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Networks and the organisation of knowledge intensive sectors

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Abstract

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Abstract

This paper addresses the role of networks in the organisation of two different knowledge intensive sectors - biotechnology and software. Its main aim is to identify and explain the differences in the architecture of the networks, formal and informal, mobilised to access resources and competences by young entrepreneurial firms in those two sectors in Portugal. Then it discusses the diversity of the actual network topologies in the light of their contribution to the organisation of those sectors, taking into account their specific environment. For this purpose, it applies a methodology that permits to assemble a vast array of data capturing the nature and contents of the range of relationships through which key innovation resources flow into the firms. The results show that, when a detailed analysis is carried out, significant inter-sectoral differences emerge, both in the network diagrams and in the measures of composition and structure. We argue that those different topologies make sense regarding the empirical literature and shed light on the specific organisation of the sectors, with their strengths, weaknesses and policy-driven influences.

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1. INTRODUCTION

This paper addresses the role of networks in the organisation of two different knowledge intensive sectors - biotechnology and software. Its main aim is to identify and explain the differences in the architecture of the networks, formal and informal, mobilised to access resources and competences by young entrepreneurial firms in those two sectors in Portugal.

For this purpose we have adopted an analytical framework combining contributions from two streams of literature: social networks and entrepreneurship in knowledge intensive sectors. This literature leads us to assume that networks (both formal and informal) are critical to access the wide range of resources necessary to identify and explore new business opportunities in both sectors, enabling firms to go beyond internal constraints. But we also expect those networks to differ across the two sectors, given the differences in the nature of the resources that are mobilised through them. These sectoral differences may be interpreted in the light of the diversity of technological patterns and strategies but also in the light of the diversity of specific stories and context of the sectors.

We have also developed a methodology to reconstruct the networks mobilised by firms in the search for resources. Combining several methods usually applied separately, it permitted to assemble a vast array of data capturing the nature and contents of the range of relationships through which key resources and competences flow into the new firm. This methodology was applied to two groups of firms, sector representative, created between 1998 and 2008 and operating in specific areas: molecular biology (for biotechnology) and software for mobile communications. Both sectors are knowledge intensive but with significant differences in terms of their knowledge base, maturity and dominant business model.

The research entailed the analysis and comparison of the structure and composition of the sectoral networks along two main aspects: a) nature of resources searched - which involved the reconstruction of two different “mobilisation networks”: knowledge networks (access to scientific and technological knowledge) opportunity and access networks (access to tangible and intangible resources); b) nature of the relationships established – which involved the reconstruction of the formal and informal networks. The objective was to identify and explain potential differences (and similarities) between sectors, at these levels.

The paper is organised as follows. First, it provides the theoretical background. Second, the empirical setting and methodological options are presented, with focus on the network (re)construction and analysis. Third, it is delivered an overview of the most relevant results of the analysis of the (re)constructed networks. The last sections discuss the results and draw some conclusions.

2. BACKGROUND

This paper aims to analyse and compare the roles and characteristics of social networks in the entrepreneurial processes that underpin the organisation of two knowledge-intensive sectors, molecular biotechnology and software for mobile communications, in Portugal.

Both sectors are knowledge intensive, meaning that technology inputs are crucial. Both sectors undergo rapid processes of technological change and both have high rates of product innovation. However, their innovation and entrepreneurial processes differ.

2.1 Social networks and entrepreneurship

Theoretically, our paper stands on a triangle: social networks – entrepreneurship – knowledge intensive sectors.

The role of social networks for entrepreneurship has originated a vast literature, since the pioneer papers by Birley (1985), Hébert and Link (1989) and Dubini and Aldrich (1991). This was due to the acknowledged necessity to study human agency and social phenomena within their context, meaning that no single social entity exists without and outside its social relations. This view applies both to the firm and to the entrepreneur (see Hébert and Link, 1989; Grebel, Pyka and Hanusch, 2003; Granovetter, 1985). Another aspect of the relational context provided by the networks approach is that it takes into consideration the “threads of continuity linking actions across a field of action that includes individuals, organizations, and environment as a totality” (Dubini and Aldrich, 1991:306) (see Sousa, 2008; and Salavisa et al, 2009). This means that they capture the stories of the firms’ relations whenever they leave an enduring trace until the present.

But they also capture structural transformations that are underway regarding industrial sectors. In fact, the fragmentation of the value chains together with the deepening of specialization of economic units has constrained firms and entrepreneurs to invent forms of coordination that are parallel to markets' mechanisms. Meanwhile, technological breakthroughs have permitted, together with transformations in the markets, a reorganization of companies, increasingly focused on their core business and resorting extensively to the outsourcing of services and goods. Large companies have split their operations and partially delocalized them to other regions or countries. Their different sites are connected by intra-company networks. Almost all have engaged in stronger and lasting interactions with suppliers, customers, competitors, public agencies, universities and research centres, technological experts, business services, finance companies – and the worldwide web. This "back to the marketplace" trend entails a bigger exposure to uncertainty and to opportunism, both present in market transactions (Ozman, 2009). The establishment of long-term relations based on predictability and mutual trust could help lessening those problems (see Dubini and Aldrich, 1991).

Networks have then become (see Ozman, 2009):

- A representation of social relations (lato sensu), in the line of the primitive social network analysis – a sociological approach, similar to that of social capital;
- A tool to access (and provide) pre-existent immaterial and material resources (information, knowledge, experts, human resources in general, goods, funding, support, influence);
- An organizational form to coordinate a decentralized multi-agents process of knowledge creation and/or of production of goods.

Likewise, networks[1] are important for the success of innovative endeavours in many different ways. Formal and informal networks[2] provide critical resources to the companies, sometimes as an alternative and sometimes as a complement to the market. They constitute conveyors of diversified elements: scientific and technological knowledge; management knowledge; information about market opportunities, skilled labour, funding sources, potential partners; ideas for new or improved products; reputation and credibility. Furthermore, they frequently are facilitators of cooperation among entities to carry on research, or a technological or commercial project. In this sense, they become organisational forms by their own.

As a consequence, networks connect various kinds of actors: individuals (entrepreneurs, scientists, etc.); firms from the sector under analysis; firms from different sectors; universities and research institutions; public agencies; science parks and incubators.

[1] As Coulon points out, social network analysis has focused on individuals. When dealing with firms or other organizations it would be more appropriate to use the term network analysis (Coulon, 2005).
[2] See Cassi and Morrison (2007) on the distinctive and complementary aspects of informal and formal networks.

When dealing with the innovation process, however, networks are usually conceived of as knowledge networks and defined in two broad senses: 1) they convey scientific and technological knowledge (Ozman, 2009); 2) they are a means of conducting collaborative research for knowledge creation. These two roles appear as a consequence of the increasing complexity and specialization of knowledge (Powell and Grodal, 2005). A broader definition however has also been used (Vonortas, 2009), encompassing resources associated to the commercialization process of new technologies.

In this paper, we will mostly conceive networks as tools to access resources, in the line of the "mobilisation networks" suggested by Castilla et al. (2000) and we will endorse a resource-base view of the firm. Considering that the nature of the resources been accessed is likely to influence the type of networks being established (Sammarra and Biggiero, 2008; Sousa et al, 2011) - we split the innovation network into sub-networks: The knowledge network includes actors and relationships used to obtain scientific and technological knowledge; the network of opportunity and access (O&A) is composed of all the actors/relationships used to identify the opportunity and to access and acquire the tangible and intangible resources necessary to explore it.

We will also analyse separately informal and formal networks, looking at the differences between them and across sectors. Networks are generally composed of formal and informal relationships. Powell and Grodal (2005) describe networks including "formal contractual relations, such as subcontracting relationships, strategic alliances or participation in an industry-wide research consortium, and informal ties, based on common membership in a professional or trade association, or even a looser affiliation with a technological community" (p. 7). However, research on firms' networks has largely focused on formal inter-organisational (often inter-firm) networks (Schwartz and Hornych, 2010), even if, as argued Smith-Doerr and Powell (2003, p. 13) "considerable activity outside the formal channels of authority is obvious to anyone who has spent any time in organizations, but curiously there is little theory to guide us in understanding informal organization".

