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1. INTRODUCTION

In technology intensive sectors, where knowledge is complex and distributed, young, small specialised firms will tend to resort more or less extensively to external organisations to obtain scientific and technological knowledge, as well as other resources necessary to produce and commercialise their products and services. The need to gain access to external resources and competences leads firms to mobilise a set of relationships that can facilitate such access. Research on social networks can therefore provide an important contribution to the understanding of these processes.

The role of social networks in the access and mobilisation of resources by firms has been extensively addressed by the literature in recent years (Ozman, 2009). But there has been limited research on the mechanisms and strategies that shape the configurations of those networks, namely on the sources of network diversity among technology intensive firms.

This paper addresses the networking strategies of firms from two different sectors and its objective is, exactly, to understand whether there is heterogeneity in the networks built by firms for accessing resources necessary for innovation and whether such heterogeneity can be associated to differences in the technological regimes under which these firms are operating.

To address these questions we combine insights mainly from two streams of literature: social networks and technological regimes.

Technological regimes are defined as combinations of technological opportunity conditions, appropriability conditions, cumulativeness of learning and the nature of the knowledge base (Dosi, 1988). They constitute the competitive environment for the creation of innovation by firms influencing its configuration and dynamics.

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But doing so, they also influence the strategies deployed by firms to access different types of knowledge and other resources, to appropriate innovation rents and to design technological strategies. This means that they do not only affect firms' behaviour regarding the development and use of technology and the production of innovation, they also affect their positioning in the market and their relation to competitors (incumbent or potential), customers, suppliers and partners (Malerba and Orsenigo, 1993).

The role of networks in the process of firm formation and growth has been object of extensive research, which has namely addressed the functions played by those networks on resource access and mobilisation (Elfring and Hulsink, 2003). According to the social networks literature, the formal and informal networks established by the entrepreneurs and/or their firms influence firms' ability to interact with the environment in the search for key resources, but are in turn influenced by the nature of that environment (Ozman, 2009). Our argument is that some features of the technological environment where firms operate will affect the type(s) of resources searched, their nature and the conditions for their access and, therefore, are likely to influence firms' network building strategies, with impact upon the structure and composition of their networks. Thus, our main research question is whether the heterogeneity of the networks used by firms for accessing knowledge can be associated to differences in the technological regimes that characterise the sectors in which they are embedded.

The literature has already recognised that there is a relationship between the structure of the knowledge of a sector and the types of networks that emerge (Malerba, 2006). However, most empirical research has focused on scientific and/or technological knowledge networks and on formal relationships. We expect to add to this research by also including in our analysis informal/personal relationships, as well as a large variety of technological collaborations, and by comparing the formal and informal networks established by firms from different sectors to access technological resources.

For this purpose, we have selected two groups of firms created between 1998 and 2008 and operating in two different areas: biotechnology (molecular biology) and software for mobile telecommunications, that, despite being both knowledge intensive, are likely to have significant differences in terms of their knowledge base (the former being science-based and the latter being primarily technology-based) (McKelvey, 2005; Giarratana, 2004). Indeed, these two groups of firms are part of broader sectors (biotechnology and software) that the literature has long recognised to be characterised by different technological regimes (Malerba and Orsenigo, 1993).

Data about firms' networks (formal and informal) was collected using a combination of complementary methods, involving both search for documentary information (on formal technological and commercial partnerships and on patents); and in-depth face-to-face interviews with the founders, that enabled the collection of information on the entrepreneurs' personal network and its importance for firms' access to resources necessary for innovation, as well as on the firms' activities, strategies and formal relationships. The data on the entrepreneurs' personal networks permitted us to include in the network the informal ties they mobilise to access different resources for their firms. Since this information is not easily obtained, it is seldom used in innovation studies.

Starting from the firm level networks (re)constructed on the basis of this data, we build six different social networks that capture the set of relationships (formal, informal and global) of the firms from each sector. The global network was obtained through the aggregation of the other two.

Finally, we analyse and compare some dimensions of these networks – e.g. actors' composition and network structure - at the light of some known properties of the technological regimes that characterise the two sectors. The objective is to investigate whether there are differences between sectors regarding the type of networks that are built to access and exchange knowledge; and to examine along which dimensions such differences may be more evident.

The results of this analysis allow a better understanding of the relationship between the nature of the technological regimes and the mechanisms and strategies underlying network building by the firms.

The structure of the paper is as follows: after a theoretical discussion about the role of social networks in knowledge access and innovation and about technological regimes (section 2), we will present our argument and research approach (section 3). The empirical research will be addressed in the remaining sections. In section 4, we present the sample and describe the data collection methodology. In section 5, we focus on the innovation networks: we present the network reconstruction methodology and analyse and compare firms' innovation networks. In section 6, we explore the possibility of identifying technological regimes that are not necessarily delimited by sectoral boundaries. In section 7, we investigate the impact of two alternative configurations of technological regimes – sector-based and sector-independent - on the importance, composition and structure of innovation networks. Finally, in section 8, we draw some conclusions.

2. THEORETICAL BACKGROUND

2.1 SOCIAL NETWORKS AND TECHNOLOGICAL ENTREPRENEURSHIP

2.1.1 The role of social networks on knowledge access and innovation

Young technology intensive firms, operating in fast changing fields derive their competiveness from their capacity to quickly expand and renew their knowledge base, in order to generate a steady stream of innovations (Liebeskind et al, 1996; Yli-Renko et al, 2001). Given the frequently complex and distributed nature of the knowledge required for innovation and given their inevitable resource limitations, these firms often end up being strongly reliant on scientific and technological knowledge originating from external sources (Baum et al, 2000; McMillan et al, 2000). On the other hand, these firms often play an intermediate role in innovation systems, acting as intermediaries between research organisations and the market or as specialised suppliers of intermediary technology inputs (goods or services) to other organisations (Hicks and Hedge, 2005; Fontes, 2005). This particular role implies that they integrate extensive technology and knowledge exchange networks (Autio, 1997). Thus firms will need to establish relationships with a variety of organisations that can act as formal or informal sources of information in relevant knowledge fields and/or as partners in technology-oriented alliances that are critical to access key resources and competences. However, admittance to the networks where knowledge (particularly new knowledge) circulates may be restricted (Zucker et al, 1998; Breschi and Lissoni, 2001).

Similarly, the ability of young firms, who have not yet built a reputation, to establish relationships with key actors, may be limited, requiring a previous credibilisation (Powell et al, 1996).

Research on social networks has shown that the process of identification and access to key knowledge sources as well as the process of admittance to the circles where such knowledge circulates and where alliances are built relies strongly on networks (Fontes, 2005; Liebeskind et al, 1996; Stuart and Sorenson, 2003; Murray, 2004; Owen-Smith and Powell, 2004). This encompasses both the personal networks built by entrepreneurs along their academic and professional trajectories and the linkages intentionally established with strategic purposes (which are often mediated by the former) (Hite & Hesterly, 2001; Grandi and Grimaldi, 2002).

In fact, recent research has shown the importance of the entrepreneurs' social capital in accessing several tangible and intangible resources needed for the formation and growth of new firms (Greve and Salaff, 2003; Singh, 2000). Entrepreneurship is described as a social process embedded in social structures and thus being strongly influenced – facilitated or constrained - by the social networks of firms' entrepreneurs (personal networks) and by the social environment in which the process takes place (inter-organisational networks).

These networks permit to circumvent some of the constraints faced by the entrepreneurs, facilitating access to relevant resources (Ozman, 2009). Their role is particularly relevant in the case of knowledge intensive firms, given the combination of high levels of uncertainty (both technological and market) and resource constraints that characterise them (Yli-Renko et al, 2001, Johanisson, 1998). In addition some authors also argue that knowledge access and exploitation are social processes (Kogut and Zander, 1992) and thus social networks can be crucial at this level, permitting to increase the scope, depth and efficiency of knowledge exchanges (Lane and Lubaktin, 1998; Schrader, 1991). Social network can also contribute to afford scientific (and market) credibility to firms who are developing technologies whose value is not yet fully demonstrated (Moensted, 2007).

Thus, young technology intensive firms are likely to mobilise or develop a set of knowledge-related relationships that can facilitate access to key knowledge sources. But it is important to take into account that, not only the nature of firms' knowledge requirements vary, but the conditions in which knowledge access takes place will differ, being influenced by the knowledge and social environment and by firms' own knowledge endowments (Malerba and Orsenigo, 1993). Therefore, it is to be expected that firms with diverse types of knowledge requirements and originating from and operating on different knowledge environments will build knowledge networks with diverse compositions and structures. However, although the literature has already recognised that there is a relationship between the structure of knowledge of a sector and the types of networks that emerge (Malerba, 2006), the mechanisms and strategies that shape the configurations of these networks, and namely the sources of network diversity, have still been object of limited research.

Previous exploratory research conducted by the authors (Sousa et al, 2010) has found that different network configurations are associated with the access and mobilisation of different types of resources and, particularly, that scientific and technological knowledge is accessed through networks that differ significantly from those mobilised to obtain other (non-technological) resources (Sousa et al, 2010). In this paper we focus on the networks established to acquire and exploit this particular resource - knowledge - and attempt to characterise these networks and to gain a better understanding of the conditions that may be behind variety in network configurations at this level. For this purpose we will use the framework and techniques provided by social network analysis.

2.1.2 The analysis of social networks

Social networks can defined as a set of nodes or actors connected by a social relationship (or tie) of a specified type (Castilla et al., 2000). Network configurations differ according to the type of actors and the type of relations they encompass. Actors may be organisations or individuals. Relations can be characterised by the type of interaction (e.g. formal vs. informal), the intensity of the tie (e.g. strong vs. weak) and its content (i.e. the type of resource(s) that circulate through it), as well as by the relative position of the network actors[1].

With respect to the structure of networks, one important contribution of the social network literature concerns the distinction between strong and weak ties and their respective effects on the process of resource mobilisation. According to Granovetter (1973), the strength of ties can be analyzed using a combination of aspects like frequency/duration of the tie, emotional intensity, intimacy and reciprocity. Strong ties are associated with higher levels of social proximity and trust, being favoured by frequent interaction (McEvily e Zaheer, 1999; Johanisson, 1998). However, building and maintaining strong ties is costly and thus actors tend to limit their number. Rather, weak ties are looser connections based on more occasional interactions and thus may be established with a wider range of actors.

The balance between strong and weak ties affects the knowledge transfer process (Maskell and Malmberg, 1999) as well as the cost of accessing knowledge (Coleman, 1988). There is some debate over the effects of different configurations, 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). According to some authors, the former, by generating trust and cooperation between the actors (Ahuja, 2000) are more beneficial: they facilitate the exchange of high quality information (Gulati, 1998; Van Geenhvizen, 2008) and of complex (Hansen, 1999) and tacit knowledge (Lundvall, 1993), and are particularly important to access scarce resources (Lovas and Sorenson, 2008). According to other authors, the latter, by enabling the establishment of relationships with multiple unconnected actors has the advantage of providing access to non-redundant information (Burt, 1992) eventually leading to the identification of opportunities of which competitors are unaware (McEvily and Zaheer, 1999; Low and Abrahamson, 1997). While it is suggested that a mix of strong and weak ties is critical for the development of young firms (Uzzi, 1997), the relative weight of the each in firm's network structures is likely to be determined by the nature and objectives of the search process: e.g. exploration vs. exploitation, search for information vs. search for knowledge; nature of knowledge being searched, namely degree of newness, complexity and tacitness (Gilsing and Nooteboom, 2005; Giuliani, 2007; Morrison and Rabellotti, 2005; Ahuja, 2000; Freel and de Jong, 2009)

[1] Network position is usually measured by network centrality measures, which are described as offering different opportunities to access the relevant sources of resources (Powell et al, 1996). Since our approach was based on an analysis of firm-level networks (i.e. ego-networks with only direct ties and thus where all actors in the network are directly related with the firm) it does not make sense to consider actors' position in the network: our ego firm is always be the most central actor and the distance between the ego and all alters is always equal to zero. To consider also indirect ties at this stage of research, we would have required to expand data collection to all alters in the whole network, which was much beyond the scope of this research.

Another relevant element in the analysis of network structure is the distinction between formal and informal relationships. Knowledge networks are generally composed of both. For instance, Grodal (2007) defines networks as formal or informal relationships between individuals (e.g. entrepreneurs, employees) or organizations (e.g. firms, projects) and Powell and Grodal (2005) describe them as 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". However despite the implicit recognition of the importance of informal knowledge flows in innovation, that is reflected on the extensive literature on spillovers (Jaffe et al., 1993; Autant-Bernard, 2001), research has largely focused on formal inter-organisational (often inter-firm) networks (Hagedoorn 1993, Gulati, 1998; Colombo et al, 2006; Okamura and Vonortas, 2006). Informal networks have been less frequently addressed, and sometimes only as a complement to more formal relationships.

