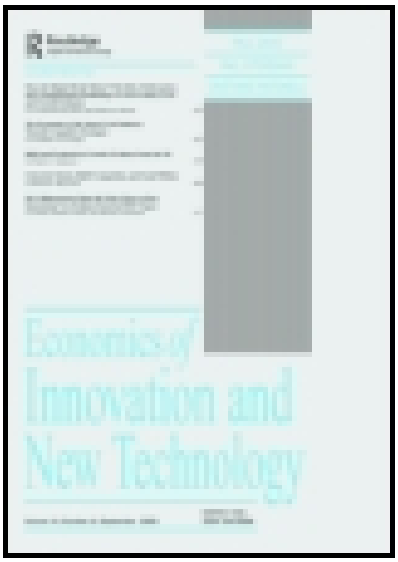

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Inter-firm networks and innovation: a survey of literature

M. Ozman [a]

[a] Bureau d'Economie Théorique and Appliquée (BETA) , Universite Louis Pasteur , Strasbourg, France

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Inter-firm networks and innovation: a survey of literature

M. Ozman*

Bureau d'Economie Théorique and Appliquée (BETA), Universite Louis Pasteur, Strasbourg, France

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This survey covers the recent literature on inter-firm networks as far as they have implications for innovation and technological change. The studies are classified according to the direction of causality in network studies. In the literature, some studies focus on the effect of networks, while others on the origins and formation of networks. These are represented as a circular flow diagram of network research. Circular diagram includes three themes of analysis as: (1) origins of networks, (2) firm performance, (3) network structure, and shows the relationship between these themes as observed in network research. The aim of this survey is to guide researchers working on inter-firm networks about the theoretical and empirical results obtained up to now in the field and to highlight those areas which need further work.

Keywords: innovation; networks; survey; inter-firm networks

1. Introduction

During the last two decades there has been a tremendous increase in theoretical and empirical research on networks in the economics and management literature. One of the fields in which network research has grown at an impressive rate is innovation and technological change, as it is now accepted that innovation is most effectively undertaken as a collective process in which networks play a central role.

The research on innovation networks is evolving with contributions from many disciplines, which use different approaches. Such an interdisciplinary focus has its advantages as well as disadvantages. For one thing, the cross fertilisation of ideas and knowledge from different disciplines increases the diversity and richness of the literature. On the other hand, it also makes it difficult to arrive at robust and general results. One can approach networks from a physicist's perspective, and analyse the structure of complex networks questioning whether they have some general structure that are observable in different domains. Or else, one can take networks from a strategic management perspective, and focus on the effect of inter-firm networks in different industries on firm innovativeness, profitability, or some other measure of performance. In another context, a sociologist would be interested in analysing the effect of social networks in the society and economy. Still another approach would be

*Email: ozman@cournot.u-strasbg.fr

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that of a geographer, who would study the spatial dimension of networks. The approach of economics of technological change is related more to the diffusion of knowledge and how networks shape technology adoption decisions.

What makes network research so rich in content is that, many network studies today involve one or more of these approaches. For example, it is possible to study inter-firm networks in geographical districts, looking at the social networks of firm managers, and questioning whether they exhibit certain complex network features. Moreover, taking into account the concept of networked organisation,[1] today networks are conceptualised as both a way of representation, and also a specific organisation type.

This survey includes studies which adopt any of the above approaches to address the dynamics and the effects of networks among *firms*. It is accepted today that innovation is a complex process which includes many actors and their interactions which take place on networks. Firms are the main actors in the process of innovation.[2] The studies covered in the survey take the nodes of the networks as firms, and the linkages as informal relations, mergers, acquisitions, R&D alliances, know-how trading, licensing, franchising, or other types of interaction in a local or a global context.[3,4] Two strands of research are excluded, which have direct and indirect relationship with innovation and knowledge diffusion in the economy. The first is the literature on network externalities where the networks are composed of artifacts, and secondly the literature on networks inside firms where the nodes can be departments, communities, or employees.[5]

Such a survey is important because after more than a decade of intensive research in the field it is useful to take a look at what the literature has taught, what are the main results, and what future areas exist that needs further work. The aim of this survey is to present an overview of research on firm networks, what they imply for innovation and technological change, and to guide researchers working in the field about the theoretical and empirical results obtained up to now in the field.