Likewise, in the innovation domain, formal knowledge networks have been much more studied (Street and Cameron, 2007; Roijakkers and Hagedoorn, 2006; Cloodt et al, 2010). In fact, although the importance of informal knowledge flows in innovation has long been acknowledged - as reflected on the extensive literature on spillovers (Jaffe et al, 1993) - informal networks have been less frequently addressed, and sometimes still largely within the boundaries of formal relationships. Some researchers have nevertheless attempted to gain a more comprehensive understanding of the actual informal knowledge flows that take place between individuals in different organisations. One stream of research used co-patenting / patent citations (Breschi and Lissoni, 2006; Singh, 2005) or co-authorships (Murray, 2002) to identify and investigate the origin and dynamics of knowledge communities that develop outside specific organisational boundaries but are highly influential in firm level.

Other strands of research have focused on "communities of practice" (Wenger, 1998; Rosenkopf and Tushman, 1998), epistemic communities (Steinmueller, 2000; Breschi and Lissoni, 2001) or invisible colleges (Crane, 1972). These communities are networks of interrelated professionals (e.g. scientists, technicians, entrepreneurs, managers) that develop largely outside organisational boundaries and are "linked in terms of their ideas, as well as in terms of various types of professional and social relationships and patterns of interaction", relying on "a mix of formal and informal mechanisms that enable both face-to-face and mediated communication" (Morlacchi et al, 2004, p.5).

Other studies have addressed directly the knowledge generating and sharing processes that arise at the micro-level, conducting purposive data collection on the interactions between individuals. Following the seminal work of Von Hippel (1987), this latter stream has traced the informal know-how trading activities that occur among firm employees (Schrader, 1991; Kreiner and Schultz, 1993; Lissoni, 2001; Giuliani and Bell, 2005; Dahl and Pedersen, 2004; Morrison and Rabellotti, 2009) or between firm employees and researchers (Østergaard, 2009; Kreiner and Schultz, 1993). According to Cassi and Morrison (2007), one important contribution of these studies was to move the focus to the identification of the relevant community of actors and the relevant type of knowledge, thus enabling a better understanding of the configuration of these informal networks. [

While research tends to focus either on formal or on informal networks, in fact, they are strongly intertwined (Cassi and Morrison, 2007). Underlying formal agreements there is frequently a variety of informal (social) relations (Powell et al, 1996), which can give an important contribution to their success (Kreiner and Schultz, 1993). These relations may have emerged as a result of interactions in the context of the formal collaboration, or may be based on pre-existing personal relationships that were mobilised to sustain or complement the formal activities or even be behind their establishment. Thus, inter-organisational relationships may encompass a dense web of ties, both formal and informal, whose contents may go beyond the specific tasks formally outlined.

However, research comparing formal and informal networks between organisations is rare (Trippl et al, 2009; Kang and Kang, 2009; Huggins and Johnston, 2010). At this level, the study conducted by Trippl et al on the Vienna software cluster is particularly interesting. They distinguished between four types of knowledge linkages: market relations (buying of embodied technology and knowledge), formal networks (durable and interactive relationships between specific partners), spillovers (exchanges of knowledge through labour mobility, face-to-face contacts, "monitoring" of competitors) and informal networks (based on trust, a shared understanding and the acceptance of common rules). They found that spillovers and informal networks are comparatively more relevant than formal networks and market linkages, at all spatial scales (and not exclusively at local scales as the literature often suggests), although they are complemented by more formalised R&D partnerships. In addition, they have concluded that the nature of innovation (more or less radical) influences the type and combination of knowledge linkages required. Trippl et al (2009) focused exclusively on knowledge networks. However, since it was found that access to different types of resources may require different networks, it will be important to take the resource dimension into account, when comparing the role played by formal and informal networks.

2.2 Differences in innovative behaviour between biotechnology and software

When comparing the two sectors under analysis, we focus on specific fields of biotechnology and software **-** molecular biology and software for mobile communications - the selection criterion being the high level of scientific or technological sophistication within the respective sectors.

Biotechnology is the most common example of a science-based or science-driven sector (or set of technologies, according to authors such as McKelvey, 2005). This young sector owes its very existence to the new technological and commercial possibilities opened up by fundamental scientific discoveries in the field of molecular biology.

The key actors in the development of this new sector were small firms, usually academic spin-offs that maintained a close relationship with the academy (McKelvey, 2005 and McKelvey et al, 2004). Despite the clearly scientific origin of this sector, different patterns appear to have emerged: a more science-based pattern and a more application-oriented one. A group of companies focus on the creation of knowledge through intensive research activities, and their aim is patenting and licensing their technologies to other firms from different industries. This strategy relies strongly on venture capital and on a tight appropriability regime, since firms' revenues derive essentially from research contracts with established companies (mostly pharmaceutical) or from licensing (Malerba and Orsenigo, 1993; Coriat et al, 2003). But, as the sector evolved, another group of companies has emerged, which develop and commercialise specialised products, often adopting a niche strategy (Luukkonen, 2005). A particularly successful example is the case of producers of diagnostic kits. Indeed, the growing difficulties experienced by firms adopting the classical science-based model (due to constraints in capital markets and to cost reduction strategies of large companies), led to the emergence of more integrated business models where the direct exploitation of scientific competences is increasingly bundled with downstream services or products (Pisano, 2006; Rothman and Kraft, 2006; McKelvey, 2008). Recent research points to the on-going experimentation with a variety of new business models which reflect adjustments to changes in the demand structure (particularly in the health sector) and/or exploit new opportunities arising from recent scientific developments (McKelvey, 2008).

As to software, the characterisation of its dominant technological regime is less consensual. Some authors have assigned it to the specialised supplier category (de Jong and Marsili, 2006) while others have labelled it simply as information-intensive (Tidd et al, 1997). Actually, a specialised supplier model seems to coexist with a complex knowledge based one, with similarities with the science-based regime. In fact, it is a diversified industry, encompassing segments (Lippoldt and Stryzowski, 2009) with various degrees of technological sophistication and reliance on scientific advances (Steinmueller, 2004). Thus, we may define software as a technology intensive sector relying on a complex and diversified knowledge base, but where tacitness appears as more relevant than in most biotechnology activities (Grimaldi and Torrisi, 2001; Aramand, 2008). Generally speaking, we are not dealing with a science-based sector as a whole. This does not mean that the relations with universities are unimportant. They tend to be informal and, although the access to academic knowledge is increasingly relevant, the access to talented highly skilled engineers is even more relevant. The level of technological opportunities is still high, but mostly depending on the user-producer relationships, especially when it comes to embedded software and applications. Likewise, the perceived needs of the clients, actual and anticipated, induce packaged software firms to innovate in problem-solving solutions. Furthermore, opportunities are reinforced by the pervasiveness of applications. Finally, the question of appropriability – very affected by the open source software movement (see Malerba, 2005 and McKelvey, 2005) - relies much less in patenting (at least in Europe) than in other forms of property protection, like standards, copy rights enforcement, techno-commercial strategies - such as lead-time and proliferation of products strategies (Giarratana, 2004) - and partnerships and alliances, both among software firms and with customers. Cooperation among firms and networking is quite relevant here (Malerba and Orsenigo, 1993).

It is well established that innovation creation is sector specific. A number of studies have analysed innovation in biotechnology and in software, and in a few comparative analyses of the two sectors (or of biotechnology and computing) has been conducted (see McKelvey, 2005; Swann and Prevezer, 1996; Weterings and Ponds, 2009; Marsili and Verspagen, 2001; Rampersad et al, 2009; Luukkonen and Palmberg, 2007). In biotechnology, innovation is science-driven, both through the creation of research spin-offs (Fontes, 2005; Zucker et al, 2002) and through the development of long-term relationships between firms and universities and the like (Murray, 2004 ; Bagchi-Sen, 2007). As a consequence, radical innovations are frequent and the innovative pace is quite rapid. In software, innovation is mostly incremental although at a rapid pace too. Universities provide a major role as providers of talented software engineers (McKelvey, 2005; Giarratana, 2004).

Stimuli from customers and the market appear as more relevant to software innovation. In fact, software houses try to adapt their products to an ever changing environment, corresponding to the requirements of customers such as telecommunications equipment suppliers or service providers. This is an area where social transformations associated with a rising need for mobility and interconnectedness have a strong influence on the industry.

