# Understanding the topologies of innovation networks in knowledge-intensive sectors

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## ABSTRACT

The main goal of this paper is to compare the networks mobilised by young entrepreneurial firms from two knowledge intensive sectors – molecular biotechnology and software for telecommunications – to access resources required for innovation. Such a comparison allows similarities and differences between networks to be identified and explained.

The analysis focuses on formal and informal networks and on the relevant types of resources. It applies a methodology that draws on a vast array of data to capture the nature and content of a broad range of relationships developed by the firms in their innovative process. The results show that networks are quite contrasted in and across the two sectors, due both to the specificity of the resources searched for and the mode of organisation of the sectors. Furthermore, the results shed light on the specificities of formal versus informal networks. Finally, they provide novel insights into the organisation and dynamics of the sectors, taking into account both the characteristics and strategies of the firms and the specificity of the environment in the Portuguese case. The approach provides tools to study the innovative process in knowledge intensive sectors which may be applied to different national and sectoral contexts.



## KEYWORDS

Innovation network; social network; formal network; informal network; knowledge-intensive sector; biotechnology; software

**JEL CLASSIFICATION:** L14, L65, L86, O32



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# 1. INTRODUCTION

The main goal of this paper is to compare the networks mobilised by young entrepreneurial firms from two knowledge-intensive sectors – molecular biotechnology and software for telecommunications – to access resources required for innovation. Such a comparison allows similarities and differences between networks to be identified and explained. But it also permits interesting features concerning the organisation and dynamics of both sectors to be uncovered, taking into account their specific environment in Portugal.

Both sectors are knowledge-intensive and in both young entrepreneurial firms play an important role and often constitute the majority of the population. Thus, we expect some similarities in their innovation networks.

However, the two sectors also display some differences in the nature of the knowledge being exploited and the organisation of the innovation processes. These differences reflect upon i) the type of resources necessary for innovation and in particular on the external resources searched by the firms; ii) the sources for these resources and the modes of access to them. Since social networks are often mobilised by young entrepreneurial firms to access key resources that are not available in-house, it is expected that these differences will have an impact on the architecture of the innovation networks built by firms in each sector.

In addition to these sector-related features, it is also necessary to consider the environmental conditions in which firms operate. In fact, the context where firms are embedded influences the process of resource mobilisation, not only in terms of quantity, quality and variety of resources available but also in terms of the nature of the relationships established to access these resources. The context may therefore introduce particular constraints on the access to some types of resources, which may be sector-specific or transversal to all technology-intensive firms. These constraints require firms to adjust their networking behaviour accordingly and so are expected to give the configuration of the innovation networks specific traits.

Thus, in order to capture and understand the similarities and differences in networking behaviour between sectors it is necessary to 1) identify the main differences in terms of the innovative behaviour between biotechnology and software firms and their implications in terms of the type of resources searched; 2) investigate the nature of the relationships built to access each type of resource; 3) consider the specific context where those relations occur.

For this purpose, the paper draws on two domains of literature: 1) the literature on innovative processes in biotechnology and in software sectors; 2) the literature on the role of networks in entrepreneurship and in innovation, in order to identify and understand the similarities and differences between networks and their role in the access to resources required for innovation.

Combining contributions from these two streams, we build an analytical framework that:

- proposes two sources of variation in the configuration of the networks: i) the *type of resource* being accessed; and ii) the *mode of access* to the resource (i.e. the nature of ties established);
- relates differences in the sectoral networks with distinctions in the *type of the knowledge* being exploited and in the *organisation of innovative activities* in each sector;
- considers the conditions found in the environment where firms operate.

Based on this framework, we put forward some expectations about the implications of sectoral differences for the architecture of the respective innovation networks and conduct an exploratory empirical analysis.

The empirical analysis is conducted on a sample of 46 young entrepreneurial firms: 23 from software (software for telecommunications) and 23 from biotechnology (molecular biology) operating in Portugal. The innovation networks mobilised by firms are reconstructed using a novel methodology. This methodology permits a vast array of data to be assembled capturing the nature and contents of the range of relationships through which key resources and competences flow into the firms, thus enabling the consideration of the two sources of network variation proposed: type of resource and nature of the tie.

On the basis of an analysis of the reconstructed networks, we investigate the main similarities and differences between the two sectors and discuss the reasons for the differences identified.



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## 2. BACKGROUND

In this section, after a brief survey and discussion of the most relevant contributions on which our study has drawn, we will present the analytical framework adopted in the research.

### 2.1. DIFFERENCES BETWEEN BIOTECHNOLOGY AND SOFTWARE IN THEIR INNOVATIVE BEHAVIOUR

It is well established that innovation is sector specific. A number of studies have analysed innovation in biotechnology and in software, and a number of comparative analyses of the two sectors (or of biotechnology and computing) have been conducted (McKelvey, 2005; Swann and Prevezer, 1996; Weterings and Ponds, 2009; Rampersad et al, 2009; Luukkonen and Palmberg, 2007). Although none of these studies has specifically compared firms' networking strategies, they provide some insights into the organisation of the sectors and the innovative behaviour of the firms that can guide our discussion.

Both sectors are highly knowledge-intensive, but differences can be found in terms of the nature of knowledge being exploited and also the role and location of scientific and technological knowledge, as compared with non-technological resources. These differences are likely to impact the nature and sources of technological opportunities and hence the nature of innovation processes conducted by the firms and therefore the resources and competences necessary to pursue them (Malerba and Orsenigo, 1993).

Biotechnology is the most common example of a science-based or science-driven sector, owing its very existence to the new technological and commercial possibilities opened up by fundamental scientific discoveries in the field of molecular biology. Small firms, usually research spin-offs founded by scientists who maintained a close relationship with the academy, were key players in the development of this sector (Orsenigo, 1989).

The dominant business model adopted by firms in this industry, at least in the early stages, was centred on the creation of knowledge through intensive research activities (frequently in collaboration with research organisations) and the patenting and licensing of the resulting technologies to established firms from other industries, in particular pharmaceuticals (McKelvey et al, 2004). This model was based on the presence of pervasive "platform" technologies that could support a continuous stream of developments, the availability of venture capital and a tight appropriability regime, since firms' revenues derived essentially from research contracts with and/or licensing or selling the technologies to more powerful customers (Malerba and Orsenigo, 1993; Coriat et al, 2003).