Some authors have nevertheless attempted to gain a more comprehensive understanding of the actual informal knowledge flows that take place between individuals from different organisations. One stream of research used co-patenting / patent citations (Breschi and Lissoni, 2009; 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 at firm level. Research on "communities of practice" (Wenger, 1998; Rosenkopf and Tushman, 1998) and epistemic communities (Steinmueller, 2000) has also offered some insights into the nature of these interactions. However, only more recently have researchers started to address directly the exchange processes that take place at the micro-level, conducting purposive data collection on the actual interactions between individuals. Following the seminal work of Von-Hippel (1987), these authors have traced the informal know-how trading activities that occur among firm employees and/or among firms entrepreneurs (who often are also researchers/technicians), or between firm employees and university researchers (Kreiner and Schultz, 1993; Lissoni, 2001; Giuliani and Bell, 2005; Dahl and Pedersen, 2004; Schrader, 1991; Morrison and Rabellotti, 2005; Trippl et al, 2009; Ostergaard, 2009) and investigated the purpose, contents and structure of the associated flows.

According to Cassi and Morrison (2007) an important contribution of these studies was to put the focus on the "identification of the relevant community of actors and the relevant type of knowledge", enabling a better understanding of the configuration of these informal knowledge networks.

While research tends to focus either on formal or on informal networks, they are strongly intertwined. Underlying formal agreements there is frequently a variety of informal (social) relations (Powell et al, 1996), which can that have an important contribution to their success (Kreiner and Schultz, 1993). Informal 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. In spite of this, formal and informal networks will only partially overlap since they may have been established with different purposes, encompassing different types of actors and evolving along diverse time spans (Kratzer el al. 2009). Thus, firms' relationships may encompass a dense web of ties, both formal and informal and it is relevant to consider their combined action and assess the effective contribution of both.

2.1.3 Networks and the nature of knowledge

In summary, when addressing the configuration of firms' knowledge networks it is possible to conclude that the actor composition of these networks reflects the type of knowledge sources and partners used by firms during the process of knowledge production and exploitation, providing an indication of the relative relevance of different types of organisations in this process. Similarly, it is possible to suggest that the structure of these networks - in this case the mix of formal and informal relationships and the relative importance of strong and weak ties – reflects the nature of the channels used by firms to access and exchange knowledge and can provide some indications regarding the nature of the flows that take place, either globally or with some particular types of actors.

Going back to our previous argument regarding the potential differences in terms of firms' knowledge requirements and endowments and in terms of the characteristics of the context where knowledge exchanges take place, it is possible to advance that the composition and structure of the firms networks will reflect, to a great extent, the nature of the knowledge firms are exploiting (namely the nature of their knowledge base) and the nature of the knowledge environment it induces. In other words, it is possible to suggest that the differences in the composition and structure of firms' networks reflect – and therefore can be at least partly explained by – the differences in technological regimes that are implied by the nature of the knowledge (Malerba and Orsenigo, 1993).

Thus, the technological regime framework can be used as one useful analytical device to investigate the sources of variety in firms networking behaviour. Although we are aware that the factors influencing firms' strategic behaviour go beyond "technological imperatives", it can be argued that in technology intensive sectors – such as biotechnology and software – the nature of knowledge being exploited and namely its impact on the conditions in which knowledge is produced, disseminated and accessed, are likely to be an important determinant of firms' networking behaviour.

2.2 TECHNOLOGICAL REGIMES

2.2.1 Origin and evolution

Since Schumpeter, the concern on the conditions for innovation by firms is central as well as is central the diversity of forms taken by the innovative processes. In fact, in Schumpeter Mark I and II models, the sources of scientific/technological knowledge are quite different. In Mark II model, innovation relies much more on in-house R&D and the process is more cumulative than in Mark I model.

Technological regimes are ways of representing the technological environments – and their diversity - of the firms. The concept of technological regimes allows to "organising" the notion of technological environment that exerts a strong influence on the behaviour of firms. It adds both simplicity and complexity to that basic notion: simplicity, because it reduces the potential multiplicity of possible technological environments to a few fundamental types; complexity and deeper understanding, because it sheds light on the fundamental properties that emerge from and simultaneously mould the environment and its influence on firms' behaviour.

Main properties of the environment are represented by the main dimensions of technological regimes - technological opportunity conditions, appropriability conditions, cumulativeness of learning and the nature of the knowledge base (Dosi, 1988). It is according to the specific and evolving configuration of these dimensions that firms develop their innovative activities. The original ideas by Dosi were later on clarified and developed by Malerba and Orsenigo (1993).

Since technology is basically knowledge about economic activities, and furthermore increasingly relying upon scientific knowledge, analogies are likely to exist between the development processes of science and of technology. In fact, both processes are strongly informed by fundamental discoveries that induce sharp ruptures, which are followed by periods of cumulativeness along a pre-defined path. The Kuhnian approach to scientific progress has proved to be a major source of inspiration to understand technological development, as Dosi has discovered and proposed in the early 1980s (Dosi, 1982). Cumulativeness (as opposed to rupture) is then a major trait of normal science development and of most technological innovations (incremental).

Technological opportunity means essentially the ease of innovating for a given investment in search for new solutions (Malerba and Orsenigo, 1993). Opportunities have long been a major point for the understanding of entrepreneurship endeavours. But in management approaches these opportunities are mostly market opportunities that are supposed to be “found” by the entrepreneur (see Shane, 2003, for a survey). In neo-Schumpeterian approaches, opportunities are built by the entrepreneur who innovates. However, once a new technological field is open it offers high technological opportunities that are rewarding in terms of high profit perspectives. This is particularly true when the technology is radically new, permits very pervasive applications and has a high potential to develop and transform itself, since it entails a very strong potential for the creation of a great number of new or significantly improved products and processes, over an extended span of time.

Appropriability conditions are crucial for technological creation, due to the knowledge nature of technology. Unlike common markets, technology transactions face a problem of property recognition and use. This is due to the quasi-public nature of technological knowledge that calls for specific institutions and firms’ strategies to secure exclusivity of use to its creators, at least over a long enough period to be compensated for the innovative efforts.

Finally, the nature of the knowledge base: knowledge can rely more or less on cutting-edge scientific advances; be more or less complex; be more or less dependent from external sources, such as universities and the like; be more or less tacit. This dimension is obviously strongly related to the other three dimensions that stand as the main characteristics of the innovative activities according to the technological regimes approach.

From a very different perspective, Pavitt (1984) has contributed in a fundamental way to the understanding of technological environment. Drawing on the notion of technological trajectories presented in subsequent research (by Dosi, Nelson and Winter, Freeman, Rosenberg, Gold, Sahal and others) and based on empirical data on significant innovations and on innovating companies in British manufacturing, he built a sectoral taxonomy made of four broad categories corresponding to the multifaceted patterns of firms’ innovative activities. Each category encompassed a group of sectors, assembled according to the sectoral sources of technology used in the sector; the institutional sources and nature of the technology produced in the sector; and the characteristics of innovating firms, such as size and principal activity (Pavitt, 1984: 346). The author identified four categories or groups of sectors, labelled as supplier dominated sectors; production intensive sectors (subdivided into specialised suppliers and scale-intensive sectors) and science based sectors. By doing so, he has proceeded to a dramatic clarification and reduction of information regarding the multiplicity of ways innovation takes place. Since his influential article, it has been admitted that firms' innovative profile can be ascribed to a main pattern within a set of patterns.

Drawing on Pavitt´s major contribution, further research has deepened and enlarged the taxonomical work on innovation, to account for the specificity of services or to adapt the original categories to specific purposes, subjects and research questions. This is the case with the addition of a fifth innovation pattern – labelled as "information intensive" – to describe innovation processes in services, especially in finance, retailing, publishing, telecommunications and travel. This extension in fact was done by Pavitt himself even if with other authors (Tidd et al, 1997).

Other authors have used different categories or regimes. This is the case of Marsili (2002) who proposed a typology to identify the technological dimensions that mostly affect entry into a sector. The typology was built according to the characteristics of technological opportunities and of the nature of knowledge in industrial sectors and encompassed five regimes: the science-based regime; the fundamental-processes; the complex (knowledge) system; the product-engineering and the continuous-processes regime. This typology was also adopted in a study on the relation between technology and industrial structures and dynamics in Dutch manufacturing (Marsili and Verspagen, 2002). Interestingly, and more recently, the same author has contributed to a taxonomical exercise that turned out to identify basically the same categories as Pavitt (1984) had done twenty years before, using a totally different data basis and a different set of variables (science-based, specialised suppliers, supplier-dominated and resource-intensive). The purpose was to study the innovative activities and correlated business practices and strategies of small – and even micro-innovative firms in Dutch manufacturing and services (de Jong and Marsili, 2006).

Services have deserved a specific attention, being quite unlikely that a unique innovative pattern could account for all innovation processes in such a heterogeneous reality. In this same line, Evangelista (2000) has drawn from the well-known heterogeneity of these activities to look for the identification of innovative patterns within the services industries in Italy. The taxonomical exercise produced four groups of sectors: technology users; S&T-based; interactive and IT based; and technical consultancy, in fact a combination of the two latter groups.

2.2.2 The evolution of technological regimes

Technological regimes are dynamic entities as we can conclude from the previous section. But their metamorphoses could be ascribed either to theoretical refinements or to factual historical reasons, or both. The point here is to introduce a time component in the analysis, enabling us to address the following questions. First, is there an ideal type of technological regime in each long phase of technological development or to put in other terms is there a correspondence between the typical dominant technological regime and the specific broad stage of capitalism? And if so, second, is it possible to identify the traits of a distinct technological regime that corresponds to the present stage? According to Archibugi (2000), the answer to the first question would be affirmative.

In fact, when proceeding to a critical assessment of Pavitt´s taxonomy sixteen years on, Archibugi raised the question of "how can this taxonomy help us to understand economic evolution" (2001: 422). He then wrote that it can be read dynamically in two different ways: predicting the most likely developments along current technological trajectories of firms; and suggesting a kind of new dominant way of innovative activities in each stage.

Adopting a long waves' approach of economic development, Archibugi writes that the emergence of specialised suppliers as a distinctive category of firms took place as a separation from supplier-dominated firms, in the transition from the first long wave to the second one. Likewise, "scientific discoveries in the field of chemistry and electricity opened up new business opportunities which were quickly exploited by a generation of new firms" (2001: 423). Science based firms would then have been created with the third long wave, in the turn of the 19th century. The next wave, labelled as Fordism, was based on mass production, new complex products, large firms and efficiency improvement and scale exploitation strategies ("cost-cut trajectories"), corresponding to the scale-intensive category. At the moment he writes, the so-called New Economy stage, the author argues that a generation of information intensive firms were rising, in manufacturing and services industries and "based on the intensive analysis and use of data-processing" (2001: 423). At this stage, and in a sketch form, the industrial organisation would be characterised by networks of firms and strong user-producer interactions.

We are not going to explore this subject now. Suffice here to say that it seems consistent that innovative activities by firms have undergone great transformations in the current techno-economic paradigm. In fact, alongside with an increase in the complexity and specialisation of knowledge creation activities, innovative activities have become more dependent on scientific knowledge; firms have become more specialised; and collaborative practices have gained an accrued importance. The incidence of these phenomena on the configuration of technological regimes is yet to be assessed.

2.2.3 Inter-sectoral and intra-sectoral diversity of technological regimes: The cases of biotechnology and software

Following along the path opened up by Pavitt, a number of authors have studied the inter-sectoral diversity of innovative activities using the analytical framework of technological regimes. A relevant paper was the one by Malerba and Orsenigo, in 1993. According to the link between the nature of technological regimes and the type of firm behaviour, they examined the histories of three relevant technology-intensive industries: the semiconductor industry, biotechnology, computer hardware and software. From a different perspective, Malerba examines the variability of innovation across sectors in subsequent papers (see Malerba, 2005). Within a diverse theoretical framework and with different aims, other papers have compared innovative processes, organisational modes in modern biotechnology and software or computing services (McKelvey, 2005; Rampersad et al, 2009; Swann and Prevezer, 1996; Wetering and Ponds, 2009).

A great number of studies focusing on one of the sectors also provide very relevant contributions to the understanding of innovation processes and their conditions and as such will be also used in the brief characterisation and comparison that follows.

Biotechnology is the most common example of a science-based or science-driven sector. In fact, modern biotechnology emerged as a result of major scientific breakthroughs in the 1970s:

recombined DNA and hybridoma technology. This young sector owes its very existence to the new technological and commercial possibilities opened up by those fundamental discoveries. Some authors claim that biotech in not an industry but rather a set of technologies (McKelvey, 2005). But since it consists of a large spectrum of scientific and technological activities with a wide application across industries, it can be labelled as a quasi-sector.