The entrepreneurial process in the two sectors is also quite different. In biotechnology, small firms are mostly focused on a specialised scientific and technological domain, and try to establish partnerships with large companies to get their technologies applied in marketable products. At least at this stage of maturity, biotech encompasses of a large number of specialised small firms (research spin-offs mostly) that associate with large companies to commercialise their technology outputs. Mixed partnerships (technological and commercial), together with the existence of lasting relationships with academes, are vital for the firms. They rely strongly on venture capital and on public funding for large periods.

In software, small, medium and large firms coexist. Small firms tend to specialise and to establish commercial partnerships with other firms, although technological partnerships are also important. Small firms sell mostly embedded software for a diversity of applications and customers, alongside with tailored solutions and services. Talented programmers are a crucial resource to their business success. Here, the firms are knowledge intensive in the sense of “embodied” knowledge.

Given this theoretical background, this research focuses on the differences between biotechnology and software entrepreneurial firms regarding the configuration of the networks mobilised to access resources and competences that are key for the innovation process.

It identifies two main potential differentiating dimensions: the type of resources being searched – knowledge vs. other resources relevant to develop and commercialise the innovation; and the type of relationships being mobilised to access them – formal, contractual relationships between organizations vs. informal, personal ties between individuals (centred in the entrepreneur). We believe that the analysis of both dimensions will permit new insights into the specificity of the networks topologies of different sectors.

3. EMPIRICAL SETTING AND METHODOLOGY

3.1 Empirical setting

The analysis was carried out using a sample of 46 Portuguese companies created between 1998 and 2008: 23 software and 23 biotechnology companies. In the case of software, we have focused on a particular application segment: software for telecommunications; in biotechnology, we focused on firms sharing the same knowledge base: the molecular biology. Our biotechnology firms can be regarded as the most science based group of firms within the sector, while in software our group corresponds to one of the most technologically advanced areas.

In the software sector, the sample is mostly composed of small to medium sized firms – 68% have less than 50 employees and the average number of workers is 117. Most companies (78%) were created between 1998 and 2003 and are located in the main metropolitan areas. Around 42% had a turnover (in 2007) between € 1 million and € 5 million. The average turnover was € 13.5 million.

Almost all companies (91%) carry out R&D activities. The average investment in these activities is 15% of the turnover and around a quarter of the total employees work on R&D activities. Only 5 companies applied patents. Also only 5 employ PhDs. In terms of sources of funding, a great majority relies on equity financing (90%). Eight resorted to some kind of public incentive, which represented, on average, only 4% of total funding.

As for the entrepreneurs, 37% of them hold a MBA and 10% hold a post-graduation in engineering, but only one holds a PhD. About 65% had worked or studied abroad over a significant period of time. Half of the entrepreneurs have conducted research activities at some point of their career.

In the biotechnology sector, the subset selected – molecular biology – belongs to the younger generation of Portuguese biotechnology: 78% have been created since 2004. Thus, several of them are still in an embryonic stage and only a few have fully developed their technologies/products. Twenty are research spin-offs.

Not surprisingly, most of these companies are very small: 70% have less than 10 employees, and the average number of employees is only 8. In 2007, 57% of the companies had a turnover of less than 100 000€. The firms are clustered around three main metropolitan areas.

The biotechnology companies exhibit a very high R&D intensity. The vast majority carry out R&D activities (78%). Their average investment in these activities is 107% of the turnover, since in a few cases R&D outlays exceed turnover. In terms of human resources, around 44% of the employees, on average, work in R&D activities. About half of the firms (48%) have patents. 15 companies out of 23 have at least one PhD. Doctorates represent, on average, one third of the workers. This high technological intensity can be partly explained by the fact that many companies are still developing their technologies. In fact, 30% have not yet introduced any technology or product into the market.

With regard to the sources of funding, the majority relies on equity (91%). Around one third resorted to venture capital. Half of the companies have received public incentives, which, on average, accounted for 20% of the total funding.

As to the entrepreneurs, their vast majority (65%) holds a PhD and nearly 86% have participated in research activities, studied or worked abroad for a significant period.

3.2 Data collection

Data about the firms (in both sectors) was collected using a novel combination of complementary methods, involving both documentary information and in-depth face-to-face interviews with the founders. The former included: published data about formal collaborative projects and patents and information on firms' formation histories, including on the websites. The interviews, conducted in 2008, were based on a semi-structured questionnaire that focused on the entrepreneurs' personal networks and their importance for the entrepreneurial process. The data thus obtained includes the origin of the relationships and the type, nature and relevance of their respective contributions. The interviews also allowed us to gather data on firm activities, strategy and performance.

3.3 Networks (re)construction

Using the data obtained through the interviews and the documentary research about the firms and their activities it was possible to (re)construct the innovation networks for each sector.

It was also possible to make a more detailed analysis of those networks taking into account the resource type and nature of the relationship.

Considering the type of resource, the (total) innovation network is divided in two sub-networks, according to the type of resource that is being obtained: opportunity and access (O&A) and knowledge. The O&A network is composed by all the actors/relationships used to identify the innovation opportunity and to access and acquire the tangible resources (capital, facilities and access to the market) and intangible resources (information, managerial knowledge and other competencies) necessary to explore it. The knowledge network includes actors/relations used to obtain scientific and technological knowledge.

Considering the nature of the relation, a distinction was made between formal and informal relations. This implies the separation of the mobilised networks in two sub-networks. Formal networks are related with a formal/codified agreement between actors (that usually involves a system of authority, distribution of competences, rights and duties and a device of conflict resolution) and informal networks are more spontaneously created, being frequently associated with personal ties, that are directly mobilised or act as mediators in the access of the resource. This distinction, in practice, is not always so clear. Sometimes the firm establishes formal and informal ties with the same organisation in different moments or for different purposes and, as stressed by several authors, formal ties are frequently based on previous informal relations (Powell et al, 1996)

So, for each sector, in addition to (total) innovation networks, four different networks were built: knowledge networks (formal and informal) and O&A networks (formal and informal). The content of each network is presented in table 1.

Table 1 – (Re)constructed networks contents

	Formal	Informal
O&A	Funding sources Facilities providers Service providers (legal, accounting, IP, marketing) Commercial partnerships	Information/advice to build business plan Information about opportunity identification/exploration Management knowledge
Knowledge	R&D Projects S&T Partnerships Patents (partners; providers) Origin of technology (if formally transferred)	Innovation (new ideas) S&T knowledge Origin of technology (if informal transferred)

The literature of inter-organizational networks considers that the intensity of the relations can be depicted as a function of two factors: the amount of resources exchanged and the frequency of contact between two organizations (Zhao and Aram, 1995). In this paper, to assess whether the tie is strong or weak, it was considered a combination of three factors: the frequency of informal contacts, the existence of multiplex ties and the existence of ties with different nature. In this case, a tie with an organisation is considered strong[3] when:

- the informal contacts take place at least once a month (frequency).
- the tie is used to access different types of resources (multiplex tie).
- the firm establishes both formal and informal relations with that organisation (nature).

3.4 Network analysis

A detailed analysis of the composition and structure of the networks was conducted using the methods of Social Network Analysis (Wasserman and Faust, 1994) and supported by the UCINET software. Network characterization, as conducted in the social network literature, usually involves several aspects. In this research the following aspects are considered:

1) *Network size:* The network size is an important element in the analysis of a network. According to Burt (2000), other things being equal, larger networks mean that an actor can receive a more diverse and complete set of resources from his network. Furthermore, the network size has an impact on some structural network characteristics as density and connectivity (for example, in network with a small number of actors, it is more likely that two of them are connected). In addition to measures like the total number of actors and the total number of ties, the analysis of the network size will integrate measures related to the existence of components (number of components and size of the biggest component). A component is a set of actors that are connected to each other, but that do not have connections outside the component. If a network is composed of a large number of small components there is a lower capacity to access resources. Those measures will allow us to compare both the size and the connectedness of the networks in each sector.

2) Network Composition: Innovation networks are composed of different types of actors. In this research we consider seven types of actors (and represented it using different symbols in the network diagrams): interviewed firms (blue squares), firms from the same sector (red circles), firms from other sectors (green circles), universities and research organisations (yellow circles),

[3] In network diagrams strong ties are represented by a thicker line.

financial institutions (grey circles); science & technology parks (pink circles) and other organisations, including professional and trade associations (purple circles). To analyse the relevance of each type of actor we have considered its share in the total number of ties.