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As the sector evolved, other business models emerged (Orsenigo et al, 2001; Mangematin et al, 2003), with new companies starting to develop and commercialise specialised products, often adopting a niche strategy (Luukkonen, 2005). The product/service focus was more frequent in the case of firms operating outside the health sector (Valentin and Jensen, 2003) or firms targeting non-drug based activities such as instruments or diagnostics (Gottinger and Umali, 2011). It also tended to prevail in countries/regions peripheral to the main centres of biotechnology (Lowe and Gertler, 2009; Costa et al, 2004). On the other hand, the growing difficulties experienced by firms adopting the classical science-based model – due to constraints in capital markets and cost reduction strategies of large companies – increasingly led these firms to adopt more integrated business models, where the direct exploitation of scientific competences is increasingly bundled with downstream services or products (Rothman and Kraft, 2006; McKelvey, 2008). Recent research points to the on-going experimentation with a variety of new business approaches, which reflect adjustments to changes in the demand structure (particularly in the health sector) and/or exploit new opportunities arising from recent scientific developments (e.g. personalised medicine) (Amir-Aslani and Mangematin, 2010; Wall, 2010). But, on the whole, innovation remains mostly science-driven, radical innovations are frequent and the pace of innovation is quite rapid.

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 knowledge-based one, bearing 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 tacit knowledge appears to be more relevant than in most biotechnology activities (Grimaldi and Torrisi, 2001; Aramand, 2008).

Generally speaking, we are not dealing with a science-based sector. The level of technological opportunities is high, but mostly depending on 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. Opportunities are reinforced by the pervasiveness of applications. In terms of appropriability – greatly affected by the open source software movement (Malerba, 2005; McKelvey, 2005) – firms rely on several forms of property protection such as patenting, standards, copy rights, techno-commercial strategies - including lead-time, proliferation of



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products (Giarratana, 2004) and partnerships and alliances, both among software firms and with customers. Overall, innovation can be described as mostly incremental, although the pace of innovation is also very rapid.

The specificities described above have implications on the organisation of the sectors namely, the nature of the relationships established by its firms. The science-based nature of biotechnology implies that long-term relationships tend to be maintained with research organisations, which are important sources of a key resource (Murray, 2004; Bagchi-Sen, 2007). In the case of software, such relationships are usually less important. Although the access to academic knowledge is increasingly relevant, universities are particularly important to gain access to talented highly skilled engineers (Giarratana, 2004), since here firms are knowledge-intensive in the sense of "embodied" knowledge. While scientific research is a key source of opportunity in biotechnology, stimuli from customers and the market appear to be more relevant to software innovation. In fact, software houses try to adapt their products to a fast 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 an increasing need for mobility and interconnectedness have a strong influence on the industry. Thus, cooperation among firms and upstream and downstream relations are quite relevant (Malerba and Orsenigo, 1993).

The specialised and frequently upstream nature of the activities pursued by biotechnology firms, the type of business models adopted and the characteristics of their main customers mean that the success of firms' innovative activities is strongly dependent on the establishment of partnerships with other, often larger companies (Baum et al, 2000; Milanov and Fernhaber, 2009). Power asymmetries between partners are thus common, even if the recent dynamics of the sector has compelled large partners to engage in more balanced and collaborative relationships (Gottinger and Umali, 2011). Partnerships can be mixed, combining technological and commercial elements and may also involve capital (Bagchi-Sen, 2007). In fact, long development lead times and high capital requirements may force biotechnology firms to rely strongly on external funding, which can be provided by venture capitalists and/or by corporate investors (Coriat et al, 2003). Given the global nature of biotechnology, these partnerships are often transnational (Owen-Smith and Powell, 2004).

Thus, the biotechnology sector typically encompasses a large number of specialised small firms that associate with a variety of other organisations to develop and commercialise their technologies or highly innovative products. Despite the on-going changes on the strategies of the various players, the division of labour between research organisations, small biotechnology firms and large established companies from application sectors is still patent (particularly in



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pharmaceuticals) (Stuart et al, 2007), with large firms retaining an important coordinating role in the complex networks that characterise the industry.

In software, small, medium and large firms coexist. Small firms tend to specialise and 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 tailored solutions and services. Partners include software firms, since outsourcing and a huge specialisation are distinctive traits of the industry. But they also comprise large companies from sectors such as computing hardware, telecommunications and the internet (Cloodt et al, 2010). Talented programmers are a crucial resource to business success. Consequently, they are the subject of intense dispute between firms and labour mobility is quite high. However, this phenomenon coexists with regular “knowledge bartering” among individuals, which is critical for problem solving. Table 1 summarises this brief characterisation of biotechnology and software innovative behaviour and organisation, highlighting the main differentiating features between them.

**Table 1 - Comparing biotechnology and software**

| | Biotechnology | Software |
|---|---|---|
| Nature of knowledge | Scientific knowledge | Tacit complex technological knowledge “embodied” in skilled individuals |
| Main sources of opportunity | Science | Market/Customers |
| Entrepreneurs background/competences | Scientists with academic background | Engineers with previous experience in industry: technical & commercial |
| Type of innovation | More radical | More incremental |
| Dominant business model | Technology development & selling in technology markets<br>Product development & high value added services becoming more important | Product development/Product’s continuous differentiation and sophistication<br>Customised products and services<br>Niche strategy in some segments |
| Position in value chain | Typically upstream – develop technologies or products to intermediate markets | Typically downstream – develop products for final markets or for customers that address final markets |
| Key partners | Universities<br>Large established firms from application sectors | Other firms from same sector<br>Firms from application sectors (computing HW, telecommunications, Internet, etc.) |



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## 2.2. ACCESSING RESOURCES THROUGH SOCIAL NETWORKS

The above discussion shows that access to external resources is critical for the success of young entrepreneurial firms in both sectors. Thus, the establishment of relationships with individuals or organisations that can provide those resources or facilitate their access is an important element of a firm's strategy. But it also suggests that there are differences in terms of the resources searched, as well as in the type of actors and the relationships established with them to access these resources. Thus, the relevant question emerging from this assessment is whether differences in terms of resources lead to differences in the networks built and maintained by young and mostly small firms to survive and to thrive in a turbulent context.

The role played by networks in the access to resources necessary for the creation and development of technology-intensive firms has been addressed both by the literature on social networks and entrepreneurship and by the literature on innovation networks. According to the former, entrepreneurship is a social process embedded in network structures (Aldrich and Zimmer, 1986; Uzzi, 1997). Thus, firm formation and development are influenced by the social networks of the founder(s) (personal networks that tend to be informal) and more generally by the social context in which the firm operates. Social networks are described as facilitating the acquisition of resources in the context in which firms are embedded, allowing some constraints in the entrepreneurial process to be overcome (Elfring and Hulsink, 2003). Likewise, innovation studies have increasingly highlighted the role of networks for the success of innovative endeavours. Networks are described as providing critical resources to companies, particularly scientific and technological knowledge, either as an alternative or as a complement to the market (Ozman, 2009).

