovative performance, both of firms and PROs. R&D internal investments and network relationships of cluster/district firms emerged as drivers for innovations.

The paradigm of the open innovation, which contrasts the close innovation one, rooted in R&D laboratories of large vertically integrated firms, seems to be quite spread among the research network regarding the Emilia Romagna life science organisations, and the cluster at large, where both firm research network and research lab network are taken into account.

Networking capabilities have been proved to contribute significantly to the determination of the innovative output, both for firms and PROs, especially for actors being positioned in a research network, which involves international nodes. With our research, we not only detected descriptively the presence, in the life science regional cluster of the Emilia Romagna, of a diffuse learning model which is based on distance research relationships, but we were analytically able to measure a positive correlation between R&D networking and innovativeness, and between innovativeness and R&D networking with external foreign nodes. The access to heterogeneous foreign competencies configures itself as a new model of district/cluster external learning, and bears numerous consequences also in terms of regional policies.

Furthermore, another interesting result of our empirical research concerns the fact that the extension of R&D cooperative networks appears to be generally stronger for the regional PROs than for the analysed firms. Almost all the sampled PROs (87%) are connected with external partners (of which 23% are international actors). On the contrary, only 58% of the sampled firms show some connections with research partners (of which 23% are external international actors). Without any doubt this positive result can be referred to the performance of regional institutions, inscribed in the long-term vitality of a consolidated model of learning region.

Finally, our results illustrate that the geography of science collaborations related to the PRO networks shows a striking symmetry with the technological networks activated by firms. One would have expected that science collaborations would be less spatially clustered than technological collaborations, as emerged in the US case discussed by Gittelman (2006). The spatial mimetic convergence of PROs open science research networks and firms technological collaborations suggests that local and long distance learning are equally important for leveraging innovation performance in both the industrial and science systems.

APPENDIX A

Classification on the basis of the main product of the enterprises of the Emilia Romagna life science sector

Manufacturing enterprises in the life science field (productive and commercial)	Firm sample
Diagnostic	**5**
Bio-image Clinical Diagnosis Functional evaluation	5
Therapy and rehabilitation	**11**
Machinery for dialysis and respiration	4
Artificial organs	1
Rehabilitation and Supporting	1
Surgical Therapy	1
Orthopaedics and prosthesis	2
Other	2
Non durable materials	**28**
Dental materials	1
Firms Hospital Materials	27
Other equipments	**21**
Aesthetic and stimulators	3
Dental equipment	
Hospital equipment	3
Electromedical equipment.	12
Various machinery	3
Pharmaceutical and biotech firms	**3**
Pharmaceutical enterprises	2
Biotech enterprises	1
Enterprises of computer science applied to telemedicine	**10**

Source: our elaborations on 78 interviews

APPENDIX B

A short description of the sub-sectors of activity of the centres inserted in the sample

The activity of scientists in Emilia Romagna by research topic

Biochemistry and experimental biology	1. Analysis on enzymes and their inhibitors
Chemistry	1. Organic Electronic and Bio-Diagnose 2. Bio-chip e biological sensor 3. Fluorescent markers for bio-diagnosis 4. Biotechnology for food application 5. fluorescent Techniques spectroscopy
Pharmacy	1.Studies of molecules deriving from natural sources 2. Studies on anti-oxidant molecules 3. Veicolation of medicine in genetic therapy 4. Studies on veicolation (Nanospheres and liposome)
Medicine	1. Medical Techniques on orthopaedic surgery 2. Researches on orthopaedy, biomechanics, medical technologies, analysis of movement, oncology, immunology, and molecular biology 3. Regeneration of bones and muscles – bones bank 4. Eyes Bank for cornea replacement 5. Laboratory of toxicology in vitro and in vivo 6. Genomic and post-genomic investigations for aging, cancer, human pathology engineering of proteins, and stem cells 7. Area of clinic reproduction 8. Diagnosis, pharmaceutics and biomedical

	9. Pharmaceutics and diagnostics 10. Pharmaceutics and diagnostics 11. Diagnosis of infective illness 12. Pharmacology 13. Diagnostic Clinic 14. Centre for medical applied research and studies on di molecular biology 15. Laboratory for experimental analysis and applications of microscopy
Engineering	1. Rehabilitation for disability 2. Studies on human Movements (biomechanics and neural control)
Morphophysio-pathology animal production	1. Bank of tam cells for reparative medicine 2. Neurobiology, and enteric system of animals
Experimental pathology	1.Studies of toxic effects of the exposure to chemical agents (with exploration of genetic modifications produced)
Interdepartmental Centre	1. Laboratory for experimental analysis and microscopy