Within biotechnology sector several distinct types or groups of firms coexist. A first group is made of companies that try to commercialise products as soon as possible, often adopting a niche strategy. It includes companies dedicated to the production of diagnostics kits based on the hybridoma technology, among others that also develop specialised applications. A second group encompasses companies that focus on the creation of knowledge through intensive research activities, and whose aim is patenting and licensing to other firms from several industries such as pharmaceuticals, agro industry and chemicals. Firms in the second group are highly based on cutting-edge scientific advances in genetic engineering (recombinant DNA) and strongly connected with pharmaceutical companies. The two groups are usually academic spin-offs that maintain a close relationship with the academy (Malerba and Orsenigo, 1993). For both groups appropriability of their knowledge outcomes is critical (Coriat el al, 2003).

Established pharmaceutical companies have developed diversified strategies to deal with the emergence of molecular biology in the 1980s (Orsenigo, 1989; Orsenigo et al, 2001). A dominant trait in those strategies is that they could not afford ignoring what was happening in the world of new small biotech firms. They had then to build collaborative relations with them, while acquiring new competencies and transforming the content of their intra-firm R&D activities. As Malerba writes: “division of labour has taken place between new biotechnology firms (NBF) which lacked experience in clinical testing and established companies that (with time) adopted molecular biology. Networks of collaborative relations (facilitated by the science base and by the abstract and codified nature of knowledge generated by NBF) emerged in the sector”. (Malerba, 2005:70). As knowledge has become more tacit, vertical integration gained relevance. Mergers and acquisitions were quick forms to achieve that integration (Malerba and Orsenigo, 1993). However, as the small firms’ world continued to expand – relying on the very fast rate of scientific creation in the field – collaboration between large and small firms went on, including universities, other public and private research organisations, venture capital companies and individual (Pisano, 1990; Rothaermel, 2001).

A striking feature in what has been written is that in biotech small firms two different patterns have emerged: a more science-based pattern and a more application-oriented one. Malerba and Orsenigo (1993: 55) had already pointed out that “in the absence of products generating revenues, the NBF became essentially research companies and specialised suppliers of high technology intermediate products, performing contract research for and in collaboration with established companies”. The split between the two types of activities seems to have consolidated over the years, with some companies becoming research companies and the others becoming specialised application-oriented. The former had a strong focus on basic research and got funded by venture capital, at first, and later on obtained their revenues through research contracts on behalf of large established pharmaceutical companies or through patent licensing. It is what Coriat et al (2003) have labelled as the “science-based type ‘2’ model”.

As to the software sector, the characterisation of its dominant technological regime is less clear and consensual. Some authors have ascribed it to the specialised supplier category (de Jong and

Marsili, 2006) while others have labelled it simply as information-intensive (Tidd et al, 1997), what appears as a simplification. Since business models have here a strong interaction with innovation processes, it is likely to happen an inner differentiation regarding technological regimes, a dominant specialised supplier coexisting with a more complex knowledge based one, with similarities with the science-based regime. In fact, it is a much segmented industry, encompassing three main segments: operating systems, applications and middleware. A particular segment is embedded software, which permanently integrates a particular hardware unit. Its main customers include the telecommunications industry, the mobile phone industry, the automobile industry, consumer electronics producers, medical equipment producers and robotics makers (Lippoldt and Stryszowski, 2009).

Provisionally, we may define software as a technology-intensive sector relying on a complex and diversified knowledge base, but where tacitness appears as much more relevant than in most biotechnology activities. Furthermore, it does not rely upon scientific advances, to the same extent as it does in biotechnology, and even less upon scientific breakthroughs. In short, we are not dealing with a science-based sector as a whole. This does not mean that relations with universities are unimportant, but the form, content and purpose of those relations is different (Coriat et al, 2003): they tend to be informal and, although the access to academic knowledge is relevant, more relevant seems to be the access to talented highly skilled engineers in order to continually improve the skills base of the companies (Giarratana, 2004). 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, where customers are also drivers of technological innovation in the software industry. Likewise, the perceived clients needs, actual and anticipated, induce packaged software firms to innovate in problem-solving solutions. Furthermore, opportunities are reinforced by the enormous (almost universal) pervasiveness of software applications. The modularity of software programming makes it a process of high complexity and often characterized by technological cumulativeness. 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 large customers from different sectors (computer producers, telecommunications equipment producers and services providers, consumer electronics, finance, business services, distribution, defence and aeronautical industries, and public services of general interest). Cooperation among firms and networking is quite relevant here (Malerba and Orsenigo, 1993).

From what has been written, we may conclude that biotechnology and software sectors present sharp differences regarding their dominant technological regimes, although both belong to a broad category of technology- intensive sectors. However, it has become also clear that in both an inner differentiation exists, inviting us to conduct an analysis that goes beyond the sectoral boundaries. This is the “démarche” followed in studies that tried to identify technological regimes drawing directly on firms data (de Jong and Marsili, 2006; Leiponen and Drejer, 2007; Peneder, 2010).

3. CONCEPTUAL APPROACH TO USING TECHNOLOGICAL REGIMES AS AN EXPLANATORY DEVICE TO NETWORKING BEHAVIOUR

3.1 Exploring variety in technological regimes

The rationale behind the definition of a "technological regime" is that the nature of the knowledge underlying the technologies that firms develop/use, will, to an important extent, shape and constrain firms' innovative behaviour – i.e., their strategies, forms of organisation and type of relationships, namely those concerned with gaining access to and transmitting knowledge (Malerba and Orsenigo, 1997). Thus, it is expected that different technological regimes, which reflect the diverse nature of the knowledge being exploited, will contribute to explain differences in firms innovation networking behaviour, as expressed through the role, composition and structure of the knowledge relationships they establish.

In order to address this question, we will start by assuming that, while both biotechnology and software are knowledge intensive sectors, the nature of knowledge being developed and used by firms in both sectors is diverse and therefore firms are likely to operate under different technological regimes. This assumption is sustained by the literature reviewed on the previous section.

However, as was also pointed out above, the assumption of sectoral homogeneity of innovative behaviour has been questioned by some authors. The objections were raised at two main levels. Some authors criticised the "technological determinism" that underlies the close association between technological regimes and innovative behaviour, arguing that it ignores the potential for variety that derives from firms different strategic responses to substantially similar conditions (given bounded rationality of the agents). They argue that firms' innovative behaviour effectively results from the interplay between technological imperatives, that induce some regularities in the way firms organise their innovation activities, and the firm-specific decisions regarding the strategic conduction of these activities (resulting from local search), that are likely to generate diversity (Leiponen and Dredjer, 2007; Nesta and Dibiaggio, 2003).

Other authors questioned the close association between sectors and technologies. The relationship between technological regimes and sectoral patterns of behaviour is based on the assumption that sector-based firms are involved in the development / use of similar technologies and thus operate under a relatively homogeneous technological environment. However, this is not necessarily the case. On the one hand, industries or sectors are often defined according to the product they supply and not the technology they use (Peneder, 2010). On the other hand industries and sectors are often too broadly defined thus encompassing segments that are likely to use quite different technologies. Thus, even only taking into consideration the influence of the technological regime upon firms' behaviour (and thus disregarding the potential diversity of firms' responses to it), there is scope for within-industry variety. This variety may be masked by the practice of using aggregate data for measuring the properties of technological regime at industry level, which results on the identification of average behaviours (Peneder, 2010).

Recent research has been conducted with the purpose to address this question, relying on the technological regime framework and using datasets that span the whole range of manufacturing and service sectors covered by the Community Innovation Survey (Leiponen and Dredjer, 2007; Peneder, 2010). It has concluded that although regularities can be found in terms of innovative behaviour, these do not necessarily take place within industries. Rather, there is also within-industry variety and across industry regularities.

The notion of intra-regime variety has also been addressed by some authors. These authors have basically focused on industries characterised by fast technological change (usually biotechnology), addressing the particular case of a broadly defined “science-based regime”, which is particularly relevant for our discussion.

For instance, Nesta and Dibiaggio (2003) have looked in detail into the sources of firms technological differentiation within an industry characterised by a science-based technological regime. While accepting that firms differ at the level of organizational structures and competencies, they consider that differences in the knowledge base are also sources of heterogeneity. They argue that firms may differ at this level for two reasons: because they develop competencies in different technologies (heterogeneity will be based on asymmetries in knowledge endowments); or because of the ways they use technological knowledge that is generally available to the firms in the industry (heterogeneity is based on their specific exploitation of bodies of knowledge). Orsenigo et al (2001) discussion on biotechnology in pharmaceuticals provides some additional insights into this latter type of variety. It illustrates the fact that, even when exploiting a seemingly homogeneous technology, firms will adopt different strategies/positionings: exploring new trajectories for incumbents (as highly specialised suppliers) in cases of application specific (co-specialised) technologies; with more autonomous product or service based strategies in the case of generic (transversal) technologies.

Coriat et al (2003) also addressed this question arguing that there are two main sources of differentiation within science-based regimes. One is the nature of relations between academic research and industry, i.e. the level of contribution of scientific research and the type of channels firms use to source knowledge from academia (ranging from scientific links through publications and conferences, to contractual relations, to informal contacts and exchange of personnel). The other are the conditions of appropriability – i.e. the impact of patents on firm’s strategies and the differences in motives for patenting (patents as sources of revenues or for signalling competences vs. patents as basis for negotiation).

It is also interesting to take into account Malerba (2005) analysis of “pharmaceuticals and biotechnology” and “software” sectoral systems, conducted in the context of his examination of five broad sectors where technological change is rapid and innovation plays a major role. His discussion of the behaviour and dynamics of these broad sectors highlights the presence of particular behaviour in specific segments and the changes that are taking place in some of them, which may generate additional variety, not reflected in previous studies.

On the whole, these streams of research led us to question the assumption of perfect overlap between sector and regime in the cases of biotechnology and of software. This option required us to to attempt a different route, that is, to uncover the technological regimes under which operated the *actual firms* encompassed by these sectors, given the nature of the technologies they were exploiting. Following the reasoning underlying the research presented above, these would be more effective in describing the structural conditions faced by the firms and thus would have a better explanatory power regarding their innovative behaviour.

For this purpose it was useful to return to the early definition and discussion of technological regimes conducted by Malerba and Orsenigo (1993), where they examine the specific opportunities and problems derived from different combinations of these basic properties of technology, as well their outcome in terms of the “menus” of viable basic technology strategies and modes of organisation available to firms. Along these lines, our approach was to examine how the particular combination of the basic properties of the technologies these firms are exploiting impacted upon their innovative behaviour. Our objective was to understand whether we can identify regularities in the patterns of behaviour they generate and whether these regularities basically develop along the sectoral boundaries, or rather go across these boundaries.

As was the case with other researchers who investigated the presence of within-industry variety, we opted for conducting the analysis at the level of the individual firm, using micro-data (collected through interviews) to operationalise the properties of regimes. While this type of data is expected to enable a greater adherence to the conditions faced by firms, it also has the disadvantage of providing only indirect measures – that is, in practice it measures the (expected) effect of these properties of knowledge on the behaviour or firms[2].

3.2 Defining and operationalising the properties of technological regimes at firm level

The operationalisation of the properties of the technological regimes is not always straightforward (Castellaci, 2007; Leiponen and Dredjer, 2007) and researchers frequently rely on indicators that are only rough proxies for the complex conditions that are being investigated and their combined effects, which cannot always measured directly. These difficulties are magnified when attempting to achieve this operationalisation at firm level (as opposed to the aggregated level), since what can effectively be observed, in most cases, is the influence of these properties on firms’ innovative behaviour, as was already pointed out above. Having in mind this limitation, we still regard this approach as worth pursuing, since only firm level data will enable us to assess eventual regime regularities that go beyond the sectoral level of aggregation

For this purpose we will draw on contributions from research conducted at industry/sector level, which have attempted to measure some dimensions of technological regimes using firm level indicators: e.g. the Yale survey in the US (Levin et al, 1987; Klevorick et al, 1995; Cohen et al, 200o), the PACE survey in Europe (Breschi et al, 2000; Arundel et al, 1995) and more recently some attempts to measurement based on data from the Community Innovation Survey (CIS) (e.g. Frenz and Prevezer, 2010; Evangelista and Mastrostefano, 2006; Marsili and Verspagen, 2002; Peneder. 2010, Castellaci, 2007). A few authors have also conducted purposeful surveys targeting more specific populations (e.g. de Jong and Marsili, 2006; Palmberg, 2001).

When attempting to measure key features of the technological regimes underlying the innovative activities of the firms being studied we will focus on two key properties – technological opportunities and appropriability. The characteristics of the knowledge base – namely pervasiveness and tacitness - will also be taken into account, but will be addressed through the impact they have on the nature of opportunities and on the appropriability conditions.

3.2.1 Technological opportunity

[2] This is nevertheless the case with most indicators used to operationalise the properties of technological regimes.

Technological opportunity is defined as the ease of innovating for a given investment in search for new solutions (Malerba and Orsenigo, 1993). While this definition focuses essentially on the level of opportunity, Malerba and Orsenigo (1997) also stress two other dimensions that are relevant for characterising technological opportunity: its sources and its degree of pervasiveness[3].