3) *Actors' Position*: Regarding network position, it is considered that different positions, usually measured by centrality measures, offer different opportunities to access the relevant sources of resources (Powell et al, 1996).To characterize the actors' position in the network we use two centrality measures: Degree centrality and betweenness centrality of each actor (Scott, 2000; Wasserman and Faust, 1994).

The degree is the number of direct ties one actor has to other actors in the network. The most central company is the one that has the highest number of ties (links/connections) with other organisations. The most central actors in the network are designated as hubs. In directed networks, as the ones used in this paper, the degree of an actor has two different elements: the indegree measures the total number of ties directed towards the actor, and so a central actor receives resources from several different organisations, being characterised by a strong attractiveness[4]; the outdegree shows the number of ties that depart from one actor, and so a central actors provides resources to a large number of firms, being characterised by a strong activity.

The betweenness measures the extent to which an actor lies between other in the network: a node with few ties (low degree) may play an important intermediary role and so be very central to the network. Then, the betweenness of a node indicates whether an actor plays the role of a broker with a potential for control over others. Brokers have important, non-redundant information to give to other actors that without this connection would be isolated from the network.

4) *Network cohesion*: This aspect of networks structures is related to extent to which the various actors in networks are linked to each other. There is some debate over the effects of different network configurations in terms of cohesion, i.e. more densely embedded or "closed" networks with many strong ties (Coleman, 1988), vs. more "open" networks with many weak ties (Granovetter, 1973) and structural holes (Burt, 1992). To analyse network cohesion two measures are computed: density and proportion of strong ties.

Network density is computed as the ratio between the number of ties that are present in the network and the maximum number of ties possible. So network density is related with network size: in general terms, the larger the network, the lower its density.

[4] In this research only interviewed firms have nonzero indegree values.

In each network, it is made a distinction between strong and weak relations, since they involve different time, energy and money to be developed / maintained. Networks with many strong ties are denser than networks with a smaller number of strong ties. So, to characterise the strength of ties it is considered proportion of strong ties, as the ratio between the number of strong ties and the total number of ties.

5) *Network Centralisation*: It refers to centrality measures calculated for the whole network. So centralization measures allow observing the extent to which the whole network has a centralised structure, i.e. a structure that is organised around its most central points. Centralisation measures are based on actor´s centrality measures, and so this paper considers the two different perspectives mentioned before: degree and betweenness. They vary from 0 to 1, being 1 associated to the maximum level of centralisation.

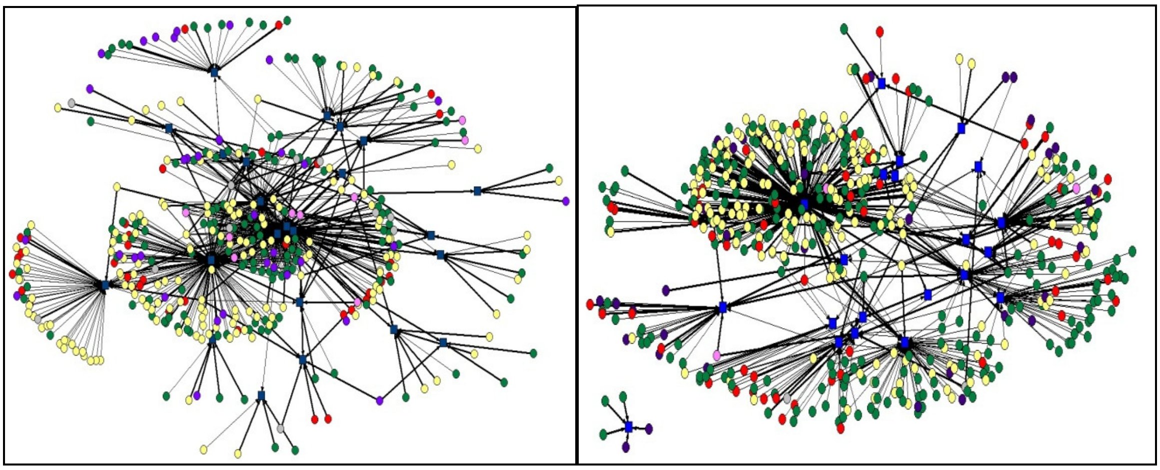
6) *Cohesive subgroups*: Cohesive groups are groups of mutually connected actors. To analyse cohesive subgroups, cliques are considered. A clique is a sub-set of actors all of each is connected to each other. Since this concept "is rather restrictive for real social networks" (Scott, 2000: 115), it is used the concept of 2-clique, that is a clique where the actors are connected directly or through a common neighbour. Also, only clique with more than three members are taken into account. It should be mentioned that an actor can belong to more than one clique. Furthermore to study cohesive subgroups, the clustering coefficient is considered. This coefficient reveals the average density of the groups of actors around individuals in the network, revealing the extent in which the actor's friends are connected to each other.

4. RESULTS AND DISCUSSION

Whole innovation networks reconstructed for the two sectors are shown in Figure 1. Graphically, these networks are quite similar. But, the diagrams suggest that the innovation network of software is more populated and has a small separate component.

Figure 1 - Whole innovation networks

(a) Biotech (b) Software



Given the methodology developed to reconstruct those networks, it is possible to disaggregate them, taking into consideration the nature of the resources and the nature of the relationships. As we go further into the analysis, network diagrams start to reveal differences between the two sectors, as shown in Figures 2 to 5. Those differences seem to be more impressive in the cases of formal O&A networks and of informal knowledge networks.

To fully understand those differences we compute and analyse several social network measures, already defined, for four different networks: formal O&A, informal O&A, formal knowledge and informal knowledge. After this analysis, the purpose is to investigate the characteristics of the networks that appear as more dissimilar between sectors.