But while both streams of literature recognise the need for and the relevance of a variety of resources for entrepreneurship and for innovation, empirical research that simultaneously addresses and/or compares the networks mobilised to access different types of resources is scarce (Sammarra and Biggiero, 2008, Sousa et al, 2011). Empirical studies usually focus on one type of resource only (knowledge, capital, information) (Jack, 2010), with innovation studies putting particular emphasis on the access to knowledge (Ozman, 2009). Thus, they only provide a single perspective to the understanding of the impact of different types of resources on the nature of the networks.

Similarly, both literatures distinguish between more formal, contractual relationships that are established between organisations, and more informal relationships that are established between individuals (Smith-Doerr and Powell, 2003). They also pay some attention to the intensity of the ties established and, in the case of the innovation literature, its influence on knowledge access (Ahuja, 2000; Uzzi, 1997). But, once again, empirical studies tend to centre on one type of relationship. In the case of the innovation literature, research on formal networks is clearly dominant (Audretsch and Feldman, 2003; Roijakkers and Hagedoorn, 2006; Cloodt et al, 2010). Research addressing the actual informal exchanges between individuals is much less frequent (Schwartz and Hornych, 2010) and it is often concerned with the networks of firms' employees rather than those of entrepreneurs (Kreiner and Schultz, 1993; Giuliani and Bell, 2005; Dahl and Pedersen, 2004). Conversely, the entrepreneurship literature puts great emphasis on the role played by entrepreneurs' personal networks, which are described as originating from the entrepreneurs' trajectory and grounded on loyalty and reciprocity between individuals (Uzzi, 1197). However, these features are rarely associated with search for particular resources (Jack, 2010).

The greater interest in knowledge networks revealed by innovation studies is also reflected at this level, with a substantial part of the research on both formal and informal networks centring on knowledge exchanges. However, the innovation literature has also addressed in some detail the establishment of formal alliances by young technology-intensive firms to support the whole process of technology development and commercialisation, thus often encompassing the access to a variety of technological and non-technological resources and competences (Colombo et al, 2006; Bagchi-Sen, 2007). But once again, comparative studies between formal and informal networks – either taken globally or focusing on the access to specific types of resources only – are rare (Fuller-Love, 2009; Trippl et al, 2009).

The scarcity of comparative research limits our understanding of how differences in the nature of resources searched influence the configuration of the networks mobilised by the firms. This calls for research that effectively addresses this issue, which is one of the purposes of this paper.

This research is necessarily exploratory. However, based on the few available comparative studies and also on research on the networks built to access specific resources, it is possible to argue that there appear to be some differences between them. In addition, these partial results can also provide insights to guide our empirical analysis and to support the discussion of our findings.



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## 2.3. USING SOCIAL NETWORKS TO CAPTURE DIFFERENCES BETWEEN SECTORS: AN ANALYTICAL FRAMEWORK

Summing up the discussion in the previous sections, we propose an analytical framework that relates the networks' architecture at sectoral level with the nature of the knowledge exploited and the organisation of the innovative activities. It is argued that these two dimensions are reflected in the variety of resources searched and consequently their sources and the type of relationships established with them.

This framework, depicted in Figure 1, starts from the notion (based on literature presented in section 2.1) that despite some similarities related to their technology-intensive nature, sectors such as biotechnology and software have clear-cut differences regarding the *nature of the knowledge* being exploited and the *organisation of innovative activities.* These differences have implications on the *type of resources required* by the firms, as well as on the need to *gain access to external sources* of these (non-available in-house) resources and the ability to mobilise them. In other words, they influence the type of the resources searched by the firms operating in these sectors, which are likely to present some differences.

The type of the resources will then influence the actors that are mobilised (*composition* of the network) and the type of relationships that are established with them (*structure* of the network), which are also likely to vary. These variations will then reflect on the architecture of the resource access networks built by firms in each sector.



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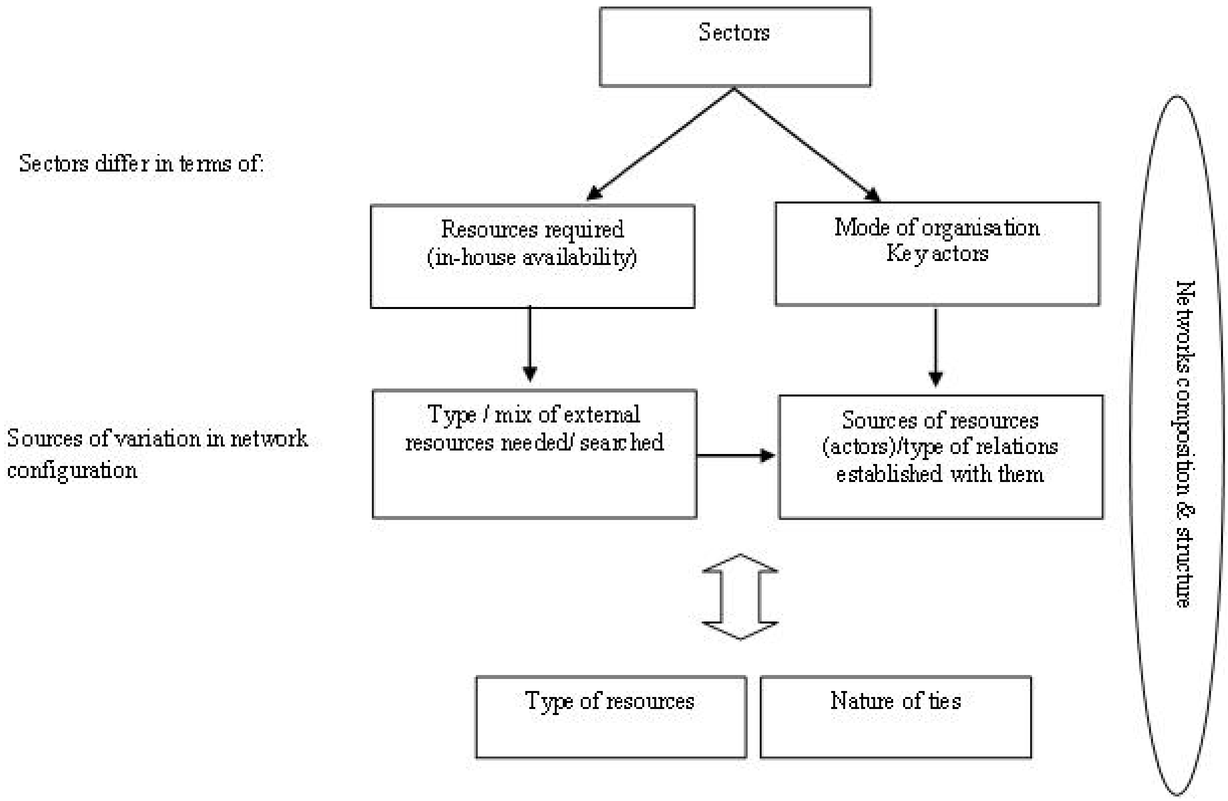
**Figure 1 – Analytical framework**




It should however be pointed out that different environmental contexts may also introduce changes in the sector´s mode of organisation. Therefore, the firms' ability to identify and gain access to the sources of required resources, and the channels used to obtain them, are also partly context dependent.