The level of opportunity is the most commonly used dimension. Since the objective is to assess the ease of producing innovative output relatively to the amount of resources devoted to innovative activities, it is usually measured in terms of intensity of R&D efforts (e.g., R&D expenditure as a share of sales or R&D employment as share of total employment). It is also possible to differentiate between research in basic science and in applied science and assess the presence and relative importance of efforts devoted to each (Breschi et al, 2000).

The distinction between basic research (which tends to be associated with the production of more generic knowledge) and applied research, (associated with the production of more specific knowledge) (Breschi et al, 2000) is also pertinent when it comes to assess pervasiveness. Pervasiveness can be defined as the possibility of using the same core knowledge in a variety of applications (Malerba and Orsenigo, 1997). At firm level this can be equated to a greater of lesser ability for diversifying into a variety of markets, or for spawning a continuous stream of new product generations. The more generic is the knowledge the greater the scope for applications, as well as the higher the possibility of enabling a variety of new search trajectories (Saviotti, 1998). Therefore, knowledge that originates from scientific research, tendentially more generic, is more likely to be characterised by higher pervasiveness (Marsili, 2002).

Pervasiveness is not easy to operationalise, particularly at firm level, which have limited its use in empirical research. However, it is possible to gain some insights into its occurrence by combining information on the nature of the knowledge being exploited – i.e. whether the knowledge is generic, thus providing the *scope* for a broader range of applications – with evidence on the actual materialisation of these opportunities – i.e. the presence of technology or product/market diversification.

The sources of technological opportunity also vary depending on the nature of knowledge firms use for innovation. Following Klevorick et al (1995) it is possible to distinguish between advances in scientific understanding, on one hand and technological advances, originating either from outside the industry, or from R&D activities internal to the industry, on the other hand. The relative importance of these different sources to the pool of technological opportunities in which firms draw varies, and these differences will also be reflected upon the balance between internal and external sources of information and upon the type of organisations on which firms rely to access the latter. In particular, the relevance of academic science is used by these authors as a proxy to the importance of new scientific developments. Therefore, the extent to which firms rely on research organisations as sources of knowledge can be regarded as an expression of such importance and as an indicator of the presence of the related type of opportunity conditions[4]. In

[3] Pervasiveness (as an outcome of the level of generality of the knowledge) as opposed to specificity is equally discussed in the technological regimes literature as a property of the knowledge base. Our interpretation is that this particular property of the knowledge has implications for the opportunity conditions faced by the firms and therefore we include it in the definition of the technological opportunity dimension.

[4] According to Klevorick et al (1985), science can provide different types of contributions: it can add to the broad stock of knowledge on which firms indirectly draw, or can provide new scientific developments that directly open new technological opportunities. While most technology intensive firms draw on the former, only some will be able to identify new scientific developments that are relevant for their activities and potentially lead to more radical

the particular case of young technology intensive firms, it may also interesting to consider firms' origin – that is, whether they are academic spin-offs – since it is often regarded as an additional indicator nature of knowledge being used[5].

In summary, in the case of young technology intensive companies, an analysis of technological opportunity at firm level, will have to take into account the level and contents of R&D effort, the structure of knowledge sources on which firms draw and – if possible – at least an approximation to the nature of the technological output being produced. Following previous research, it is to be expected that an higher degree of technological opportunity is associated with higher intensity of R&D effort and stronger reliance on scientific research, as generator of more generic knowledge and thus offering a greater pervasiveness potential.

Biotechnology is generally characterised by a great proximity between science and its applications, which will, in principle, have implications for the technological opportunity conditions faced by the firms. It is to be expected that scientific knowledge plays a more important role as source of opportunity for innovation for a significant subset of biotechnology firms - although there may be differences among them regarding the relative importance of basic vs. applied science - and that, therefore, they will have more intense relationships with suppliers of this type of knowledge and will also be more likely to start-up as spin-offs from research organisations. However, this general appraisal does not mean that all biotechnology firms will follow this "science-based" model or, conversely, that we cannot find a subset of software companies that also fit into this model.

The differences between biotechnology and software firms may be less clear cut concerning the absolute level of R&D effort (even if the nature of that effort may vary) and the level of reliance on external sources of knowledge (even if the source organisations may vary). However, it can be expected that the nature of the knowledge introduces some differences on the type of exchange that takes place with external sources. For instance, while biotechnology firms rely on scientific knowledge that tends to be more frequently codified (Arora and Gambardella, 1994), software firms rely more strongly on tacit knowledge and thus the latter will be relatively more likely to establish informal relationships for knowledge exchange. Finally, while the potentially more generic nature of the biotechnology knowledge may create conditions for greater pervasiveness, the effective exploitation of the opportunities thus generated is a strategic option and the ability to pursue with it depends on a number of other factors (market and management related) factors[6].

3.2.2 Appropriability

innovations. In this context, a close link to academic research and the recognition of its importance for firms' activity can be an indicator of high opportunity conditions.

[5] The importance of knowledge originating from academic research - in particular knowledge originating from new scientific developments that can break with the knowledge base of firms in the industry - may be regarded as providing an indication of low relevance of previously accumulated knowledge (Winter, 1984) and therefore of low cumulativeness.

[6] Despite the potential range of opportunities, small firms may still chose to specialise, given resource or skills constraints. Technology entry barriers (Marsili, 2002) can also limit the choices open to new entrants, namely forcing them to specialise and/or enter in alliances with established firms, as is frequently the case in biotechnology (Orsenigo et al, 2001). On the other hand, since generic technologies are more distant from applications firms exploiting them may have greater difficulties and/or take longer searching for/selecting and developing specific applications (Costa et al, 2004).

Appropriability can be defined as the conditions concerning the protection of intellectual property assets against imitation, either through legal mechanisms (e.g., patents, copyright, formal non-disclosure agreements) or “natural” barriers to imitation, afforded by characteristics of the technology (tacitness, difficulty in reverse engineering) (Pisano and Teece, 2007). In general, higher appropriability conditions increase the likelihood that companies earn profits from their innovation. But, appropriability levels differ between sectors and the appropriability mechanisms that are available and effective also vary (Hurmelina-Laukkanen and Puumalainen, 2007). In the particular case of patents, the literature has shown that their incidence and effectiveness is confined to a few sectors, with alternative protection methods being extensively used in the majority of industries (Cohen et al, 2000; Arundel, 2001).

The different incidence of patents has been explained by Levin et al (1987) as related to the differences between technologies underlying these industries which influence patent effectiveness. They differentiate between “complex” technologies, in which new products result from a combination of many elements (that may be separately patentable) and “discrete” technologies, in which innovations result from relatively stand-alone, isolated discoveries. Biotechnology is based on discrete technologies, so patenting of one specific invention can effectively be used to stop competitors from using it and thus may be critical to enable firms to benefit from their innovation. On the contrary, computing is based on complex technologies, where a product may require the combination of different components that may be developed by different firms. Thus firms are less likely to have proprietary control over all the complementary components required to obtain a complete product, which leads to greater mutual dependence and to the development of extensive technology supply relationships. The latter may assume the form of cross-licensing when technologies are patented. But, in these contexts a loose appropriability regime can be a condition for innovation to occur, since it stimulates the development of new innovative combinations (Coriat et al, 2003). However, it has been has shown that the recent increase in the levels of patenting had particular incidence in “complex product industries” where patents were traditionally less used (Hall, 2005).

In biotechnology patents can also play other roles, besides being a protection mechanism. In fact they can be used by firms that have not yet developed a product to prove the presence of “knowledge assets”, thus being a basis for valuing the company, or a way to signal technological competence in the establishment of technological partnerships (Coriat et al, 2003; Rothaermel, 2002).

In some knowledge intensive fields (of which biotechnology is an example) new firms are often exploiting knowledge that was directly transferred from academic research. This type of knowledge has some specific characteristics in what concerns appropriability. First of all, there is a greater possibility that it is patented and that the patent was transferred or licensed to the firm. In fact, not only scientific knowledge is, in principle, more abstract and codified (Saviotti, 1998) making patenting easier, but research organisations are putting growing emphasis on the IP protection of technologies with commercialisation potential. On the other hand, knowledge associated with new scientific discoveries may have a high tacit component, which is derived from its very novelty and which endows it with “natural excludability” (Zucker et al, 1998). This can provide the firm with temporary protection against imitation, which is particularly important when formal mechanisms such as patenting are not viable or are less effective.

When protection through patents is not possible or has reduced effectiveness (namely given small firms' limited capacity to withstand patent litigation), technology intensive companies will need to resort to other means for appropriating their innovations (Teece, 1986). One particularly effective mechanism is "lead-time", that is the ability to be the first to enter a market and the capacity to stay ahead of competitors with a continuous stream of new technologies/products (Levin et al., 1987; Harabi, 1995; Cohen et al., 2002)

For instance in software the use of patent protection is not necessarily easy because of legal restrictions (Rao and Klein, 1994). While secrecy can have an important role, the high mobility of labour creates a constant risk (Atkins, 1998). Thus rapid development can be a better mode of protection (Hurmelinna-Laukkanen and Puumalainen, 2007). Indeed, "product proliferation" has been described as strategy often followed by software firms (Giarratana, 2002).

As was pointed out above, the capacity to generate new generations of technologies or products is often associated to the presence of more generic (general purpose) technologies, which can give rise to different applications, providing firms with a "platform" that supports a continuous stream of development and thus enables them to sustain competitiveness through time. Kim and Kogut (1996) describe the advantages of a technology platform as the development of technological skills that give the firm the ability to diversify into related subfields following the branching of the underlying technological trajectory and the identified market opportunities. Presence of such a technology platform (which may or may not be protected by patents) can act as a strategic appropriability mechanism, affording firms a lead time advantage upon competitors. Hicks and Hedge (2005) found that small patent-based based specialist suppliers that manage to survive and have long lasting success, develop technology that is more general purpose, has a broader range of applications (these technologies were also more basic and closer to science). While this type of advantage is more likely to prevail in biotechnology, it will also be possible in software (Kim and Kogut, 1996).

In summary, an analysis of appropriability conditions at firm level will have to take into account both the possibility and effectiveness of patenting, and the relative relevance of patenting and of other protection mechanisms. Considering that in technology intensive fields lead time can be a particularly effective strategy, the extent to which this mechanism is used should also be of interest. Therefore when addressing appropriability conditions we will consider both the presence of patents and the evidence of a lead-time strategy.

According to the literature reviewed above, appropriability through patents is more likely to be present in the biotechnology sector, although it may also be used by some software firms. On the other hand, appropriability through a lead time strategy is more likely to be the sole mechanism available to a substantial proportion of software firms, as well as by biotechnology firms that do not patent (because of the nature of their knowledge, or for strategic reasons). However, it should be noticed that a lead time strategy can equally be adopted by firms who benefit from "natural excludability" (given the temporary nature of this protection) and by firms that patent. In the latter case this strategy is more likely to be associated with the development of a platform technology that is patented and that serve as basis to a sequence of licensable technologies and/or its combination with the development of own products.

It is to be expected that reliance on appropriability through patents will be a differentiating feature of a more science-based type of regime, which may or may not be combined with appropriability through lead time (some firms in these conditions are still at a too early stage to be possible to uncover its future options). On the other hand, sole reliance on appropriability through lead time is more likely to be a differentiating feature of an alternative regime.

The potential advantages of the above approach to the identification of the technological regime under which firms actually operate and, therefore, its potentially greater explanatory power concerning the impact of the nature of knowledge on the firms networking behaviour, will be subsequently tested empirically in the case of biotechnology and software firms.

4. EMPIRICAL RESEARCH

4. 1 Empirical setting

The analysis was carried out using a sample of 46 Portuguese companies created between 1998 and 2008: 23 software companies and 23 biotechnology companies. Our samples were selected with a view to obtain industry segments that were relatively uniform, in order to reduce the scope for internal variety, as well as relatively comparable in terms of size and age of firms[7]. In the case of the *software*, we have focused on one particular application segment: software for telecommunications; in the case of *biotechnology* we selected a group of firms broadly based in the same technology: the molecular biology companies. In the case of biotechnology this can be regarded as the most science based group of firms, while in the case of software this is one of the areas where more advanced technologies are being developed and applied.

In the **software sector**, all firms produce applications for telecommunications, The sample is mostly composed of small to medium sized firms created between 1998 and 2003 (18 out of 23). A third of the total had a turnover (in 2007) between € 1 million and € 5 million. The 23 companies are located in metropolitan areas, mainly in the Greater Lisbon area (52%), but also in the Centro region (35%) – in mid sized cities such as Aveiro, Coimbra and Leiria – and finally in the North (13%).

As for the entrepreneurs, their average age is 37. Most of them (39%) hold both a degree in engineering and a MBA or a post-graduation in engineering, but only 1 entrepreneur holds a PhD. About 26% attended foreign universities and 65% worked or studied abroad over a significant period of time. Half of the entrepreneurs have conducted research activities at some point of their career (as part of project or research teams), but only 30% have published at least one scientific paper.