Figure 2 - Formal O&A networks

(a) Biotech (b) Software

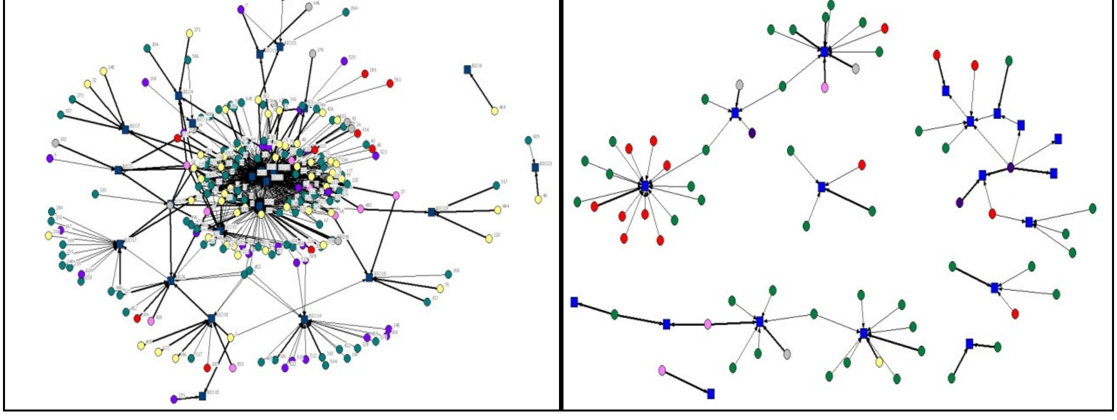


Figure 3 - Informal O&A networks

(a) Biotech (b) Software

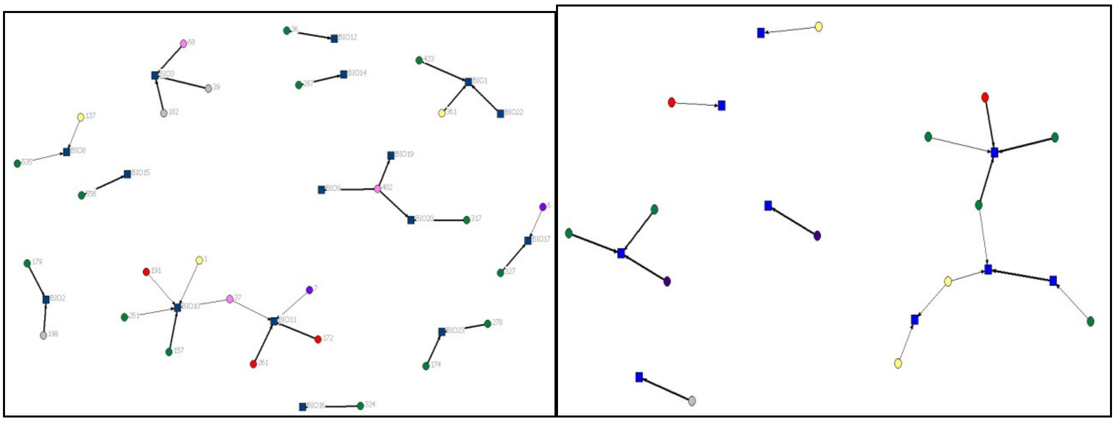


Figure 4 - Formal knowledge networks

(a) Biotech (b) Software

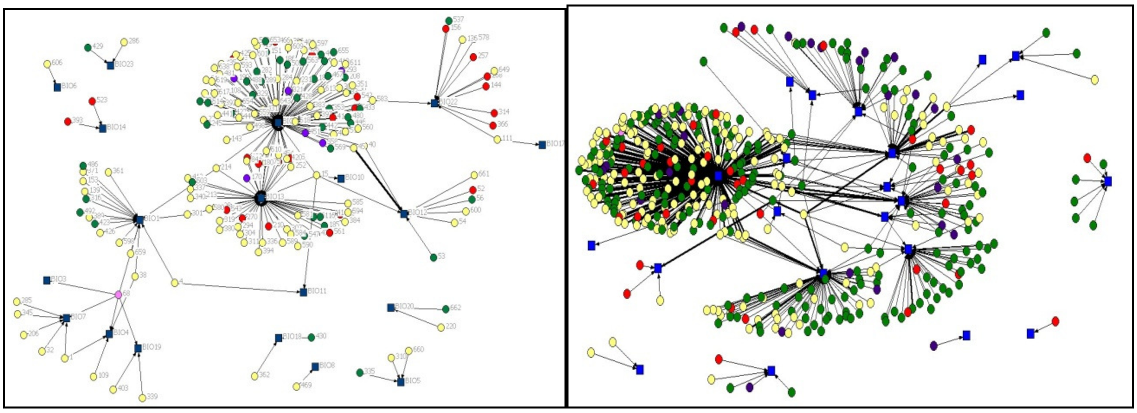
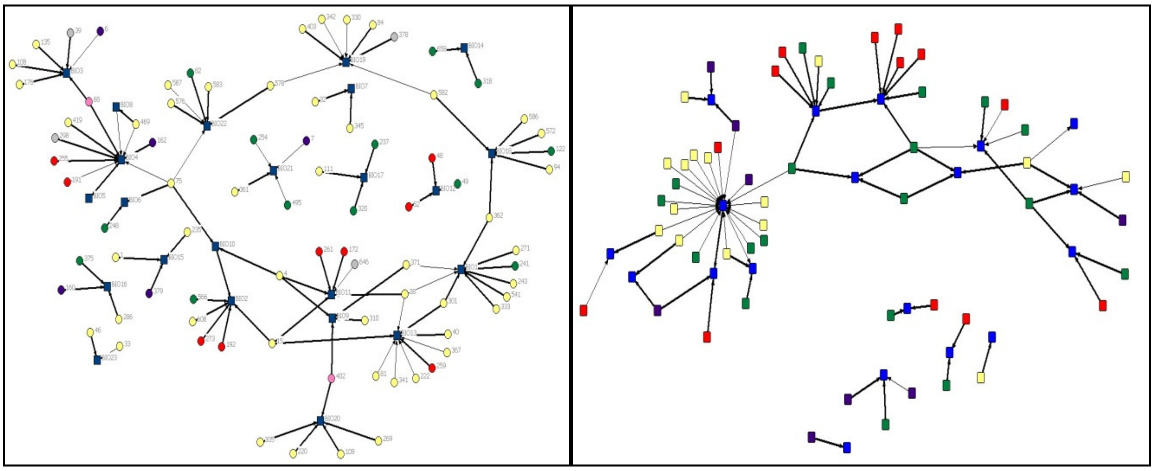


Figure 5 - Informal knowledge networks

(a) Biotech (b) Software



4.1 Innovation networks in biotechnology

In terms of network size, the data (Table 2) show that formal networks are larger both in terms of number of actors and of number of ties, regardless of the specific resource under consideration. Thus, innovation networks are clearly dominated, in terms of size, by formal relationships. Formal networks also have a smaller number of components and the weight of the largest component is greater than in informal ones (more than 90% of all actors versus around 70%).

The composition of the networks is strongly affected by the type of resource: firms predominate in O&A networks and universities in knowledge networks. The main differences between formal and informal networks lie in two aspects: the universities have a higher expression in formal networks and companies in the same sector have a higher expression in informal networks. It is also interesting to notice that financial Institutions have some weight in biotech informal networks, namely in the knowledge network. The interviews suggest that some venture capital companies play an advisory role, not only regarding business issues but also concerning the directions of research to pursue in the early years.

Looking at the cohesion measures, sharp contrasts between biotech formal and informal networks become visible again: informal networks are denser and have a higher proportion of strong ties, denoting higher levels of interaction and trust. The very small proportion of strong formal ties in the knowledge network is consistent with the kind of technological alliances in this sector and their high turnover (Hagedoorn, 2002; Smith-Doerr and Powell, 2003).

The measures of centrality of actors also reveal differences between the networks. The formal O&A network shows the higher degree centrality, indicating a higher level of activity (the average number of relations is 4) and of betweenness centrality, indicating that central brokerage positions play a more important role in the formal access of O&A related resources. The high value of the coefficient of variation for all networks and measures (but particularly for betweenness) suggests the existence of a model core-periphery with a small number of very central actors and a large number of peripheral ones.

Table 2 – Innovation network analysis in biotech

		O&A		Knowledge	
		Formal	Informal	Formal	Informal
Size	No. of actors	229	43	203	104
	No. of ties	620	12	213	102
	No. of components	3	10	8	9
	Size of largest component	224	31	183	74
Composition (%)	Firms from same sector	14	44	21	31
	Firms from other sectors	41	30	22	12
	Universities	24	7	54	46
	S&T Parks	4	7	0	2
	Financial institutions	4	7	0	4
	Other	13	5	3	5
Cohesion	Density (overall)	0.8	2.4	1.1	2.5
	Strong ties (%)	14	71	6	73
Centrality of actors (average)	Degree*	4 (0.8)	2 (1.0)	1 (0.8)	3 (0.7)
	Betweenness*	4.4 (8,8)	0 (0)	0.2 (14.2)	0.1 (8.5)
Network centralisation (%)	Outdegree	2.7	5.9	0.9	2.1
	Indegree	20.5	5.9	17.9	6.7
	Betweenness	0.6	0.0	0.1	0.1
Cohesive subgroups	Clustering coefficient (%)	68	0	15	3
	No of 2-cliques	45	11	25	36

* Numbers in brackets are the coefficients of variation

The networks centralisation measures indicate if the network has a centralised structure. That structure is more visible for indegree centrality in formal networks, showing the existence of some highly attractive biotech firms that are surrounded by more peripheral actors. If we consider the betweenness measure, that centralised structure is totally absent.

Taking into account the clustering coefficient, it is visible that formal networks are more interconnected, in the sense that a higher proportion of actors share the same “friends”. This situation is particularly intense in formal O&A network.

Finally, all networks are composed of several 2-cliques, being their number higher in formal O&A and informal knowledge networks, revealing that those networks comprise a large number of sub-sets of actors, all of each is connected to each other directly or through a common neighbour.

4.2 Innovation networks in software

In software, knowledge networks are much more populated than O&A networks (table 3). Additionally, formal networks are larger than informal networks. Data show a very similar number of components in all types of networks, but the weight of the largest component differs, especially when one considers the type of resource, being higher in knowledge networks.

The composition of the networks reflects the fact that firms are the major resource providers for the innovation process of software companies. The presence of firms from the same sector is particularly significant in informal networks, indicating a strong informal bartering at the horizontal level.

The density values of the various networks are similar, being the informal networks slightly denser. Additionally, these networks exhibit a higher proportion of strong ties.