More specifically, while we expect to find some similarities - given the technology-intensive nature of firms' innovative activities and the predominance of young entrepreneurial firms – we also expect that:

- the differences in the origin of technological opportunities (science vs. market) and the nature of the dominant business model pursued by the firms (technology vs. product development) will have implications on the type of resource needs (both in terms of scientific and technological knowledge and non-technological resources);
- concerning knowledge resources, the differences in the nature of the knowledge being exploited will have implications on the relative importance of research organisations vs. other sources;



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- concerning non-technological resources, the differences in business models will have implications on the specific resources that are searched for (e.g. capital) and on the relative role of different types of sources;
- both the nature of the resource searched and the type of actor mobilised are also expected to influence the type of relationship that is established;
- the specific context where firms are embedded is expected to affect the availability and ease of access to some resources, thus influencing the architecture of the networks built to access them.

The analytical framework presented above will now guide our empirical analysis.

## 3. EMPIRICAL SETTING AND METHODOLOGY

### 3.1 EMPIRICAL SETTING

The analysis focused on specific fields of biotechnology and software - molecular biology and software for telecommunications. It was carried out using a sample of 46 Portuguese companies formed between 1998 and 2008: 23 software and 23 biotechnology companies. Our biotechnology firms can be regarded as the most science based group of firms within the sector, while our software 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 set up 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%) conduct R&D activities. The average investment in these activities is 15% of the turnover and around a quarter of the total employees work in R&D activities. Only 5 companies applied patents. Also only 5 employ PhDs. In terms of sources of funding, a great majority rely on equity financing (90%). Eight resorted to some kind of public incentive, which represented only 4% of total funding, on average.

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

In the biotechnology sector, the subset selected – molecular biology – belongs to the younger generation of Portuguese biotechnology: 78% have been set up 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 the 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% on average of the employees work in R&D activities. About half of the firms (48%) have patents. Out of 23 companies, 15 have at least one PhD holder. On average, PhDs represent 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 onto the market.

With regard to the sources of funding, 57% of the firms had external capital, around one third resorting to venture capital. Half of the companies have received public incentives, which accounted on average for 20% of the total funding.

As to the entrepreneurs, the vast majority (65%) hold a PhD and nearly 86% have participated in research activities, studied or worked abroad for a significant period. However, only a small number had previous industrial or business experience.

As was pointed out above, although sector level determinants are expected to strongly influence firms' resource requirements and relationships, the context where firms operate – an intermediate developed economy - can also have some impact upon the availability of these resources and the mode of access to them. However, even if the firms being analysed are all operating in the same country, which provides a basically similar institutional setting with respect to some aspects relevant for the activity of young technology-intensive firms, other contextual conditions may vary substantially between sectors. Software is at a more mature stage of development and has benefited from the high competitiveness of the domestic telecommunications operators. Conversely, biotechnology is at a more incipient stage of development and its activities take place in an industrial environment that appears to be less supportive, in particular regarding the access to non-technological resources. These contextual differences may have some impact on the networks built in each sector.

## 3.2 DATA COLLECTION

Data about the firms (in both sectors) were 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 a variety of information on the history of the firms' formation. The interviews, conducted in 2008, were based on a semi-structured questionnaire that focused on: i) the entrepreneurs' personal networks and their importance for the innovation process and ii) firm's activities, strategy and performance, with particular emphasis on innovation and technological development and on formal cooperation arrangements with other organisations. The data thus obtained include the origin of the relationships and the type, nature and relevance of their respective contributions.

## 3.3 NETWORKS (RE)CONSTRUCTION

Using the data obtained through the interviews and the documentary sources it was possible to (re)construct the innovation networks for each sector. Based on the proposed analytical framework, networks were reconstructed taking into account the resource type and nature of the relationship.

Considering the type of resource, and drawing on the suggestion of Castilla et al (2000), the (aggregate) innovation network is divided in two sub-networks: opportunity and access (O&A), and knowledge. The O&A network is composed of all the actors/relationships used to identify the innovation opportunity and to access and acquire the tangible resources (capital, facilities and commercial channels) as well as intangible resources (information, managerial knowledge and other competencies) necessary to exploit it. The knowledge network includes actors/relations used to obtain scientific and technological knowledge.

The nature of the relations was distinguished as formal or informal. Formal networks are related with a formal/codified agreement between actors (usually involving a system of authority, distribution of competences, rights and duties and a conflict resolution device) while informal networks are more spontaneously formed, and are frequently associated with personal ties that are directly mobilised or act as mediators in the access to the resource. In practice, this distinction is not always clear-cut. The firm sometimes establishes both formal and informal ties with the same organisation at different moments or for different purposes and, as stressed by several authors, formal ties are frequently based on previous informal relations (Powell et al,



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1996). However, our methodology allows us to identify the nature of the relations present in each dyadic interaction.

So in addition to (aggregate) innovation networks, four different networks were built for each sector: two O&A networks (formal and informal) and two knowledge networks (formal and informal). The content of each network is presented in table 2.

**Table 2 – (Re)constructed networks contents**

| | Formal | Informal |
|---|---|---|
| O&A | Funding sources<br>Facilities providers<br>Service providers (legal, accounting, IP, marketing)<br>Commercial partnerships | Information/advice to build business plan<br>Information to identify/exploit opportunities<br>Management knowledge |
| Knowledge | R&D Projects<br>S&T Partnerships<br>Patents (partners; providers)<br>Origin of technology (if formally transferred) | Innovation (new ideas)<br>S&T knowledge<br>Origin of technology (if informally transferred) |

## 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 characterisation usually involves several aspects. In this research the following aspects are considered:

a) *Network size:* The size is an important element in the analysis of a network. According to Burt (2000), all 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, such as density and connectivity (for example, a network with a small number of actors is more likely to have two that are connected). In addition to measures like the total number of actors and the total number of ties, we include 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 have no external connections. If a network is composed of a large number of small components there is a lower capacity to access resources. These measures will allow us to compare both the size and the connectedness of the networks in each sector.