The technical staff of these companies is mainly composed of graduates: in about half of the firms they make up between 81% and 100% of the total technical staff. Only 5 companies employ doctorates and in all cases they represent less than 20% of the total employees. Almost all companies (91%) carry out R&D activities. However, the average investment on these activities is only 18% of the turnover and most companies (52%) have less than 20% of their employees working on R&D activities. Only 5 companies (22%) hold patents.

[7] For this reason, while in biotechnology we have included the universe of firms created up to 2008, in software we excluded a small group of relatively older firms (6 firms created before 1998)

In terms of sources of capital, the great majority of the software companies relies on equity financing, which in more than half of the cases account for 81% to 100% of total funding. Only 8 resorted to some kind of public incentive, but it represented always less than 20% of total funding. The majority (61%) of the firms exports, mainly for EU countries and Portuguese-speaking countries. Regarding the type of customers, 13 companies (57%) have domestic firms as main customers, while multinationals predominate for 8 companies (35%). Only 1 company indicated the government as its main client.

In the **biotechnology sector** the subset selected - the molecular biology companies - belongs to the younger generation of Portuguese biotechnology: 80% were created from 2003 onwards. Thus several of them are still in an embryonic stage of development and only a few have fully developed their technologies/products.

Not surprisingly, most of these biotechnology companies are very small. The average number of employees is 8 and the majority (57%) has 10 workers or less. About half of the companies had a turnover (in 2007) of € 100,000 or less and only 22% had a turnover of more than € 1 million. The firms are clustered around three metropolitan areas: the Greater Lisbon (57%), responsible for the highest R&D investment in the country; the town of Coimbra (26%), which has developed good competences in the health sector, around a major university hospital; and the country's second city, Porto (13%).

20 out of the 23 biotechnology companies are research spin-offs. They were created by entrepreneurs originating from research organizations, although some also brought-in individuals with managerial or industrial experience. The teams were mostly composed of by young researchers, some also involving one senior researcher who retained the university position. The majority of those entrepreneurs holds a PhD (65%) and has participated in research activities (78%) and studied or worked abroad over a significant period of time (83%).

The biotechnology companies exhibit a very high R&D intensity. The vast majority (78%) carry out R&D activities and, in about half of these, R&D expenditures account for 50% or more of total turnover (in two cases they even exceed the turnover). In terms of human resources, 65% of the firms have employees dedicated to R&D activities and in 35% these represent more than 50% of total employees. These companies also employ an unusually high number of doctorates: 65% have at least one and in 30% of the cases doctorates represent at least 50% of the total employees. About half of the firms (11) have patents.

This high technological intensity can be partly explained by the fact that many companies are still developing their technologies. In fact, 30% of the companies have not yet introduced any technology or product into the market. The incipient stage of development may account for the fact that about half of the companies (52%) do not export. But, for those who do, foreign business has substantial a weight: exports are, on average, 34% of the turnover and for 5 companies they account for more than 50% of the total turnover. European countries are the main export destinations (especially Spain), followed by the United States. The main costumers are hospitals, clinics and laboratories (26%) and other companies (26%), followed by end-users (17%) and universities and research centres (17%).

More than half of the companies (13) have external capital. With regard to sources of funding, the majority of companies relies both on equity (87%) and on funding from outside investors (venture capital, corporate investors and private investors or business angels) (82%), but only 5 have resorted to bank loans. Nearly half of the companies (48%) have received public incentives, which, on average accounted for 21% of the total funding.

4. 2 Data collection

Data about the firms (in both sectors) was purposefully collected. Data on networks was obtained using a novel combination of complementary methods, involving both documentary information and in-depth face-to-face interviews with the founders (Sousa et al, 2010). The former included: published data about formal collaborative projects and patents and information on firms' formation histories. The interviews, conducted in 2008, addressed both the entrepreneur and the firm. They were based on two semi-structured questionnaires. The first focused on the entrepreneurs' personal networks and their importance for the innovation process. The data thus obtained includes the origin of the relationships and the type, nature and relevance of their respective contributions. The second focused on firms activities, strategy and performance. The interview conducted on the basis of the second questionnaire permitted to obtain information of firms' networking strategies and practices. Additionally it also enabled us to collect data on firms knowledge production activities, organisation and business strategies, that supported the operationalisation of the properties of the technological regime at the micro-level.

5. INNOVATION NETWORKS: RECONSTRUCTION AND ANALYSIS

5.1 Network reconstruction and methodology of analysis

Using the data obtained through the questionnaires and the documentary information about the firms and their activities, we were able to (re)construct the individual firms' innovation networks. These networks encompass the relationships that were mobilised to access a set of resources identified as required for the innovation process: scientific knowledge, technological knowledge, highly skilled human resources, as well as complementary assets necessary to achieve the innovation. In these networks we have distinguished between formal and informal relations. The former include the participation of the firm in collaborative projects, technological partnerships and patents with other organisations. The latter include the ties with individuals to whom the entrepreneurs resort to obtain information about innovative opportunities and to access scientific and technological knowledge, which were assigned, for operational purposes, to the organization to which these individuals belong.

The level of intensity of ties has been depicted in the literature of inter-organizational networks 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 the intensity of the ties – i.e. whether the tie was strong or weak - was obtained using two methods: the frequency of contacts (in the case of the informal networks) and the number of connections that the firm mobilizes with the same organization. In the first case, we have considered that a contact that takes place at least once a month is a strong connection as is, in the second case, the existence of more than one tie with the same organization. In the presence of more than one connection (multiplex ties) between our companies and other organizations - whether these multiplex ties are a sum of informal and formal ties, or different types of formal or informal ties – we represent that tie as a strong tie.

After network reconstruction, a detailed analysis of the composition and structure of the networks was conducted, at firm level, using the methods of Social Network Analysis (Wasserman and Faust, 1994) and supported by the UCINET software.

Networks are composed of different types of actors, and relationships with them can have different origins. We identify the various actors present in the different networks - other firms from the same sector, firms from other sectors, universities and research centres, science & technology parks, financial institutions, and other institutions such as professional and trade associations – and assess their importance measured through the respective proportion in the total number of actors.

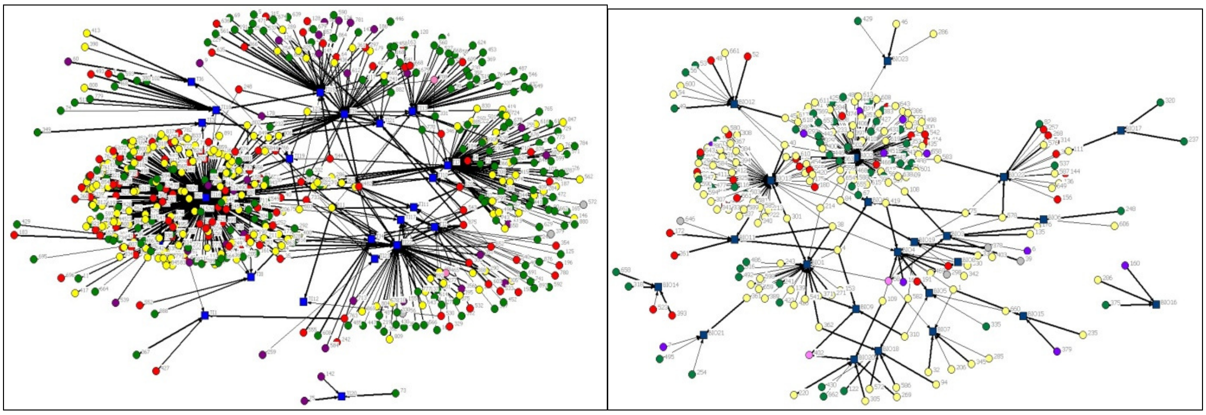
The network structure can be measured in terms of density. Networks with a bigger proportion of strong ties are denser. The traditional density measure – the ratio between the number of ties that are present in the network and the maximum possible ties (Wasserman & Faust, 1994) - is not particularly useful in this case, since the reconstructed network only encompass the firms' ego-networks (thus excluding indirect ties). Thus, to characterize network density we have used two measures i) the average strength of connection between actors (Burt, 2000), computed as the ratio between the sum of all ties considering the respective strength and the total number of ties; ii) the proportion of strong ties, computed as the ratio between the number of strong ties and the total number of ties.

Finally, the data collected through the questionnaire-based interviews also permitted to obtain information on the *importance attributed* by firms to both formal and informal. In fact, during the firm-level interview, the entrepreneurs were asked to rate, in a scale of 1 to 7, the importance attributed to formal relationships with other firms and with universities and other research organisations (denoted as "universities" from now on) to access a set of resources and competences. The ratings assigned to the same set of resources that were identified above as necessary for innovation (scientific knowledge, technological knowledge, highly skilled human resources, complementary assets), were aggregated and compose what could be described as the *perceived importance of formal networks to access knowledge relevant for innovation*. Similarly, during the personal interview, the entrepreneurs were asked to rate the importance attributed to informal/ personal relationships with the members of other organisations, to access the same resources. The ratings assigned to the same sub-set of resources were similarly aggregated and composed what could be described as the *perceived importance of informal networks to access knowledge relevant for innovation.*

5.2 The networks in software and biotechnology

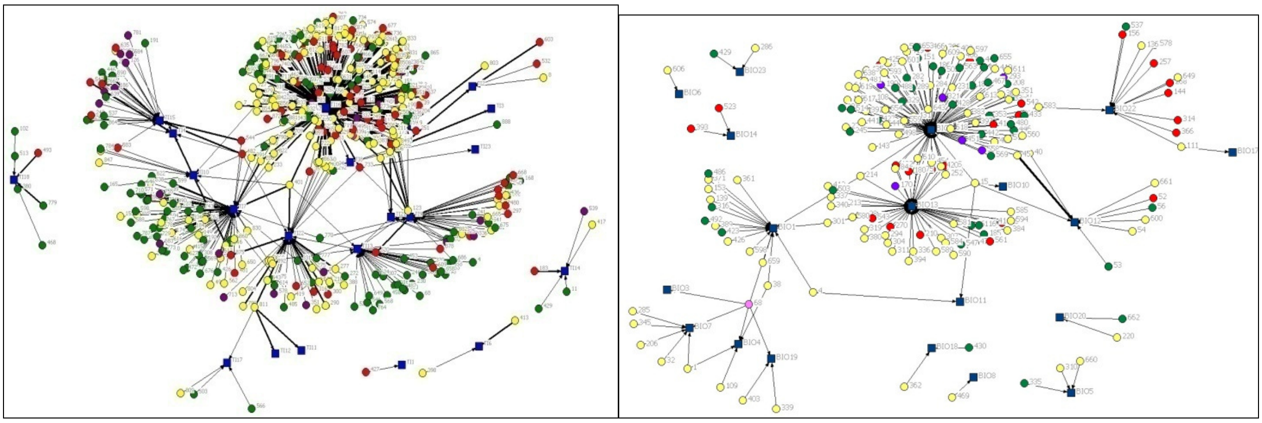
The reconstructed networks were graphically represented using Netdraw software. In figures 1 to 3, we present the innovation networks at sectoral level, showing separately the formal (figure 2) and the informal (figure 3) networks. These networks are the combination of the innovation networks of all firms in each of the sectors. The different types of actors are represented by different colours: firms from our sample (in blue); other firms from the same sector (red); firms from other sectors (green); universities and research centres (yellow); science & technology parks (pink); financial institutions (grey); other organisations (purple). The strength of the tie is represented by the thickness of the line. The description and comparative analysis of the two networks is conducted in greater detail elsewhere (Salavisa et al, 2010). Here we will simply provide a brief comparison of the main features of these aggregated networks, along a few relevant configuration dimensions.