Table 3 – Innovation network analysis in software

		O&A		Knowledge	
		Formal	Informal	Formal	Informal
Size	No of actors	86	23	484	74
	No of ties	80	17	525	73
	No of components	7	6	6	6
	Size of largest component	32	11	464	60
Composition (%)	Firms from same sector	39	48	13	43
	Firms from other sectors	50	26	44	26
	Universities	2	13	38	20
	S&T Parks	3	-	0	-
	Financial institutions	3	4	-	-
	Other	3	9	5	11
Cohesion	Density (overall)	1.6	2.1	1.5	2.3
	Strong ties (%)	27	53	25	63
Centrality of actors (average)	Degree*	2 (1)	2 (0.9)	2 (0.7)	2 (0.9)
	Betweenness*	0.14 (6.2)	0.04 (4.7)	0.56 (21.1)	0.58 (7.4)
Network centralisation (%)	Outdegree	3.0	3.9	0.7	3.6
	Indegree	6.6	13.4	34.2	8.7
	Betweenness	0.1	0.2	0.11	0.7
Cohesive subgroups	Clustering coefficient (%)	0	0	6	1
	No of 2-cliques (n≥3)	21	7	48	26

* Numbers in brackets are the coefficients of variation

The innovation networks are highly heterogeneous in terms of their structure of influence and power, as denoted by the high coefficient of variation of the centrality measures used, indicating the existence of a model core-periphery. The average degree is equal in all networks, but betweenness is higher in knowledge networks indicating the greater relevance of knowledge brokers.

Looking at the overall centralisation, one observes that a centralised structure only emerges in formal knowledge network when indegree centrality is considered, suggesting the presence of some highly central software firms that are surrounded by more peripheral actors.

All networks exhibit groups of connected sub-sets of actors, which abound particularly in the formal knowledge network. The clustering coefficient displays very low values in all networks, revealing that actors share very few friends.

4.3 Formal and informal networks: regularities across sectors

In both sectors (and for both resources) formal networks are bigger and more connected. This result, which somewhat contradicts the literature, is partially related with our methodological options, namely the fact that mobilised networks did not include all informal ties but only the "core", i.e. those that were regarded by entrepreneurs as important.

We also found some regularities regarding the composition of networks: regardless of resource, informal networks include more firms of the same sector and formal networks include more firms from other sectors. This result points to the prevalence of informal relations within sectors and of formal relations across sectors. Additionally, firms are a more relevant origin of resources used to identify and explore new opportunities.

As expected, informal networks are denser and characterised by strong ties. So those networks encompass higher levels of trust, fact that is referred in the literature of knowledge networks. For example, Dahl and Pedersen (2004) underscore the importance of reputation and trust for the acquisition of high-value knowledge through informal networking.

All networks are highly heterogeneous in terms of centrality of actors, fact that points to the existence of situations of core-periphery in the structure of power and influence. So, a small set of very central actors coexists with a large number of peripheral ones.

In knowledge networks, indegree centralisation is higher for formal relations, indicating that of some firms resort extensively on formal partnerships to access knowledge. We can also observe that those formal relations are associated with more clustered networks, ie, networks where more firms share the same partners.

4.4 Sectoral differences

Although biotechnology and software are both knowledge-intensive sectors, their innovation networks have relevant differences in composition and structure, especially when we analyse them at a disaggregated level.

Starting with composition, results show that biotech resort more to S&T parks and financial institutions, not only to access tangible resources (formal O&A) but also information and advice (informal networks). We also found an interesting difference in knowledge networks, related to the nature of relevant knowledge in these sectors: in biotech, both knowledge networks are dominated by universities, while in software the leading role belongs to firms.

Sectors also display some differences in terms of their networks' structure. However, those differences become particularly evident when we disaggregate the networks by resource type and by the nature of the relation, as we will see below.

All in all, main differences between sectors are found when we compare formal O&A and informal knowledge networks. Thus, access to tangible and intangible resources, other than knowledge, gives rise to considerably different formal networks; while access to knowledge gives rise to considerably different informal networks.

Regarding the formal O&A network, the observation of figure 2 and of tables 2 and 3 reveal striking differences between biotechnology and software, in terms of size, composition and structure of this network.

The biotechnology network is larger, more connected, more balanced in terms of composition, less dense, more centralised and more clustered. The configuration of this network is partly policy-driven. Most firms in the molecular biology field are operating in the health sector and, in Portugal, there is currently an explicit policy of promotion of a "Health Cluster". This policy has contributed to the formation of a more integrated space of relations aiming to the identification and exploitation of innovation opportunities, thus changing significantly the environment where biotechnology firms conduct their business activities. The development of the health cluster is reflected on the composition of the O&A formal network (size and type of actors) and also on the high degree of clustering that was found. In fact, six of the firms interviewed are formal members of the Health Cluster structure, which also join together most organisations that can be relevant partners in health biotechnology: universities, hospitals, S&T parks, financial institutions, and a large number of firms, both Portuguese and multinational in pharmaceuticals, medical devices, instrumentation and clinical trials.

In the software sector, the formal O&A network is very fragmented: it has six components and the largest one integrates less than half of the actors. It is possible to observe three large cliques (with 10 or more actors), mainly composed of firms from other sectors. It is also possible to find that those cliques are connected to other network elements through bridges established by two mobile communication operators (Vodafone and Optimus) and a large international IT company (IBM).

As to informal knowledge networks of the two sectors, they also exhibit significant differences in terms of composition and structure (Figure 3 and Tables 2 and 3).

In this case, the differences between biotechnology and software are likely to be related with the nature of knowledge and its role in the innovation processes in these sectors. Informal access to knowledge by biotech firms is primarily achieved through universities. However, other biotech firms also play an important role. Conversely, in the case of software, knowledge bartering with firms from the same sector predominates (Table 2 and 3).

In terms of structure, the informal knowledge network in biotechnology has a large component, which integrates more than 70% of the actors, and 8 small components (up to 5 actors). The largest component displays a cyclic form, connecting different cliques, generally made of several universities and a biotech firm. These sub-groups have strong inner connections (presence of strong ties) and usually a single connection to the rest of the network. It resembles the kind of knowledge communities mentioned in the literature. Those communities are bridged by universities, which are usually present in two different cliques. This bridging role is performed by national (IGC, ITQB, IMM, FC/UL, ICBAS and CEBQ) and foreign (Imperial College, London University and Ghent University) organisations. So, the informal knowledge sharing in biotech is organised around knowledge communities agglutinated by universities performing the role of informal knowledge providers.

In software, the informal knowledge network also has a large component. In this component we can observe two different segments that are bridged by a mobile communication operator (TMN). In one half of this component, universities are almost absent and firms informally seek knowledge in other companies, focusing on relationships within the supply chain, namely with clients, but also with other software developers. The other half is dominated by a large clique (with 22 actors, of which 10 are universities). In the centre of this clique, we find a software firm – which we can designate by "star" firm. This firm acts has a hub (concentrator) of informal knowledge, exhibiting a very high indegree centrality (19 when the network average is 2), and also as a broker, since it has the highest betweenness centrality (37 for an average of 0.6). Star firms have already been mentioned in the literature (Hanaki et al, 2010) and they play a major role in their respective industries. Size, reputation, credibility make them preferential partners to the others (preferential attachment is here involved), and in this way, they have a positive "structuration effect" in the sector.

5. CONCLUSION

This paper addresses the role of networks in the organisation of two different knowledge intensive sectors - biotechnology and software. Its main aim is to identify and explain the differences in the architecture of the networks, formal and informal, mobilised to access resources and competences by young entrepreneurial firms in those two sectors in Portugal. Our research provides some insights into the differences between formal and informal in different sectors.

A detailed analysis of the network diagrams and of the conventional measures of composition and structure has revealed differences and regularities across the two sectors.

The differences are particularly evident in the cases of formal O&A networks and of informal knowledge networks. In the first case, they are related with different development dynamics in the environment where firms pursue their business activities. In the second case, the differences are mainly related with the nature of knowledge and its role in the innovation processes in the two sectors.