*b) Network Composition:* Innovation networks are composed of different types of actor. In this research we consider seven types of actor (and represent them using different symbols in the diagrams): interviewed firms (blue square), firms from the same sector (red circle), firms from other sectors (green circle), universities and research organisations (yellow circle), financial institutions (grey circle); science and technology parks (pink circle) and other organisations, including professional and trade associations (purple circle). The relevance of each type of actor is analysed by considering its share in the total number of actors.

c) *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 characterise the actors' position we use two centrality measures: degree centrality and betweenness centrality (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 with the highest number of ties (links/connections). Actors with the highest degree centrality are designated hubs. In directed networks, like those 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. So a central actor receives resources from several organisations and is characterised by a strong attractiveness[2]. The outdegree shows the number of ties that depart from one actor. So a central actor provides resources to many firms and is characterised by a strong activity.

The betweenness measures the extent to which an actor lies between others in the network: a node with few ties (low degree) may play an important intermediary role and so be very central. 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 others, which would be isolated otherwise.

d) *Network cohesion*: This aspect of the network structure is related to the extent to which the various actors 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). Two measures are computed to analyse network cohesion: density and proportion of strong ties.

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



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

A distinction is to be made between strong and weak ties, since they require a different amount of time, energy and money to be developed/maintained. The literature on inter-organisational 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 contacts between two organisations (Zhao and Aram, 1995). In this paper, we take a combination of three factors to assess whether the tie is strong or weak: the frequency of contacts, the existence of multiplex ties and the existence of ties of a different nature. In this case, a tie 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 another organisation (nature).

Networks with many strong ties are denser than those with a smaller number of strong ties. In order to characterise the strength of the ties, we consider the proportion of strong ties, i.e. the ratio between their number and the total number of ties.

e) *Network Centralisation*: This refers to centrality measures calculated for the whole network, allowing the observation of the extent to which it has a centralised structure, i.e. a structure that is organised around its most central nodes. As centralisation measures are based on actors' centrality measures, this paper considers the two different perspectives mentioned above: degree and betweenness. They vary from 0 to 1, where 1 is associated to the maximum level of centralisation.

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

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



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# 4. RESULTS AND DISCUSSION

## 4.1 THE TOPOLOGY OF INNOVATION NETWORKS

In this section we present the actual topology of the innovation networks in both sectors. This topology is captured by the network diagrams sketched with Netdraw software. Figures 2 to 5 present the diagrams considering the type of the resource – knowledge vis-à-vis opportunity and access - and the nature of the relationships established in each case – formal and informal networks. The diagrams reveal differences between the two sectors, which seem to be more marked in the cases of formal O&A networks and of informal knowledge networks.

**Figure 2 - Formal O&A networks**

(a) Biotechnology (b) Software

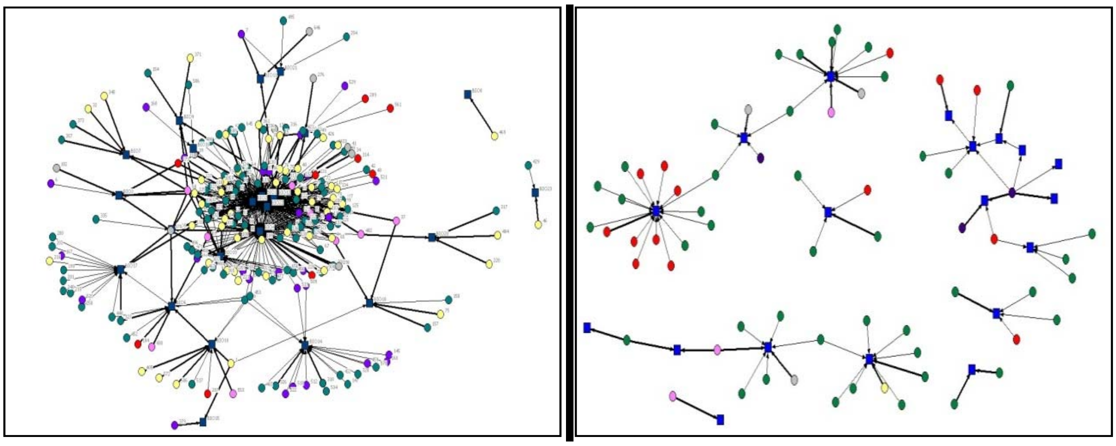

**Figure 3 - Informal O&A networks**

(a) Biotechnology (b) Software

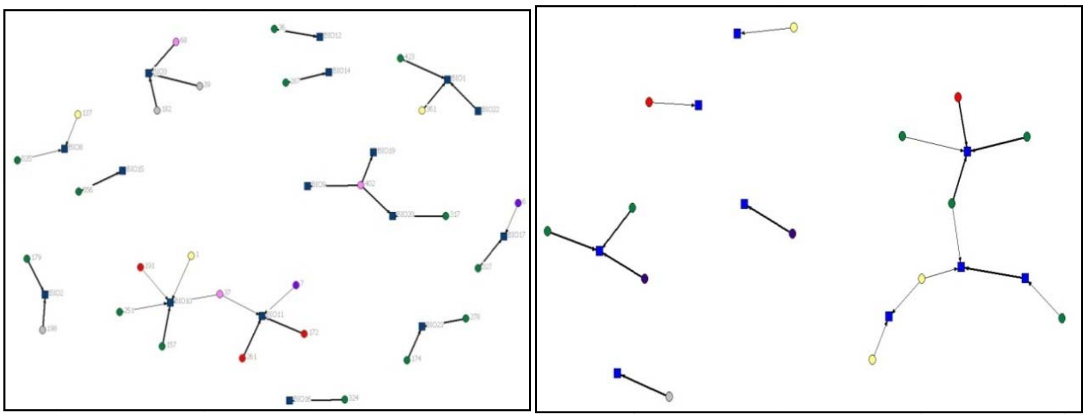



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**Figure 4 - Formal knowledge networks**