Figure 1 - Innovation Networks (formal and informal)



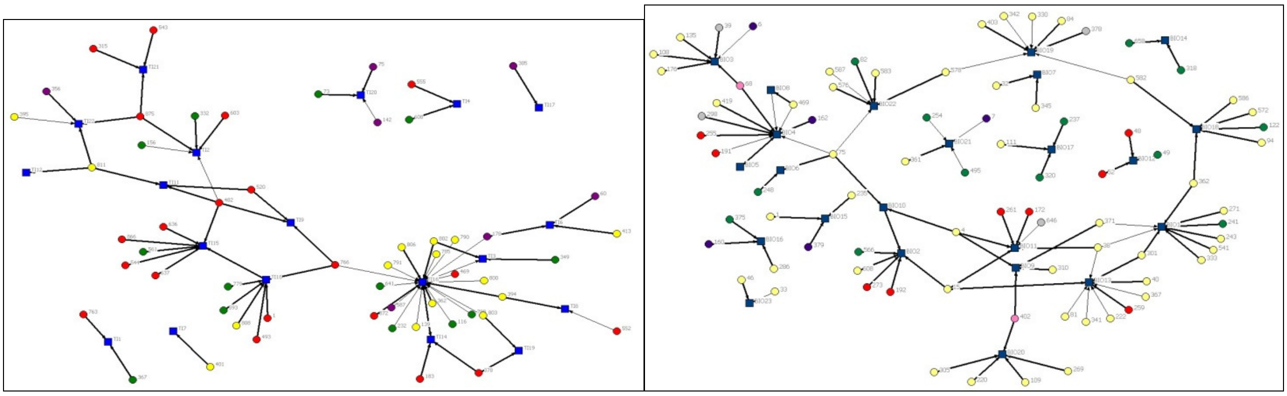
(a) Software (b) Biotech

Figure 2 – Formal Innovation Networks



(a) Software (b) Biotech

Figure 3 – Informal Innovation Networks



(a) Software (b) Biotech

Globally the innovation network in the software sector is considerably larger (almost twice as big) than in the biotechnology sector. However, even though both informal and formal networks are larger in the software sector, the main difference in network size lies in the formal network. The much larger size in the case of software can be partly explained by the fact that, globally, software firms are older than biotechnology firms, and so have already built a bigger set of relationships. However, this result may also be influenced by our methodological options. In fact we decided to include all mixed (techno-commercial partnerships) in the innovation network, assuming that, in this type of sectors, the technological component is determinant in the formation of such partnerships. Since software firms are usually in a more advanced stage of development, they are more likely to have a wider range of mixed partnerships than biotechnology ones[8]. If we do not take the size effect into consideration, global and formal networks seem very similar in both sectors. The same is not true, however, for informal networks: the informal network is more integrated in biotechnology, where various universities act as brokers, linking between the firms' ego-networks.

Regarding composition, the predominant actors in the biotechnology sector are clearly universities (in all networks), whilst in software universities are the most frequent actors only in the formal network. In both sectors, firms from the same sector emerge as important actors in the informal networks, being the predominant actor in the case of software. This fact denotes a strong informal bartering at the horizontal level. Rather, an examination of formal networks shows that software firms establish formal alliances are more frequently with firms from other sectors – suggesting a greater tendency to partner with suppliers or clients rather than with competitors - while in biotechnology horizontal and vertical alliances have a similar weight[9]. It is also interesting to notice that financial Institutions have some weight in the biotech informal network, whilst they are absent in the software sector. The interviews suggest that some venture capital companies have an advisor role concerning the directions of research to be pursued in the early years.

As for tie strength, results suggest that informal ties tend to be considerably stronger in both sectors and particularly in biotechnology. Conversely formal ties are generally weak, again particularly in biotechnology, where the formal innovation networks have almost no cases of strong ties. The higher strength of informal ties suggests that in both sectors there are some organisations that are important informal sources of knowledge and/or other resources needed for innovation, either through the presence of several personal ties and/or through frequent interaction[10]. The very small proportion of strong formal ties in the biotech innovation network, is consistent with the variety of technological alliances in this sector and their high turnover (Hagedoorn, 2002; v. Smith-Doerr and Powell, 2003).

This brief descriptive analysis suggests that there are indeed some differences between the networks of firms from the two sectors, both in terms of composition and in terms of structure.

[8] For the same reason it is also possible that some of these partnerships have a greater commercial component in software than in biotechnology, where the technological component may dominate.

[9] Notice that given the differences in market structure, firms in the same sector are more likely to be competitors in software that in biotech, since the former are more likely to target similar markets (telecommunications), while the latter may develop applications for different markets.

[10] The value obtained for the mean strength of ties confirms this, denoting high levels of trust in informal relations mobilised to access knowledge and other resources for innovation.

6. A MICRO-LEVEL APPROACH TO BUILDING TECHNOLOGICAL REGIMES

6.1. Identifying sector-independent regimes - cluster analysis methodology

In order to investigate whether the firms in our sample could be grouped according to the specific features of a technological regime that did not exactly correspond to the sector boundaries, we have conducted a cluster analysis. The objective was to investigate: whether it was possible to group firms in categories as homogeneous as possible according to the variables that were defined as measuring the properties of the technological regime at firm level; and whether or not these categories broadly corresponded (or not) to the definition of the sector. For this purpose we conducted the cluster analysis in two steps. First we conducted the cluster analysis only among firms of the same sector, to assess the presence of regime homogeneity within each sector. Second, we conducted cluster analysis including all firms irrespective of their sector, in order to assess whether we did find some regime-related regularities, independently of the sector where firms operated. In both analysis we have consider the same set of binary variables and used the hierarchical cluster procedure with furthest neighbour linkage cluster method and binary squared Euclidean distance measure. In order to measure the dimensions of the technological regime we used micro-data obtained through the questionnaire-based interviews on firms' activities.

6.2. Operationalisation of regime properties

The variables used in this analysis to try to capture some relevant dimensions of two the properties of the technological regime - technological opportunity and appropriability – that were described above as pertinent for this analysis, are as follows.

Technological opportunity: *R&D effort* is measured on the basis of the ratio of R&D employees on total employment. The choice of an indicator based on human resources devoted to R&D rather than on the ratio of R&D expenditures on sales can be explained by the nature of the firms in the sample: not only several firms preferred not to disclose their sales and/or an R&D expenditures, but several (biotechnology) firms still did not have sales or had an insignificant amount despite having a strong investment in R&D, thus making an indicator based on them meaningless. We have used a binary variable that assumes the value 1 when the firm has an R&D effort above 50% and the value 0 otherwise[11].

The *contents of R&D activities* are measured on the basis of firms' answer to a question on the type of R&D activities conducted: basic research, applied research and development. Since it was concluded that biotechnology and software firms attributed substantially different meanings to these concepts – and particularly to the concept of "basic research" as compared with "applied research" - in order to jointly analyse firms from both sectors it was decided to avoid the former and to build a new indicator that combines applied research and development. We considered a binary variable that assumes the value 1 if the firm perform both applied research and development and the value 0 otherwise.

When measuring the *sources of opportunity* we focused on the *relative importance of scientific advances*, which are operationalised as the importance of academic science and measured on the basis of the origin of the technology that led to the creation of the firm. This measure does not

[11] The choice of this cut-off point at 50% was based on a previous cluster exercise, performed with a continuous variable and the two step cluster procedure. In it we found this threshold level that clearly separated the groups of firms.

simply consider whether the firm was an academic spin-off (which was the case for most biotechnology firms), but rather, whether the knowledge or technology was at least partly developed in a research organisation[12]. So we have considered a binary variable that assumes the value 1 if the technology was transferred from a research organisation and the value 0 otherwise[13].

As pointed out above, the combination of relevance of scientific knowledge (as an indication of more generic knowledge) with evidence of extensive product (or technology) diversification can be regarded as a proxy to *pervasiveness*. Thus pervasiveness can be measured combining the indicators of importance of academic science (origin of the technology) and of lead time strategy (product diversification or presence of a technology platform) which is described below.

Appropriability: *Appropriability through patents* is measured by the presence of patents submitted (international or national). Patents submitted were preferred over patents granted given the relatively young age of several firms. For the same reason, we included both national patent applications and PCT applications: despite the limited scope of the former and the preliminary status of the latter they reflect a steady intention to patent, which is appropriate for our purposes. The operationalisation of *appropriability through lead time* was less straightforward and required the adoption of different approaches in the case of biotechnology and software firms, reflecting the different forms it adopted in the two sectors. In the case of software it generally assumed the form of extensive product diversification. Therefore, the firms were classified on the basis of their strategic orientation. In the case of biotechnology it could assume two forms: the case of firms that adopted a relatively similar approach to product diversification; the case of firms that had developed a platform technology, which was serving the basis for several generations of technology or product development. Firms in the latter case we equally classified as achieving appropriability through lead time.

6.3 Cluster results

The cluster dendrograms in Figures 4 to 6 illustrate the results of the hierarchical clustering procedure. As we move to the right of this graph, the degree of association between the firms is higher and they become part of the same cluster. Thus, firms that have less similarities, according to the variables considered, take longer to get into the same group.

[12] This means that we had a few firms that were not formally spin-offs but whose knowledge was effectively developed in a research organisation and conversely a few firms whose entrepreneurs came from research organisations but whose technologies had been mostly developed independently from the parent organisation

[13] The importance of external sources of knowledge was not included in this particular analysis since firms' behaviour in terms of external knowledge sourcing – namely the nature of actors, the structure of the external relationships, and their roles – is exactly the phenomenon that we are trying to explain in this research. Thus it would be redundant to consider the type of external sources of knowledge also at this level.

Figure 4 – Dendrogram for biotechnology firms hierarchical cluster analysis

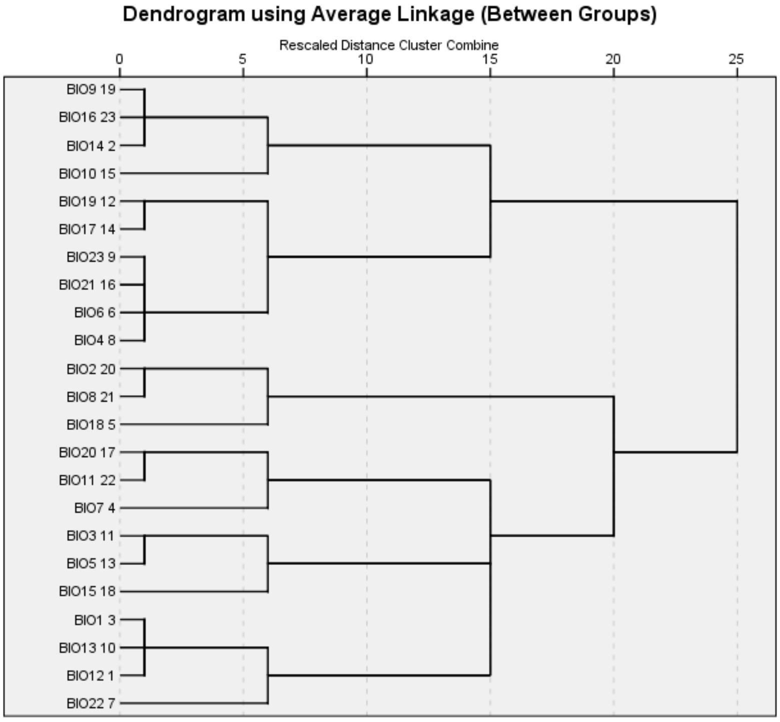
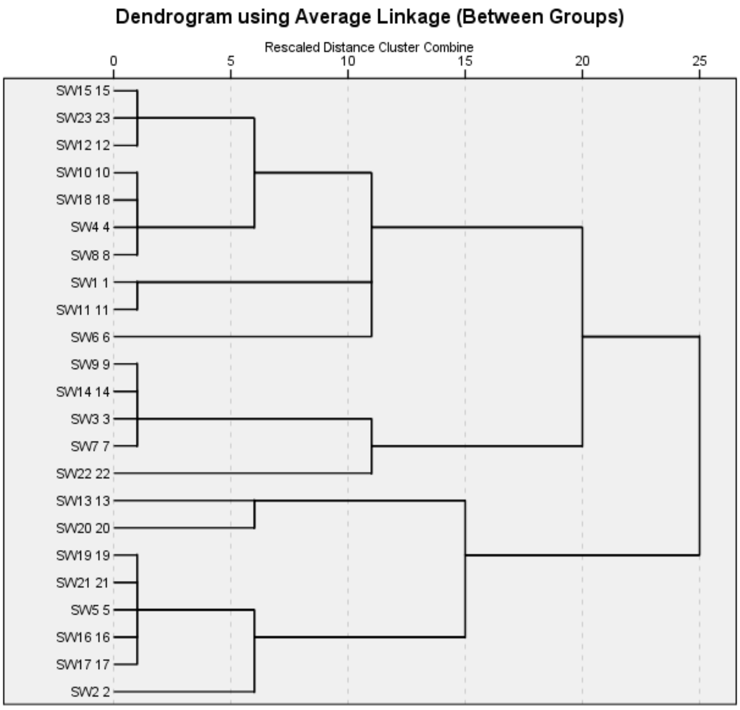