In essence network view is a process view (Imai 1989) because the state of the network in one period influences the state of the system in subsequent periods, as a result of a dynamic process of experience accumulation and learning. The structure of networks are thus in a state of continuous change, where the behaviour of firms shape networks, and networks in return shape the performance and state of firms. The classification of network studies in this survey is inspired from this process view of networks, which is presented in Figure 1 as the circular flow of network research.

Majority of the research on inter-firm networks fit into this circular flow. The main idea behind this classification is the direction of causality in network research, where studies fall into two categories; the effect of network which is represented by the left part of circular flow, and formation of networks which is given in the right part.

The sections of this survey correspond to the rectangular boxes in the circular flow (starting from Section 3), which denote themes of analysis.[6] In the literature, these themes are usually explained through various mechanisms which are shown in circular flow by incoming arrows to each box. These mechanisms form the subsections of the survey (see Appendix for a mapping of literature onto the circular flow). The content of studies covered under each theme is as follows:

1. Origins of networks: the studies covered in this part address the following questions. Why do firms collaborate? Which firms collaborate? With whom do they collaborate? What is the effect of external conditions and firm-specific attributes on collaboration decisions? What is the effect of network structure or firms' network position on partner selection?

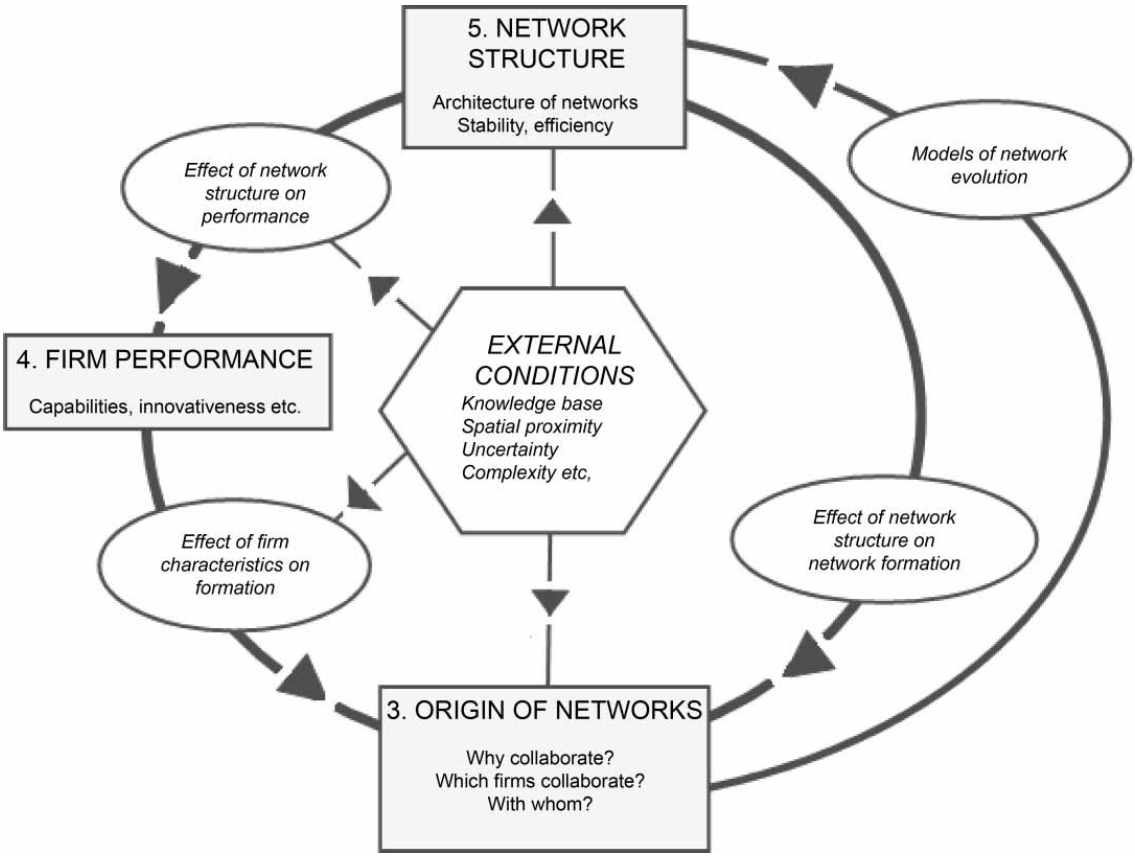

Figure 1. Circular flow diagram of network research.