(a) Biotechnology (b) Software

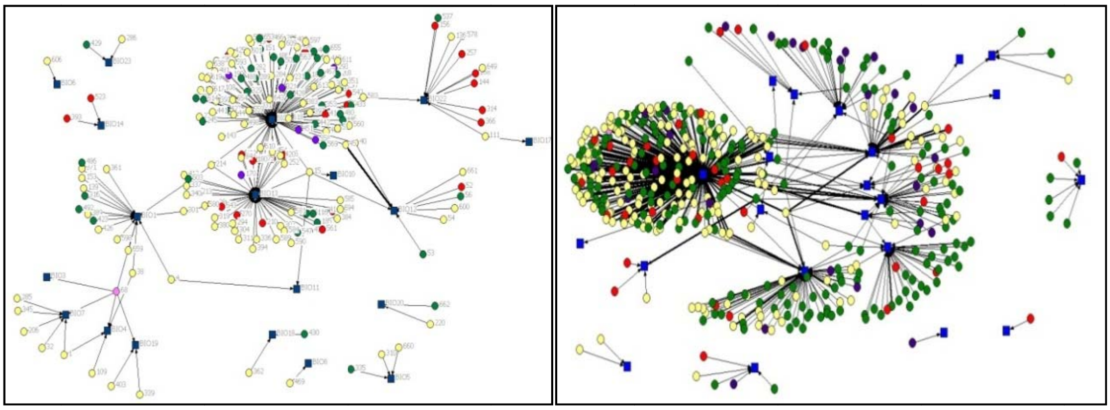
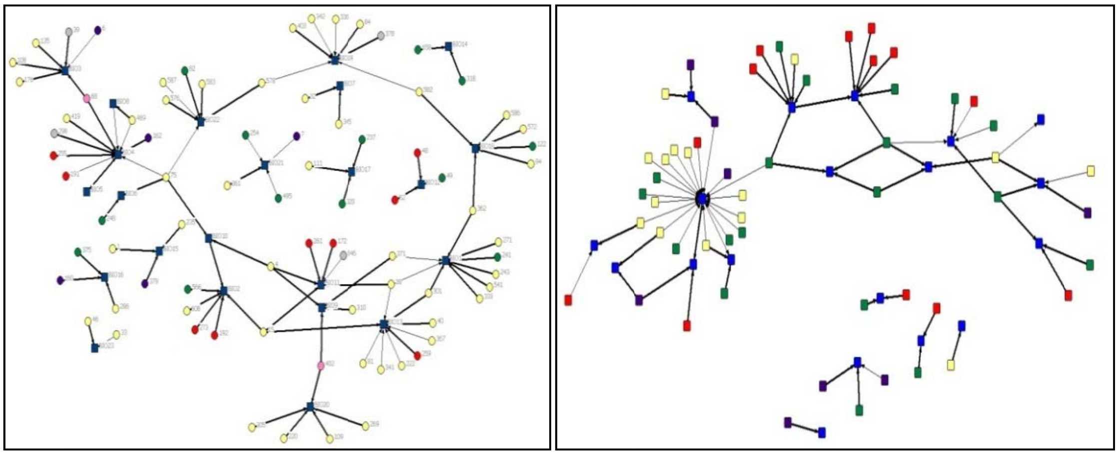


**Figure 5 - Informal knowledge networks**

(a) Biotechnology (b) Software



If we aggregate all the resource-based networks and build the aggregate innovation networks for each sector, the differences between the diagrams are significantly reduced and the networks appear to be quite similar (Figure 6). This suggests two conclusions: first, that the existing differences between the networks of the two sectors have to be captured at a disaggregate level, which is the only one able to unveil the sectoral specificities; and second, that resources and modes of access to these resources are effectively important sources of network variation in these two technology-intensive sectors.



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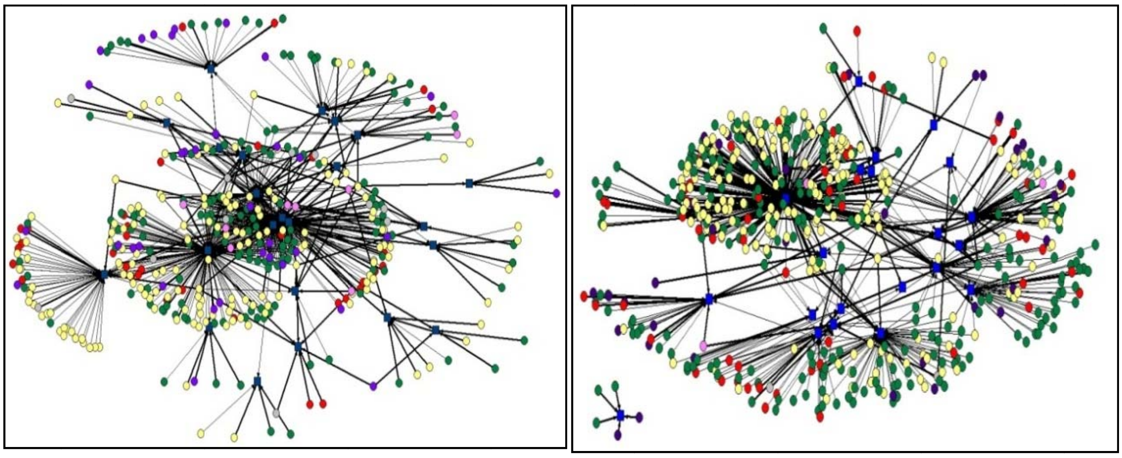
**Figure 6 - Aggregate innovation networks**

(a) Biotechnology (b) Software



We compute and analyse the above mentioned social network measures to fully characterise the reconstructed networks. Based on these data, we will first describe their main features and subsequently conduct a comparison between the two sectors.

## 4.2 MAIN CHARACTERISTICS OF SECTORAL NETWORKS

In this section we present a description of the four reconstructed networks in the two sectors, starting with biotechnology. More than providing a comprehensive description of each of the networks, we point out aspects that are distinct and relate them with the two sources of variation considered in our analytical framework: the type of resource and the mode of access/nature of the tie.

### 4.2.1 Innovation networks in biotechnology

In terms of network size, the data (Table 3) show that substantial differences emerge when we consider the nature of the tie. Formal networks are much larger than informal ones both in terms of the number of actors and the number of ties, regardless of the specific resource under consideration. Thus, innovation networks are clearly dominated 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%), indicating a higher connectivity.

The composition of the networks is strongly affected by the type of resource. As expected, firms predominate in O&A networks and universities in knowledge networks. This result is in line



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with the science-driven nature of the sector (universities are the main source of knowledge) and with the need to interact with other firms in the access to resources to exploit opportunities.

Still regarding composition, we can also find differences between formal and informal networks. Universities and firms from other sectors are more strongly present in formal networks. This may be related with the need to appropriate the innovation results in the interaction with universities and powerful customers. Inversely, companies in the same sector, S&T parks and financial institutions have a stronger presence in informal networks, suggesting a greater informality in the interaction with these types of actor.