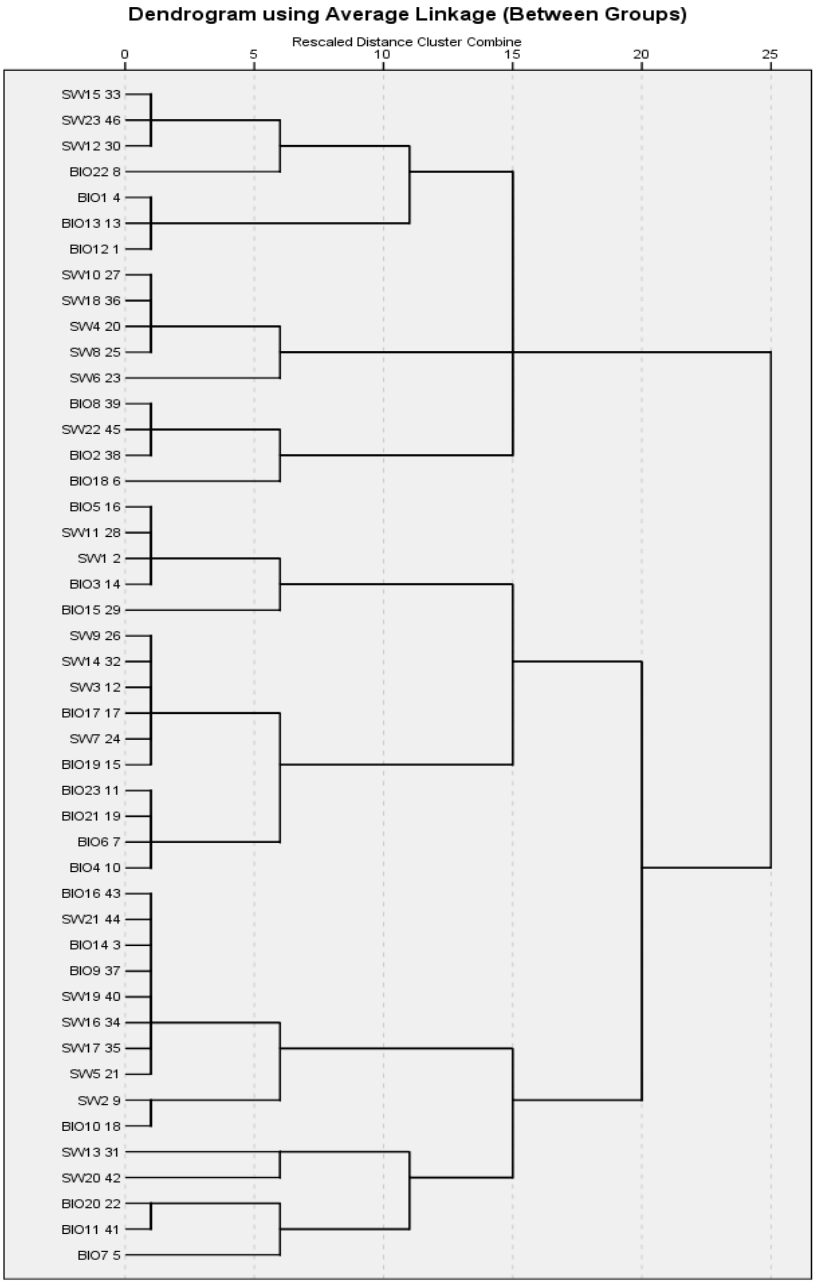
Figure 5 – Dendrogram for software firms hierarchical cluster analysis



In the first cluster analysis we have considered the firms from each sector separately. In the case of biotechnology we found two clear groups (Figure 4), which can be characterised as distributed along the application oriented vs. science-based lines of activity: production and sales of diagnostic tools and stem cells based services vs. more knowledge intensive firms engaged in the long term development of platform technologies with a view to license technologies or to develop more radical innovations. We have found more homogeneity in the case of software (Figure 5): a small group of more knowledge intensive companies vs. more clearly application-oriented companies.

In a second stage, we refrained from assuming sector specific regimes and have conducted a cluster analysis with all 46 companies. The objective was to investigate whether firms would effectively cluster around sectors, or whether we would rather identify regime-related regularities that went beyond sector boundaries. In this analysis (Figure 6) we have found two different clusters that do not correspond to sectoral distinctions.

Figure 6 – Dendrogram for all firms hierarchical cluster analysis



The first cluster (TR1) includes a relatively higher number of biotechnology firms, mostly belonging to the group already identified in the previous step as those engaged in the long term development of platform technologies with a view to license technologies or to develop more radical innovations. It also includes a relatively smaller group of software firms that stand up as more research oriented and engaged in the development of more advanced technologies. Globally, a qualitative evaluation of this group of firms, based on a wider variety of information on their behaviour, suggest that they correspond to more science-based pattern of behaviour.

The second cluster (TR2) includes a relatively higher number of software firms that exhibit a more typical behaviour for the sector, and a relatively smaller number of biotechnology firms, mostly corresponding to the group that is applying the technology to customer oriented applications, such as diagnostic tools or specialised services. In this case, a similar qualitative evaluation suggested that this group corresponds to a more application oriented (or specialised supplier) pattern of behaviour.

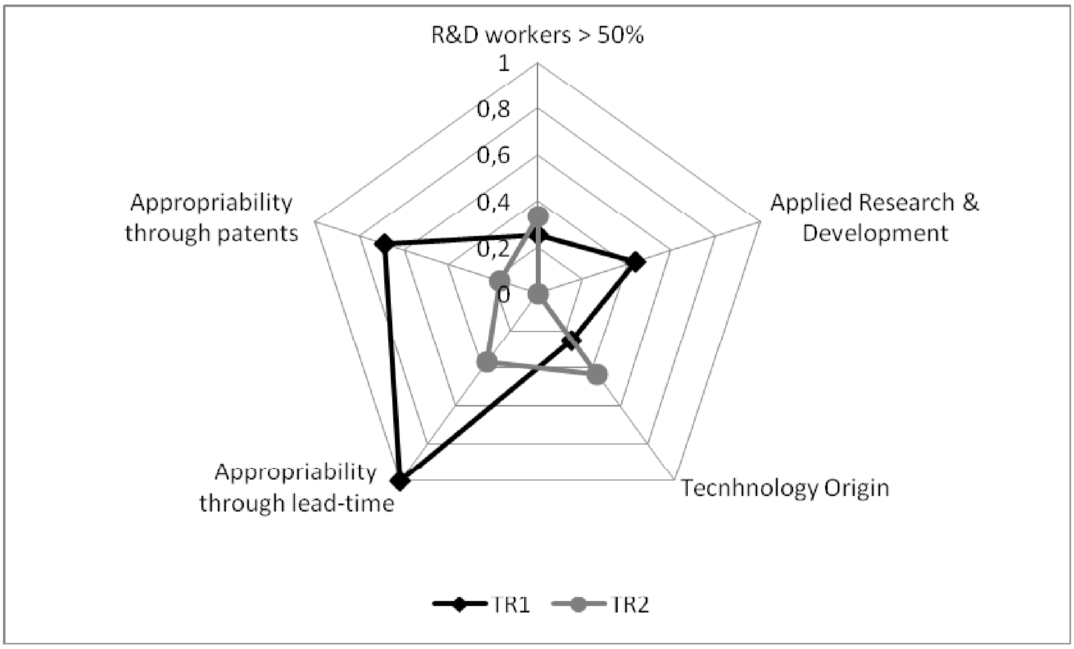
Interestingly, although we can find more biotechnology firms in the "science-based" group and more software firms in the "application-oriented" group, it is also a fact that there is a group of software firms and a group of biotechnology firms whose behaviour appears to be closer to firms in the other sector than to those in their own, at least in what concerns some of dimensions selected to characterise the technological regimes. This is an interesting finding that confirms the presence of intra-sector heterogeneity and of inter-sector regularities in terms of technological regimes.

Finally, Figure 7 summarises the characteristics of these two clusters along the selected technological regimes dimensions. Each line in the web represents a cluster. We can observe that TR1, as compared with TR2, has a higher proportion of firms with appropriation through patents and through lead-time[14] and combining applied research and development. However, it also has a much lower proportion of firms with more than 50% of their workforce engaged in R&D and also a lower proportion of firms using technology that had its origin in the university than TR2.

These latter results seem inconsistent and depart from our expectation regarding the configurations of regimes. They also are unexpected considering the *actual characteristics* of the firms included in each cluster. In fact, a closer observation of the data shows that firms in TR1 have more R&D employees in absolute terms (in average they have 9 employees in R&D vs. only 4 for TR2 firms) thus a higher absolute R&D effort, but because they are generally bigger in terms of number of employees, this fact is not captured when we consider proportions. Similarly, a closer analysis of the interviews suggests that the fact that the technology has not come from the university does not necessarily mean that firms are less science-based. In fact, some of them – particularly in biotechnology - are highly knowledge-intensive firms that are developing in-house science-based products/technologies, often in close cooperation with universities. In addition, some of them have indeed strong academic antecedents, but we have realised that often firms that already have a "history" tend to create some distance regarding the role of universities in their early stages, namely rejecting an academic origin for their technologies.

[14] Notice that the variable used to measure appropriability through lead time was also presented as part of a measure of pervasiveness (combined with relevance of scientific knowledge). Therefore this result, in the context of this group, also suggests greater pervasiveness of the technologies being exploited by this group of firms. With respect to its contribution to assess appropriability, it has been found that small firms may find it more difficult to defend their IPR in case of patent litigation and therefore they often use a combination of mechanisms (including strategic ones), which globally provide a more efficient protection (Hurmelina-Laukkanen and Puumalainen, 2007)

Figure 7 – Technological Regimes characteristics along selected dimensions



These results point to some limitations in the variables that were used to operationalise R&D intensity and relevance of scientific knowledge, suggesting the need for rethinking some of them, in order to achieve a greater adherence to the reality.

In any case, the results obtained suggest that the sector-independent regimes have some potential in terms of explaining variety in firms' networking behaviour and will therefore be used along the sector in the analysis of the impact of technological in that behaviour.

7. INFLUENCE OF TECHNOLOGICAL REGIMES ON INNOVATION NETWORKS

7.1 Definition of the models

In this section we investigate the influence of technological regimes on the configuration and perceived importance of the innovation networks built by biotechnology and software firms. For this purpose we compare the explanatory power of the two approaches to the notion of technological regime that were previously discussed: a) the regime associated to sector where firms operate; b) the regime defined independently of the sector.

We run three sets of regressions using the OLS procedure. Tables 1 to 3 provide the description of the variables used in those regressions.

We have used two different independent variables, which express the two different approaches to the technological regime: i) a dummy for the sector-based technological regime (biotechnology vs. software): ii) a dummy for the sector-independent technological regime, obtained through the cluster analysis (Table 1). These independent variables have been used, in an alternative way, in all regressions.

Table 1 – Independent variables description

Variable	Description	Type	Values
Sector	Firm sectoral affiliation	Dummy	0 if software; 1 if biotech
Technological Regime	Firm technological regime affiliation	Dummy	0 if TR2; 1 if TR1

The first group of regressions attempts to capture the effect of the technological regime (sector-based vs. sector-independent) on the *importance of networks* in the access to a set of resources needed for innovation. In these regressions, the dependent variable reflects the importance of innovation networks *as perceived by the entrepreneurs*. For this purpose we consider three different variables: i) the importance attributed by each firm to formal innovation networks; ii) the importance attributed by each firm to informal innovation networks; iii) the importance attributed by each firm to innovation networks taken globally (both formal and informal).

The second group of regressions estimates the effect of the technological regime (sector-based vs. sector-independent) on the *network composition*. For that purpose we have considered two different dependent variables: i) the share of universities on the total number of actors in the innovation network of each firm; ii) the share of firms on the total number of actors in the innovation network of each firm.

Finally, in the third set of regressions we investigate the influence of technological regime (sector-based vs. sector-independent) on *network structure* and estimate its effect on the strength of ties. For that purpose we have considered two different variables that measure network structure in terms of the strength of ties: i) the mean strength of ties; ii) the proportion of strong ties in each firm's innovation network.

Table 2 – Dependent variable description

Variable	Description	Mean *	SD	Min	Max
Univ	Proportion of universities in firm innovation network	0.47	0.37	0	1
Firm	Proportion of firms in firm innovation network	0.39	0.33	0	1
Perc Import	Perceived importance of firm innovation network	43		7	80
Perc Import Formal	Perceived importance of firm formal innovation network	26		4	52
Perc Import Informal	Perceived importance of firm informal innovation network	19		4	28
Mean Strength	Mean strength of ties in firm innovation network	1.85	0.68	1	3
Strong ties	Proportion of strong ties in firm innovation network	0.42	0.34	0	1

* Perceived importance variables are ordinal. For them we report median values.

We have considered the same set of control variables in all regressions (Table 3). The first control variable is the age of the firm (in years). We also control for firm size, measured by the turnover in 2007. Finally, we control for the "business model" – which is regarded as an important source of variation in firms behaviour (Chesbrough and Rosenbloom, 2002) - using a proxy related with the presence of venture capital. The rationale behind the choice of this proxy lies in the fact that, for several firms, the output variables available cannot yet provide a clear indication of the type of business model adopted by the firm, but the presence of venture capital can give some indications in that direction. This is because venture capital companies tends to invest in firms that are identified as having a high growth potential, even if that is only latent and associated with an qualitative appreciation of (and bet on) the potential of the "knowledge assets" under development, or the quality of the human resources exploiting them (Coriat et al, 2003). Therefore VC investment can be regarded as signalling high innovativeness and growth potential.