Source: our elaboration on the 30 interviews in the group of research/centres interviewed

APPENDIX C

Sources of information and knowledge for innovation activities, year 2004 (N=78)

Type	**Knowledge source**	**Occurrence**		**Importance (score: 1-10)**
		N	**%**	**Mean**
Market-based	R&D enterprises	23	29.5	7.91
	Regional firms imitation	9	11.5	5.22
	National firms imitation	10	12.8	5.40
	Foreign firms imitation	17	21.8	6.35
	Research agreements with other firms	8	10.2	4.89
	Clients and customers	51	65.4	8.57
	Suppliers of intermediary goods	15	19.2	7.47
	Patent acquisitions	8	10.2	7.87
	Distribution network	27	34.6	7.74
	Average – Market sources	**18.78**	**24.00**	**6.82**
Institutional	CNR (National Research Centre)	7	9.0	8.29
	R&D Regional Universities	24	30.8	8.25
	R&D National Universities	23	29.5	8.09

	R&D Foreign Universities	15	19.2	8.13
	Average – Institutional sources	**17.25**	**22.12**	**8.19**
Semi-public	Fairs, exhibitions	37	47.4	6.95
	Internet	44	56.4	7.25
	Scientific publications	40	51.3	9.20
	Average – Other sources	**40.33**	**51.70**	**7.80**

Source: Elaboration from our survey

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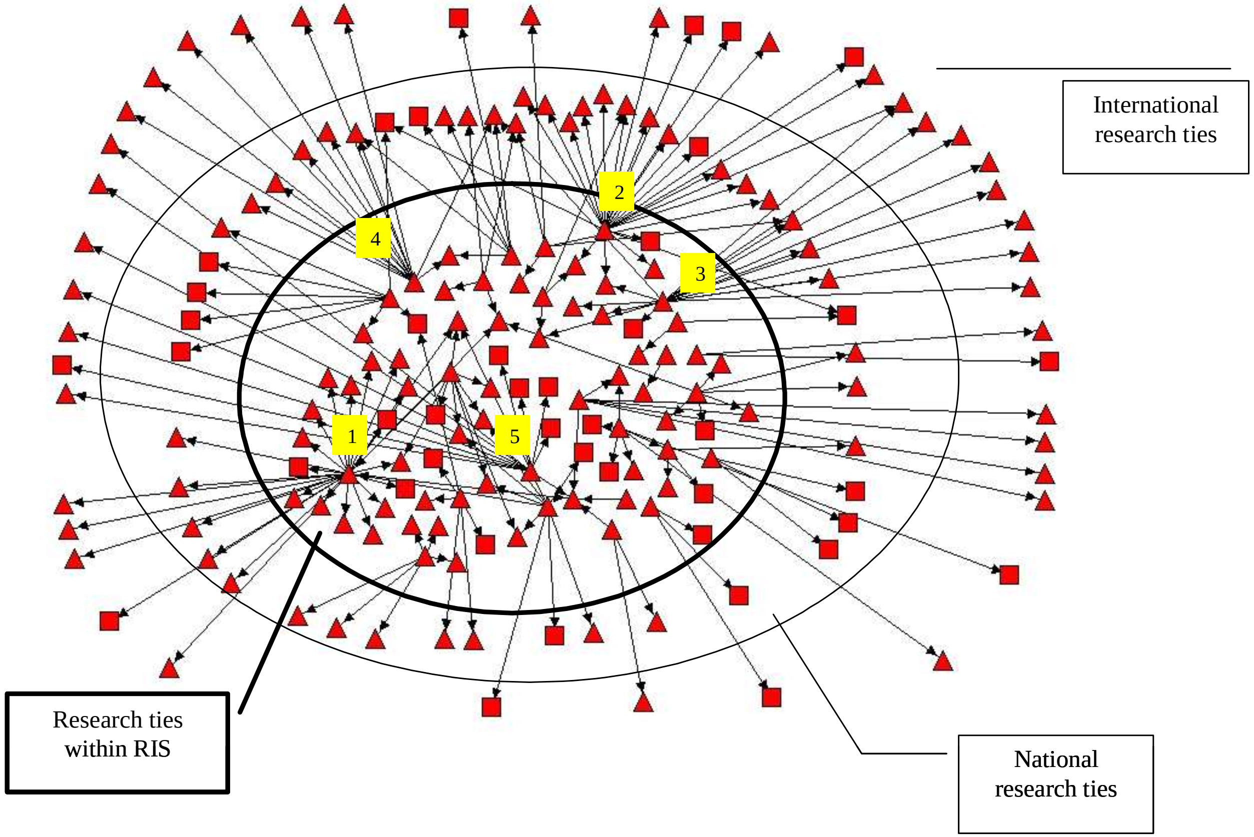