We want to highlight the weight of financial institutions in the informal knowledge network. The interviews suggest that some venture capital (VC) companies play an advisory role, not only on business issues but also on the directions of research to pursue in the early years. The influence of VC actors therefore goes beyond the access to financial resources.

**Table 3 – Innovation network analysis in biotechnology**

| | | O&A | | Knowledge | |
|---|---|---|---|---|---|
| | | Formal | Informal | Formal | Informal |
| Size | No. of actors | 229 | 43 | 203 | 104 |
| | No. of ties | 620 | 34 | 213 | 102 |
| | No. of components | 3 | 12 | 8 | 9 |
| | Size of largest component | 224 | 10 | 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



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Looking at the cohesion measures, we can see that the most obvious differences are related to the nature of the tie. Therefore, sharp contrasts between formal and informal biotech 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 ties in the formal knowledge network is consistent with the kind of technological alliances in this sector and their high volatility (Hagedoorn, 2002; Smith-Doerr and Powell, 2003).

The measures of the actors' centrality also reveal differences between the networks. Here, there seems to be a cross-over effect between the resource type and the nature of the tie. The formal O&A network shows the highest degree centrality, indicating a higher activity, and the highest betweenness centrality, indicating that a central brokerage position plays a major role in the formal access to 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.

The centralisation measures of the network indicate if it 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. So in this case, differences in the networks appear to be particularly associated with the nature of the tie. Considering the other measures, we do not observe either a great variation of values or the existence of a centralised structure.

Taking the clustering coefficient into account, it is again visible that the main differences are related to the nature of the relationship. Formal networks are more interconnected in 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, revealing that they comprise a large number of sub-sets of actors, all of which are connected to each other directly or through a common neighbour. The number of cliques is higher in formal O&A and informal knowledge networks. Thus, we can find differences between the networks which seem to be caused by the joint action of the resource type and the nature of the tie.



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### 4.2.2 Innovation networks in software

We can also observe differences between the reconstructed networks in software (table 4). Starting with size, the distinctive features are induced by the resource type and the nature of the tie. Knowledge networks are much more populated than O&A networks. Additionally, formal networks are larger than informal networks. Data show a very similar number of components in all networks, but the weight of the largest component differs, especially if we consider the type of resource, being much 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. However, we can find some variation related with the type of resource and the nature of the tie. First, not surprisingly, the relevance of universities is considerably higher to access knowledge. Second, the presence of firms from the same sector is particularly significant in informal networks, indicating the typical strong informal bartering at the horizontal level that characterises the industry.

**Table 4 – 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 | 0.1 | 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



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The density values of the various networks are quite similar. However, we can find differences related with the nature of the tie: informal networks are slightly denser. Additionally, the nature of the tie influences the intensity of the relations since the higher proportion of strong ties in informal networks is clear-cut.

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, suggesting the existence of a model core-periphery. The average degree assumes the same value in all networks, but betweenness centrality is influenced by the type of resource and is higher in knowledge networks. This indicates a great relevance of brokers in the access to knowledge resources.

Looking at the overall centralisation, we can observe 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.

The clustering coefficient displays very low values in all networks, revealing that actors share very few alters. However, it is possible to observe some differences related with the type of resource, since knowledge networks are more clustered.

All networks exhibit sub-sets of connected actors, which abound particularly in the formal knowledge network. Here we can see dissimilarities related both to the type of the resource and to the nature of the tie: formal networks and knowledge networks exhibit a large number of cliques.



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## 4.3 COMPARING NETWORKS OF THE TWO SECTORS

As noted before, we can find differences between the four reconstructed networks in each sector. These differences may be associated with the type of the resource and/or the nature of the tie. In this section, we present a comparison between the two sectors. We identify and discuss similarities and differences between the respective networks. Using our analytical framework, we relate the differences with the type of resources needed for innovation and with the mode of organisation.

### 4.3.1 Regularities across sectors

As previously stated, the nature of the tie is an important source of variation in the topology of the sectoral networks. However, some regularities can still be found across sectors and this provides some insights into the characteristics of formal and informal networks.

In both sectors (and for both resources), formal networks are bigger and more connected. This result, which somewhat contradicts the innovation literature, is partially related with our methodological options, namely the fact that we are considering the informal networks mobilised only by the entrepreneurs. Furthermore, we only included the "core" informal ties i.e. those that were regarded by entrepreneurs as important. Because of these options, this analysis departs from the majority of the studies examining the informal innovation networks. In fact, those studies focus on knowledge flows and on informal know-how trading activities that occur among firm employees or between firm employees and researchers (Østergaard, 2009; Kreiner and Schultz, 1993).

We also found some regularities in the composition of sectoral networks: regardless of the 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 the most relevant origin of resources used to identify and exploit new opportunities.

As expected, informal networks are denser and characterised by strong ties. Informal networks are often associated with the trajectory of the individuals and thus encompass higher levels of trust and reputation. The literature refers to the importance of trust and reputation in informal interactions. For example, in innovation networks, Dahl and Pedersen (2004) underscore their importance for the acquisition of high-value knowledge through informal networking. And in the literature of entrepreneurship, Shane and Cable (2002) stress the importance of reputation in obtaining financing through VC.



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All networks are extremely heterogeneous in terms of centrality of actors, thus pointing to the existence of core-periphery situations 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, which indicates that some firms rely extensively on formal partnerships to accede knowledge. We can also observe that formal relations to access knowledge are associated with more clustered networks, i.e., networks where more firms share the same partners.

Although biotechnology and software innovation networks display the above mentioned similarities, they also have relevant differences in composition and structure, especially when we analyse them at a disaggregated level. We will now turn to those differences and discuss them in the light of our analytical framework.

#### 4.3.2 Sectoral differences in the networks composition

Starting with composition, results show differences related with the types of resource and with the organisation of the sectors. Biotechnology firms resort more to S&T parks and financial institutions, not only to access tangible resources (formal O&A) but also information and advice (informal O&A and knowledge networks). These results are related to time and capital requirements for the development of new biotechnology technology, the greater presence of academic spin-offs and the lesser maturity of companies in this sector.

As expected, the composition of the O&A networks also reflects differences in the main source of opportunity. Software firms resort more to firms in the context of the identification of new opportunities, since customers are the major source of new ideas, and biotechnology companies resort more to universities, reflecting the importance of scientific research in the emergence of new opportunities.