Regarding formal O&A networks, biotech firms are developing their activities within a largely policy-driven "health cluster" which has joined together the main actors operating in the health sector in Portugal. This structure, although relatively recent, appears to have an increasingly relevant role as a supplier of at least some of the resources necessary for these firms' early development. The role played by specialised clusters in providing complementary assets that are critical for firms' early development is typical of biotechnology (Feldman, 2001). However, given the characteristics of the Portuguese health sector, molecular biology firms hardly find in this cluster one key actor – large pharmaceutical companies. This may explain the high proportion of firms oriented to clinical applications, which come closer to the core cluster specialisation, as well as the central positions occupied by research organisations and hospitals.

In the software sector, the organisation appears to be typical of software development: sub-networks are organised around the main telecom operators (large users that may be simultaneously suppliers of certain resources) (Malerba, 2005).

Regarding informal knowledge networks in biotech, we found small knowledge communities composed of the universities each firm is connected with. Possibly some of them were part of the academic trajectory of the entrepreneur, thus reflecting the youth/early stage of development of sector. Some universities act as bridges, since they are likely to have an important role in the production of knowledge in the field. International connections are also important for the same reason – the relevance of international knowledge access is typical of biotechnology (Owen-Smith and Powell (2004), but may assume even a more important role in the case of an intermediate developed economy (Fontes, 2005b).

In software, the informal knowledge network comprises two groups: a first group of firms doing informal bartering among them, which is typical of informal relations in software (Smith-Doerr and Powell, 2003); a second group, constituted around a large firm (our "star" firm), which creates technological knowledge of a great relevance to other firms in the sector.

In short, our software innovation networks are close to what is established in the literature. This might be attributed to the higher maturity of the sector, which is structured around a few large users and a very large knowledge intensive company, already denoted as a star firm. Typical bartering takes place in these networks.

As to biotechnology, innovation networks are more context-specific, although knowledge networks display traits typical of regions that are distant, but attempt to connect to major biotechnology clusters (Gilding, 2008). A clustering effect exists, partly policy-driven. However, given the characteristics of the Portuguese environment, research universities rather than pharmaceutical companies are the agglutinating element.

When compared with software, biotechnology innovation networks also reflect the differences in maturity between the two sectors (Luukkonen and Palmberg, 2007). In the Portuguese case, those differences are even more evident since most biotechnology firms are still in an early stage of development.

REFERENCES

ARAMAND, M. (2008), Software products and services are high tech? New product development strategy for software products and services, *Technovation*, 28, pp. 154-160.

BAGCHI-SEN, S. (2007), Strategic Considerations for Innovation and Commercialization in the US Biotechnology Sector, *European Planning Studies*, 15 (6): 753-766.

BIRLEY S. (1985), The role of networks in the entrepreneurial process, *Journal of Business Venturing*, 1, pp. 107-117.

BRESCHI, S. and LISSONI, F. (2001), Knowledge Spillovers and Local Innovation Systems: A Critical Survey, *Industrial and Corporate Change*, 10, pp. 975-1005.

BRESCHI, S. and LISSONI, F. (2006), Mobility of inventors and the geography of knowledge spillovers. New evidence on US data, *Working Paper 184*, CESPRI, Bocconi University.

BURT, R. (1992), *Structural holes: The social structure of competition.* Cambridge: Harvard University Press.

BURT, R. (2000), The network structure of social capital. In R. S. Sutton (ed.), *Research in Organizational Behaviour*. Greenwich: JAI Press.

CASSI, L. and MORRISON, A. (2007), Social networks and innovation: concepts, tools and recent empirical contributions, *Working Paper 2007/59,* Lisbon: DINÂMIA.

CASTILLA, E., HWANG, H., GRANOVETTER, E. and GRANOVETTER, M. (2000), Social Networks in Silicon Valley. In Lee C.M., Miller W., Hancock M. G., Rowen H. R. (eds.), *The Silicon Valley edge - A habitat for innovation and entrepreneurship*. Stanford: Stanford University Press, pp. 217-247.

CLOODT, M. , HAGEDOORN, J. and ROIJAKKERS, N.(2010) 'Inter-firm R&D networks in the global software industry: An overview of major trends and patterns', Business History, 52: 1, 120-149.

CORIAT, B., ORSI, F. and WEINSTEIN, O. (2003), Does biotech reflect a new science-based innovation regime? *Industry and Innovation*, 10, pp. 231–253.

COLEMAN, J. (1988), Social Capital in the Creation of Human Capital, *American Journal of Sociology*, 94, pp. 95-120.

COULON, F. (2005), The use of social network analysis in innovation research: a literature review, Lund University.

CRANE, D. (1972), *The Invisible Colleges: Diffusion of Knowledge in Scientific Communities*, University of Chicago Press, Chicago, IL.

DAHL, M. S. and PEDERSEN, C. O. R. (2004), Knowledge flows through informal contacts in industrial clusters: myth or reality?, *Research Policy*, 33, pp. 1673-1686.

DE JONG, J. P. J. and MARSILI, O. (2006), The fruit flies of innovations: A taxonomy of innovative small firms, *Research Policy*, 35, pp. 213-229.

DUBINI, P. and ALDRICH, H. (1991), Personal and extended networks are central to entrepreneurial process, *Journal of Business Venturing*, 6, pp. 305-313.

FELDMAN, M. P. (2001), The Entrepreneurial Event Revisited: An Examination of New Firm Formation in the Regional Context, *Industrial and Corporate Change*. 10(4): 861-891.

FONTES, M. (2005), The process of transformation of scientific and technological knowledge into economic value conducted by biotechnology spin-offs, *Technovation*, 25(4): 339-347.

FONTES, M. (2005b), Distant Networking: The Knowledge Acquisition Strategies of 'Out-cluster' Biotechnology Firms, *European Planning Studies,* 13(6), 899-920.

GIARRATANA, M.S. (2004), The birth of a new industry: entry by start-ups and the drivers of firm growth – The case of the encryption software, *Research Policy,* 33, pp. 787-806.

GILDING M. (2008), The tyranny of distance: Biotechnology networks and clusters in the antipodes, *Research Policy* 37, 1132–1144.

GIULIANI, E. and BELL, M. (2005), The micro-determinants of meso-level learning and innovation: evidence from a Chilean wine cluster, *Research Policy*, 34, pp. 47-68.

GRABHER, G. and POWELL, W. (eds.) (2004), *Networks*. Cheltenham: Edward Elgar (Critical Studies in Economic Institutions Series).

GRANOVETTER, M. (1973), The Strength of Weak Ties, *American Journal of Sociology*, 78, pp. 1360-1380.

GRANOVETTER, M. (1985), Economic action and social structure: the problem of embeddedness, *American Journal of Sociology*, 91(3), pp. 481-510.

GREBEL, T., PYKA, A. and HANUSCH, H. (2003), An evolutionary approach to the theory of entrepreneurship, *Industry and Innovation*, 10(4), pp. 493-514.

GRIMALDI, R. and TORRISI, S. (2001), Codified-tacit and general-specific knowledge in the division of labour among firms: A study of the software industry, *Research Policy*, 30(9), pp. 1425-1442.

HAGEDOORN, J. (2002), Inter-firm R&D partnerships: an overview of major trends and patterns since 1960, *Research Policy*, 31(4), pp. 477–492.

HANAKI, N., NAKAJIMA, R. and OGURA, Y. (2010), The dynamics of R&D network in the IT industry, *Research Policy,* 39, pp. 386-399.

HÉBERT, R. and LINK, A. (1989), In search of the meaning of entrepreneurship, *Small Business Economics,* 1, pp. 39-49.

HUGGINS, R. and JOHNSTON, A. (2010), Knowledge flow and inter-firm networks: The influence of network resources, spatial proximity and firm size, *Entrepreneurship & Regional Development* 22, 457-484.

JAFFE, A., TRAJTENBERG, M. and HENDERSON, R. (1993), Geographic localization and knowledge spillovers as evidenced by patent citations, *Quarterly Journal of Economics,* 108, 577-598.

KANG, K.H. and KANG, J. (2009), How do firms source external knowledge for innovation? Analysing effects of different knowledge sourcing methods, *International Journal of Innovation Management,* 13 (1), pp. 1-17.

KREINER, K. and SCHULTZ, M. (1993), Informal Collaboration in R&D. The formation of Networks across Organizations, *Organization Studies*, 14(2), pp. 189-209.

LIPPOLDT, D. and STRYSZOWSKI, P. (2009), *Innovation in the Software Sector*, Paris, OECD.