Node Key:
Squares = firms; Triangles = PROs

1 = University of Bologna - Electronic Engeneering (32 ties)

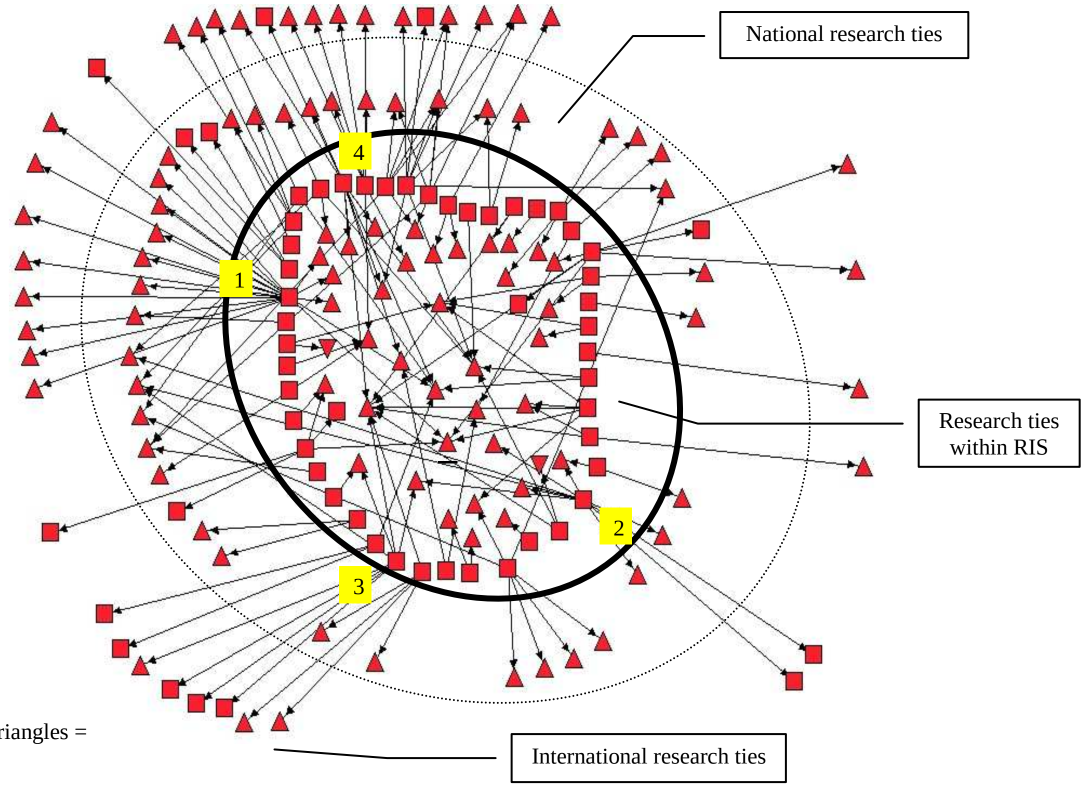
2 = University of Ferrara - Pharmacy (24 ties)

3 = University of Parma – Lab tossicology (17 ties)

4 = University of Bologna – Lab physiology (13 ties)

5 = Policlinic S. Orsola – CRBA (12 ties)

Fig.1 The geography of the PROs R&D network



Node Key:
Squares = firms; Triangles = PROs

1 = Medicap (19 ties)
2 = Bellco (10 ties)
3 = GambroDasco (8 ties)
4 = FreseniusHemocareItalia (8 ties)

Fig.2 The geography of the firms R&D network