Still in the context of O&A networks, we also find striking differences in the mode of access to resources through universities: biotechnology firms prefer formal relations while software companies favour informal ties. We can relate this result to the fact that many biotechnology companies resort to universities for access to laboratory facilities and to the participation of many universities in the Portuguese Health Cluster (we will return to this issue later). For their part, software companies mobilised informal ties with universities, mainly to access information and human resources.

Knowledge networks also display some interesting differences, which can be related to the nature of relevant knowledge in these sectors: in biotech, knowledge networks (both formal and informal) are dominated by universities, while firms play the leading role in software. These



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results confirm our expectation that the nature of the knowledge exploited and the respective sources have implications for the relative importance of academic knowledge sources.

Biotechnology firms, as compared with software firms, are more likely to attribute greater importance to the search for scientific knowledge and this reflects on the higher participation of academic institutions in knowledge networks. Given the need to protect this key asset, those relations tend to be formalised. But informal exchange can also be critical to firms operating on the knowledge frontier, since new scientific knowledge often circulates in informal "epistemic communities" (Breschi and Lissoni, 2001).

As to software companies, they rely more on tacit knowledge "embodied" in individuals with experience in the sector and related with customer requirements. This reality emerges in the composition of knowledge networks: informal networks reflect the importance of firms from the same sector in informal bartering among engineers and formal networks reflect the importance of technological partnerships with customers.

### 4.3.3 Sectoral differences in the networks structure

Sectors also display some differences in their network structure, namely in terms of cohesion, centrality and clustering. These differences become particularly evident when we compare formal O&A and informal knowledge networks. Thus, sectoral specificities emerge mainly in the formal access to tangible and intangible resources, other than knowledge, and in the informal access to scientific and technological knowledge.

Regarding the formal O&A network, figure 2 and tables 3 and 4 reveal striking differences between the topology of the innovation networks in biotechnology and software. In this case, differences can be attributed to the organisation of sectors and to the specific context where firms are embedded.

Biotechnology's formal O&A network is larger, more connected, less dense, more centralised and more clustered than that of software. So biotechnology firms rely more on formal relations in the access to non-knowledge resources, and those relations express a sectoral logic more than the sum of corporate networks.

This architecture is strongly affected by contextual elements and 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 to promote a "Health Cluster". This policy has contributed to the formation of a more integrated space of relations aiming to identify and exploit innovation opportunities, thus changing the environment where biotechnology firms conduct their business activities significantly.



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The development of the health cluster reflects on the composition of the O&A formal network (size and type of actors) and also on the high level of clustering that was found. In fact, six of the firms interviewed are formal members of the Health Cluster structure, which also brings together most organisations that can be relevant partners in health biotechnology: universities, hospitals, S&T parks, financial institutions, and a large number of Portuguese and multinational firms in pharmaceuticals, medical devices, instrumentation and clinical trials.

In the software sector, the formal O&A network is very fragmented: it has six components, the largest of which 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. 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). Therefore, in the software case, the architecture of the network reflects the importance of telecommunications operators and MNCs in the structuring of the sector.

The informal knowledge networks of the two sectors also exhibit significantly different structures (Figure 5 and Tables 3 and 4). In this case, the sectoral differences are likely to be related with the nature of knowledge and its role in the innovation processes.

The informal knowledge network in biotechnology has one large component, which integrates more than 70% of the actors, and eight small components (up to five 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/epistemic 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. Thus, the informal knowledge sharing in biotech is organised around knowledge communities agglutinated by universities, which perform the role of informal knowledge providers.

The informal knowledge network also has a large component in software. 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, notably with clients, but also with other software developers. The other half is dominated by a large clique (with 22 actors, 10 of which are universities). In the centre of this clique, we find a software firm – which we can designate "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 and credibility make them preferential partners over the others (preferential attachment is involved here), and in this way, they have a positive "structuring effect" in the sector.

## 5. CONCLUSION

In this paper we have compared the networks mobilised by young entrepreneurial firms from two knowledge-intensive sectors – molecular biotechnology and software for telecommunications – to access resources required for innovation. Such a comparison has allowed relevant similarities and differences between these networks to be identified and explained. It has also permitted interesting features concerning the organisation and dynamics of both sectors to be uncovered, taking into account their specific environment in Portugal.

As expected, our analysis revealed similarities in the topologies of the innovation networks of these sectors. Those similarities are related to their knowledge-intensive nature and to regularities based on modes of access to resources that are typical of young entrepreneurial firms in fast changing environments. Thus, this work shows that some characteristics of formal and informal networks are transversal to the two sectors.

The results also provide some support to our argument that the architecture of the innovation networks reflects sectoral differences both in the nature of knowledge exploited and in the organisation of the innovative activities. Interestingly each of these dimensions appears to be more precisely captured through specific lens.

Thus, the composition of the networks – that is, the mix of actors to which firms resort – reflects more clearly the nature of the knowledge being exploited – i.e. the origin of technological opportunities and the nature of the dominant business pursued by the firms to exploit them, which, as argued above, influence the type of resources being searched by the firms and their sources.

On the other hand, the structure of the networks –i.e. the web of relations – , although also obviously influenced by the type of resources being searched, appears to be more affected by the conditions in which these resources can be accessed. Thus, differences in the organisation of the sectors and, in particular, the specific features of the firms' embeddedness influence the structure of the networks.

Using the conventional measures of structure, the differences appear as particularly evident in the cases of formal O&A and of informal knowledge networks. In the first case, they are related with distinct dynamics of 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 develop their activities within a partially policy-driven "health cluster" which has brought together the main actors operating in the health sector in Portugal. Although relatively recent, this structure appears to have an increasingly relevant role as a supplier of at least some of the resources necessary for the early development of these firms. A clustering effect appears, in which research universities rather than pharmaceutical companies are the agglutinating element.

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

Regarding informal knowledge networks in biotech, we found small knowledge communities. 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. In fact, international knowledge access is typical of biotechnology (Owen-Smith and Powell, 2004), but may assume an even more important role in the case of an intermediate developed economy (Fontes, 2005), reflecting the need to connect to major biotechnology clusters (Gilding, 2008).

In software, the informal knowledge network comprises two groups: a first group of firms doing informal bartering with each other, which is typical of informal relations in this industry (Smith-Doerr and Powell, 2003); a second group, constituted around a large firm (our "star" firm), which creates technological knowledge of 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 greater maturity of the sector, which is structured around a few large users and a very large knowledge-intensive company.

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, these differences are particularly evident since most biotechnology firms are still in an early stage of development.

In spite of its exploratory nature and the specificity of the context to which it has been applied, this research contributes to fill a gap in the literature, regarding the sources of sectoral variation of innovation networks. It also permits to improve our understanding on the way those networks are shaped in knowledge-intensive sectors.

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