LISSONI, F. (2001), Knowledge codification and the geography of innovation: the case of Brescia mechanical cluster, *Research Policy*, 30, pp. 1479-1500.

LUUKKONEN, T (2005), Variability in organisational forms of biotechnology firm, *Research Policy*, 34, pp. 555–570.

LUUKKONEN, T. and PALMBERG, C. (2007), Living up to the Expectations Set by ICT? The Case of Biotechnology Commercialisation in Finland, *Technology Analysis & Strategic Management,* 19: 3, 329- 349.

MALERBA, F. (2005), Sectoral systems of innovation: A framework for linking innovation to the knowledge base, structure and dynamics of sectors, *Economics of Innovation and New Technology*, 14 (1-2), pp. 63-82.

MALERBA, F. and ORSENIGO, L. (1993), Technological Regimes and Firm Behaviour, *Industrial and Corporate Change*, 2, pp. 45-71.

MARSILI, O. and VERSPAGEN, B. (2001), Technological regimes and innovation: Looking for regularities in Dutch manufacturing, ECIS, Eindhoven University.

MCKELVEY, M. (2005), What drives innovation processes in modern biotechnology and open source software?, *Innovation: Management, Policy & Practice,* February.

MCKELVEY, M. (2008), Health Biotechnology: Emerging Business Models and Institutional Drivers, OECD International Futures Project on “The Bioeconomy to 2030: Designing a Policy Agenda”, April.

MCKELVEY, M., ORSENIGO, L. and PAMMOLLI, F. (2004), Pharmaceuticals Analysed Through the Lens of a Sectoral Innovation System. In Malerba F. (ed.), *Sectoral Systems of Innovation*. Cambridge University Press.

MORLACCHI, P., WILKINSON, I.F. and YOUNG, L. (2004), Social Networks of Researchers in Business To Business Marketing: A Case Study of the IMP Group 1984-1999, *SPRU Electronic Working Paper Series*, No. 116, May.

MORRISON, A. and RABELLOTTI, R. (2009), Knowledge and information networks in an Italian wine cluster, *European Planning Studies*, 17 (7), pp. 983-1006.

MURRAY, F. (2002), Innovation as co-evolution of scientific and technological networks: exploring tissue engineering, *Research Policy*, 31, pp. 1389-1403.

MURRAY, F. (2004), The role of inventors in knowledge transfer: sharing in the laboratory life, *Research Policy*, 33: 643-659.

OSTERGAARD, C. R. (2009), Knowledge flows through social networks in a cluster: Comparing university and industry links, *Structural Change and Economic Dynamics*, 20, pp. 196-210.

OWEN-SMITH, J. and POWELL, W. (2004), Knowledge Networks as Channels and Conduits: The Effects of Spillovers in the Boston Biotechnology, *Organization Science* 15, 6-21.

OZMAN, M. (2009), Inter-firm networks and innovation: a survey of literature, *Economics of Innovation and New Technology*, 18(1), pp. 39-67.

PISANO, G. (2006), Can Science Be a Business? Lessons from Biotech, *Harvard Business Review*, 84 (10), pp. 114-125.

POWELL, W., KOPUT, K. and SMITH-DOERR, L. (1996), Interorganizational Collaboration and the Locus of Innovation: Networks of Learning in Biotecnology, *Administrative Science Quarterly*, 41, pp. 116-145.

POWELL, W. and GRODAL, S. (2005), Networks of Innovators. In Fagerberg, J., Mowery, D. C. and Nelson, R. R. (eds.), *The Oxford Handbook of Innovation*. Oxford: Oxford University Press, pp. 56-85.

RAMPERSAD, G., QUESTER, P. and TROSHANI, I. (2009), Managing innovation networks: Exploratory evidence from ICT, biotechnology and nanotechnology networks, *Industrial Marketing Management*, 39(5), pp. 793-805.

ROIJAKKERS, N. and HAGEDOORN, J. (2010) Inter-firm R&D partnering in pharmaceutical biotechnology since 1975: Trends, patterns, and networks, Research Policy 35 (2006) 431–446.

ROSENKOPF, L. and TUSHMAN, M. (1998), The Coevolution of Community Networks and Technology: Lessons From the Flight Simulation Industry, *Industrial and Corporate Change*, 7, pp. 311-346.

ROTHMAN, H. and KRAFT, A. (2006), Downstream and into deep biology: Evolving business models in 'top tier' genomics companies, *Journal of Commercial Biotechnology*, 12(2), 86-97.

SALAVISA I., VIDEIRA P. and SANTOS F. (2009), Entrepreneurship and social networks in IT sectors: the case of the software industry in Portugal, *Journal of Innovation Economics*, 2009/2, pp. 15-39.

SAMMARRA, A. and BIGGIERO, L. (2008), Heterogeneity and Specificity of Inter-Firm Knowledge Flows in Innovation Networks, *Journal of Management Studies,* 45: 800-828.

SCHRADER, S. (1991), Informal technology transfer between firms: Cooperation through information trading, *Research Policy*, 20, pp. 153-170.

SCHWARTZ, M. and HORNYCH, C. (2010), Informal networking – An overview of the literature and an agenda for future research, *Jena Contributions to Economic Research*, 2010/1, University of Applied Sciences, Department of Business Administration, Jena.

SCOTT, J. (2000), *Social Network Analysis – A Handbook,* 2nd Edition*,* London: Sage Publications.

SINGH, J. (2005), Collaborative networks as determinants of knowledge diffusion patterns, *Management Science,* 51(5), pp. 756-70.

SMITH-DOERR, L. and POWELL, W. (2003), Networks and Economic Life. In Smelser, N. and Swedberg, R. (eds.), *The Handbook of Economic Sociology*. Princeton University Press.

SOUSA, C. (2008), Redes Sociais, Capital Social e Empreendedorismo: Questões teóricas e metodológicas, *Working Paper 2008/68,* Lisbon: DINÂMIA.

SOUSA, C., VIDEIRA, P. and FONTES, M. (2011), The role of entrepreneurs' social networks in the creation and early development of biotechnology companies, *International Journal of Entrepreneurship and Small Business*, 12 (2), pp. 227-244.

STEINMUELLER, W.E. (2000), Does Information and Communication Technologies Facilitate 'Codification' of Knowledge?, *Industrial and Corporate Change*, 9, pp. 361-76.

STEINMUELLER, W. E. (2004), The European software sectoral system of innovation. In Malerba, F. (ed.), *Sectoral Systems of Innovation*. Cambridge University Press, pp. 193-242.

STREET C.T. and CAMERON A. (2007), External Relationships and the Small Business: A Review of Small Business Alliance and Network Research, *Journal of Small Business Management*, 45, 239–266.

SWANN, P. and PREVEZER, M. (1996), A comparison of the dynamics of industrial clustering in computing and biotechnology, *Research Policy,* 25, pp. 1139-1157.

TIDD, J., BESSANT, J. and PAVITT, K. (1997), *Managing Innovation - Integrating Technological, Market and Organisational Change,* Chichester, Wiley.

TRIPPL, M., TODTLING, F. and LENGAUER, L. (2009), Knowledge Sourcing beyond Buzz and Pipelines: Evidence from the Vienna Software sector, *Economic Geography*, 85(4), pp. 443-462.

VONORTAS, N. S. (2009), Innovation networks in industry. In Malerba, F. and Vonortas, N. S. (eds.), *Innovation Networks in Industries*. Cheltenham: Edward Elgar, pp. 27-44.

WASSERMAN, S. and FAUST, K. (1994), *Social Network Analysis: Methods and Applications*, Cambridge: Cambridge University Press.

WENGER, E. (1998), Communities of Practice and Social Learning Systems, *Organization*, 7 (2), pp. 225-246.

WETERINGS, A. and PONDS, R. (2009), Do regional and non-regional knowledge flows differ? An empirical study on clustered firms in the Dutch life sciences and computing services industry, *Industry and Innovation*, 16(1), pp. 11-31.

ZHAO, L. and Aram, J.D. (1995), Networking and Growth of Young Technology-Intensive Ventures in China, *Journal of Business Venturing*, 10(5), pp. 349-370.

ZUCKER, L., DARBY, M. and ARMSTRONG, J. (2002), Commercializing Knowledge: University Science, Knowledge Capture, and Firm Performance in Biotechnology, *Management Science*, 48: 138-153.