Table 3 – Control variables description

Variable	Description	Type	Values
Age	Firm age (years)	Continuous	Mean = 6 SD = 3 Min = 1 Max = 11
Size	Firm turnover in 2007 (Euros)	Ordinal	1 < 100 000; 2 [100 000-200 000[3 [200 000-500 000[4 [500 000-1 000 000] 5 [1 000 000-5 000 000] 6 [5 000 000-25 000 000] 7 [25 000 000-50 000 000] 8 ≥ 50 000 000
Business model	Proxy of the firm business model	Dummy	0 if no venture capital; 1 otherwise

7.2 Econometric results

In the first set of models (Table 4), we test the impact of the sector-based technological regimes and of the sector-independent technological regimes on the importance that entrepreneurs attribute to innovation networks. Results of the first two regressions show that sector-independent regimes have a significant impact on the perceived importance of total innovation networks, contrarily to sector-based ones. The positive sign of the coefficient means that firms in TR1 (more science based regime) attribute higher importance to networks, taken globally, to access resources needed for innovation, when compared to firms in TR2 (more application oriented regime). A similar conclusion can be drawn for the importance of formal innovation networks, but not for informal ones, where we find that none of the independent variables is statistically significant.

Results also indicate a positive and significant relation between age and perceived importance of innovation networks, which holds for all type of networks that we have considered. So, our data, suggest that older firms perceive innovation networks as more important than younger ones.

Table 4 – Estimation of the sector/technological regime effect on the perceived importance of innovation networks

	Total		Formal		Informal	
	(1)	(2)	(3)	(4)	(5)	(6)
Sector	7.276		7.715		-0.395	
	(1.187)		(1.518)		(-0.184)	
Technological Regime		15.285***		13.824***		1.548
		(2.666)		(2.919)		(0.726)
Age	3.470***	2.895***	2.043**	1.472**	1.432***	1.425***
	(3.556)	(3.294)	(2.524)	(2.027)	(4.200)	(4.357)
Business model	8.063	5.545	5.373	3.131	2.672	2.382
	(1.394)	(1.010)	(1.120)	(0.690)	(1.322)	(1.166)
Size	-0.371	-1.070	0.585	-0.151	-0.934**	-0.901**
	(-0.278)	(-0.944)	(0.527)	(-0.161)	(-1.998)	(-2.137)
C	17.176*	24.261***	4.439	12.075***	12.546***	12.041***
	(1.984)	(4.658)	(0.618)	(2.807)	(4.147)	(6.213)
No. observations	46	46	46	46	46	46
R^2	0.277	0.370	0.193	0.303	0.349	0.357
Adj R^2	0.198	0.320	0.106	0.228	0.278	0.288
F	3.538	5.436	2.211	4.025	4.949	5.138
Sig. F	0.015	0.002	0,087	0.008	0.003	0.002

*** Significant at the 1% level; ** Significant at the 5% level; * Significant at the 10% level

Results for the second set of regressions, that test the impact of technological regimes on network composition, are reported in Table 5. There we found evidence of influence of sector-based, but not of sector-independent regimes, on the proportion of universities and on the proportion of firms that are present in the innovation networks. Not surprisingly, results show that biotechnology firms´ innovation networks have a higher proportion of universities and a smaller proportion of firms, when compared to software firms.

Table 5 – Estimation of the sector/technological regime effect on the network composition

	Universities		Firms (all)	
	(1)	(2)	(3)	(4)
Sector	36.112***		-27.898**	
	(3.259)		(-2.474)	
Technological Regime		10.240		-8.413
		(0.820)		(-0.694)
Age	1.011	-0.772	0.887	2.273
	(0.573)	(0.689)	(0.494)	(1.223)
Business model	-14.321	-15.042	18.557*	19.204
	(-1.369)	(-1.257)	(1.743)	(1.653)
Size	-3.287	-6.609***	2.148	4.715**
	(-1.359)	(-2.677)	(0.873)	(1.967)
C	36.645**	75.164***	36.929**	7.198
	(2.341)	(6.625)	(2.318)	(0.653)
No observations	46	46	46	46
R^2	0.407	0.251	0.341	0.242
Adj R^2	0.343	0.170	0.270	0.160
F	6.351	3.092	4.796	2.959
Sig. F	0.001	0.027	0.003	0.032

*** Significant at the 1% level; ** Significant at the 5% level; * Significant at the 10% level

When we consider the technological regimes identified through the cluster analysis, instead of those based on a sectoral distinction, the global quality of adjustment diminishes and size emerges as the main variable explaining network composition. In this case, results show that the larger the firm, the smaller the proportion of universities and the higher the proportion of firms in its innovation network. This is likely to reflect the fact that larger firms are also those that are already in a more mature stage of development and therefore have already moved beyond an extensive reliance on university-based relationships, that are critical for the early development of their technologies and have established a more extensive range of relationships with other firms, that are relevant for more application-oriented development and/or (in the case of techno-commercial relationships) are related with their position as suppliers of intermediary technology inputs to other firms.

The business model was also found to have some influence upon network composition, the results suggesting that firms with higher growth prospects (as reflected on venture capital investment) have a greater proportion of other firms in their networks. This can be an indication of the impact of the signalling and/or brokering effect of venture capital on the establishment of relationships with technology partners (Stuart et al, 1999).

Table 6 reports the results for the third set of regressions that test the impact of technological regimes on network structure. We found no evidence of the relevance of sector-based or sector-independent technological regimes on the strength of ties. From the set of variables used, the only found to have some explaining power is firm age, particularly when we consider the proportion of strong ties in the firm's innovation network.

Table 6 – Estimation of the sector/technological regime effect on the strength of ties

	Mean Strength		**Proportion of strong ties**	
	(1)	(2)	(3)	(4)
Sector	0.270		0.113	
	(0.887)		(0.864)	
Technological Regime		-0.084		-0.059
		(-0.272)		(-0.449)
Age	-0.074	-0.085*	-0.042**	-0.046**
	(-1.525)	(-1.792)	(-2.034)	(-2.294)
Business model	-0.042	-0.019	-0.057	-0.043
	(-0.147)	(-0.064)	(-0.463)	(-0.34)
Size	0.034	0.010	0.014	0.004
	(0.512)	(0.157)	(0.493)	(0.148)
C	1.987***	2.283***	0.576***	0.701***
	(4.624)	(8.163)	(3.117)	(5.844)
No observations	46	46	46	46
R^2	0.128	0.111	0.183	0.171
Adj R^2	0.033	0.015	0.100	0.081
F	1.355	1.155	2.067	1.903
	0.268	0.346	0.105	0.13

*** Significant at the 1% level; ** Significant

These results suggest that older firms have more loose innovation networks, with a smaller proportion of strong ties and lower mean strength of ties. This result is consistent with the network literature that argue that as firms evolve the structure of their networks change. In early stages ties are manly informal and based on previous personal contacts and the network structure conducive to success is more cohesive. Later on, relations tend to be more formal and centred on firm's business activity, and structural holes become more critical for success (Hite and Hesterly, 2001).

8. DISCUSSION & CONCLUSIONS

The objective of this paper is to understand whether there is heterogeneity in the networks built by firms – from two potentially diverse knowledge-intensive sectors (biotechnology and software) - to access and exchange knowledge necessary for innovation; and whether such heterogeneity can be associated to differences in the technological regimes under which these firms are operating.

For this purpose we have reconstructed and analysed the innovation networks of two groups of comparable firms in molecular biotechnology and in software for telecommunications and have tested whether the technological regime – either defined in sectoral terms or defined independently of the sector – had some explanatory power in terms of the network composition and structure, as well as in terms of its perceived importance.

The results obtained are still preliminary, but already provide some interesting insights into the influence of the nature of knowledge being exploited on firms' innovation networking behaviour, in knowledge-intensive sectors.

First of all, it was found that the nature of knowledge, expressed through the technological regime under which firms operate, has some impact upon the importance attributed to networks for knowledge access and exchange, as well upon the actor composition of these networks, although it was not found to have influence on the structure of these networks (measured in terms of density).

Second, in consonance with recent research (Leiponen and Dredjer, 2007; Peneder, 2010), it was found that, while technological regimes have an important sector-specific element, they are not necessarily confined to sectoral boundaries. At least when we address this issue at the micro-level, sectors (even defined at a very disaggregated level) do not always seem to encompass only one technological regime and regimes can be transversal to different sectors. In fact, in the case of firms operating in specific segments of the biotechnology and software industries, it was found that if we depart from the assumption of regimes being closely associated with sectors and attempt to identify regularities and differences in terms of some properties that define the regime, independently of the sector, two regimes emerge that cut across the sectors and encompass firms from both. This suggests that despite the structural elements that globally shape the sector, there remains some scope for variety. The structural characteristics possibly account for the fact that, in each regime, there is a greater predominance of firms from one sector or the other. But there is always a group of firms whose behaviour is closer to that of some firms from the other sector than that of the bulk of firms of their own sector (software emerging as relatively more homogeneous than biotechnology).

Some authors have explained this heterogeneity with the potential for variety that derives from firms different strategic responses to substantially similar conditions (given bounded rationality of the agents). Other authors have attributed it to the fact that sectors are not necessarily defined according to technologies, but to products and therefore a sector may encompass different technologies. While we agree that both explanations are pertinent, we add that the specific configuration of the "regimes" we have found may be related with the turbulent nature of the knowledge intensive sectors being analysed. This induces processes of constant change, expressed through the emergence of new technologies, which may (or may not) generate substantially new problem solution trajectories, but which are likely to give rise to more "science-based" behaviour on the part of a more advanced group of firms, while the "core" focuses on the further development/exploitation or more stabilised technologies. To some extent, these behaviours mirror the two basic roles that Autio (2007) described as being played by technology intensive firms in a "technological articulation process", through which scientific knowledge is transformed in basic technologies and then basic technologies are transformed into application specific technologies. The potential for variability thus identified is consistent with Malerba (2005) description of the dynamics of transformation that takes place in sectoral systems characterised by fast technological change.

A constant surge of new technologies is more typical of biotechnology (Orsenigo et al, 2001), particularly the molecular biology field, thus making the "science based" behaviour more prevalent in the case of biotechnology firms. But it is nevertheless present in the case of some software segments (Malerba, 2005), of which software for telecommunications is a good example. In addition, the case of software can be regarded as an example of a sector where the changing dynamics taking place in some areas imply that a few firms depart substantially from the "normalised" behaviour of the sector.

The different make-ups (configurations) of a technological regime – either implicitly associated with sector and thus reflecting its structural elements, or more closely associated with some micro-level properties of knowledge – are likley to effectively correspond to different dimensions through which the nature of knowledge influences the behaviour of firms. Therefore, it was not unexpected that they would have different impacts upon one specific aspect of that behaviour: firms' innovation networks.

In fact, it was found that the sector-based regime had explanatory power in terms of the actor composition of these networks, while the sector-independent regime had explanatory power in terms of the importance attributed by firms to these networks in knowledge access for innovation. These results are interesting and to some extent confirm our previous arguments. The relevance attributed to the networks reflects the entrepreneurs' perceptions. These are more likely to be influenced by the context where the firms effectively operate and that are not necessarily sector determined. Conversely, the type actors to which firms can connect is more structural and thus more likely to be sector determined. These findings will need to be better specified, by conducting more disaggregated analyses (namely in terms of actor composition) in order to gain a better understanding of these processes.

The lack of explanatory power of the technological regime relatively to the network structure (at least when measured in terms of the relative importance of strong vs. weak ties) is worth considering. One possible explanation may be that the network structure may indeed be related with the nature of the knowledge, but in a broader way. That is, the network structure of knowledge-intensive and specialised firms in technologically advanced sectors may have similarities that are related with the process of development of this type of firms and the evolution of their relations with external sources. The fact that age emerges as the stronger determinant adds to this possibility. On the other hand, if the finer characteristics of the knowledge influence tie strength (as suggested by some literature), it is possible that the firms analysed have a similar mix of strong/weak ties for different reasons and involving a different mix of actors[15]. This calls for a more in-depth (qualitative) understanding of the actual nature and contents of the ties.

Two final remarks must be made. The first concerns the quality of the empirical data that is not homogeneous: the wealth of data obtained for the networks is not always matched by the data on business organisation and strategies, which sometimes is not completely satisfactory. This calls for future refinements at this level. One second remark is related with our results that are still preliminary. Ours finding must be validated after some data revision and improvement is completed. We expect that the more interesting insights will hold, and of which some inconsistencies will be clarified or solved.

[15] For instance biotechnology firms may have more strong ties at start-up with research organisation because entrepreneurs tend to have originated from them, while software firms may have strong ties with firms for the same reason; biotechnology may establish a range of weak ties (potentially more formal) with a variety of organisations for development purposes; software may establish a variety of weak ties (potentially more informal) with a variety of individuals from different organisations, for informal knowledge bartering purposes. Structures will be similar but the contents are different and these may be related with differences on the knowledge being exploited.

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Appendix

Nonparametric correlation matrix of the independent and control variables – Spearman's Rho

Variable	**1**	**2**	**3**	**4**	**5**
1. Sector	1.00	0.153	-0.512**	-0.585**	0.099
2. Technological Regime		1.00	0.087	0.041	0.131
3. Age			1.00	0.567**	-0.268
4. Size				1.00	-0.146
5. Business Model					1.00

** Correlation is significant at the 1% level (2-tailed); * Significant at the 5% level