2. Firm performance: possibly this is the area in which majority of network research is concentrated. How does the structure of networks influence firm performance? How do the environmental conditions influence performance through their effect on networks? (For example, uncertainty in the environment can affect how the network influences firm innovativeness). One broad category of studies included in this part is geographical districts. Here spatial proximity among firms is taken as an external condition, and studies which explore networks and innovation in industrial districts are covered.[7]
3. Network structure: by network structure is meant the physical architecture of the network. How is overall network structure shaped through the individual decisions of many firms? Which networks are stable and efficient? How do the external conditions affect network structure? Here those studies which analyse overall structure in different empirical contexts are also covered.

In the majority of the studies included, the external conditions play an important role, so it needs explanation. External conditions refer to those conditions which are not the direct result of networks, but they shape how networks form as well as their influence on innovativeness.[8]

The survey begins with a general introduction where networks are defined and how they are taken in the economic theory is explained briefly. Second section focuses on network formation, third section on firm performance, and the final part on network structure, followed by some concluding remarks.

2. Definition and place in economic theory

The domain of interactions among firms in the economy can take countless forms, ranging from legal ownership agreements to informal know-how trading. A major process that accompanies the inter-firm relations is the knowledge flow that takes place between the actors, which is an important engine for innovation. These knowledge spillovers can be also the result of informal communications among firms as in the form of collective invention (Allen 1983). As firms rely more on external collaboration, the boundaries of the firms get blurred, and the firm becomes a dense collection of communication links within a larger network through which there is continuous knowledge flow.

Adopting a network perspective enables constructing the mutual relation between the pattern of technological change and firm networks. The emergence of a certain network structure is usually a function of specific industry settings (Kogut 2000) and networks also influence the way technology evolves (Soh and Roberts 2003). In the literature, inter-firm networks have been called in many different ways, each focusing on particular aspects but sharing many commonalities in the core.

2.1. Terms used for networks

In the literature, networks of firms have been termed in various ways. Some examples are business groups (Granovetter 1998) which refer to the group of firms that are bound together in some formal or informal way, which is neither complete (like the case where firms consolidated into a legal single entity) nor weak (like in short-term strategic alliances); the keiretsu in Japan, chaebol in Korea are the most prominent examples. Powell, Koput, and Smith-Doerr (1996) use the term networks of learning, where their emphasis is on the way networks facilitate organisational learning and act as the locus of innovation. Ring and Van De Ven (1994) and Oliver (1990) use the term cooperative inter-organisational relationships. Many other terms have also been used, including networks of innovators (DeBresson and Amesse 1991), network organisation (Miles and Snow 1986), strategic network (Jarillo 1988) and inter-firm networks (Grandori and Soda 1995). Despite the many different terms used, most of these studies investigate what Jones, Hesterly, and Borgatti (1997) call to be network governance, and which is also the one adopted in this survey:

> a select, persistent and structured set of autonomous firms engaged in creating products or services based on implicit and open-ended contracts to adapt to environmental contingencies and to coordinate and safeguard exchanges (1997, p. 2).

If networks are taken as a new organisational form, why and how did this organisational form become an important one in many industries? One way to start studying networks is to investigate the changes that took place in industries which placed networks as a new mode of production besides firms and markets. In modern economic theory, transaction cost economics (TCE) is the dominant approach to analyse firms and markets. How are networks handled in a transaction cost theory framework, and what are the weaknesses of TCE in explaining networks?

2.2. TCE and networks

TCE consists of the analysis of two extreme governance modes as markets and firms. The more networks gained importance in literature, the greater was the need to understand their underlying mechanisms, which distinguishes them from markets on one hand and firms on the other. In other words, if markets are one type of economic exchange, and if firms are the other, then how can networks be explained was the main question asked. This question has occupied the agenda of many scholars in the beginning of network research two decades ago.

The coordination of economic exchange is based on two essential features of industrial systems: the boundary between markets and organisations; and the intra-firm organisation. Neoclassical economics largely ignores both of these features, and reduces the firm to a representative profit-maximising unit, where the boundaries of firms are explained via economies of scale and scope. TCE traditionally focuses on the trade-off between markets versus firms. According to TCE firms exist to minimise the costs associated with transactions (Coase 1937). Underlying TCE are two basic assumptions regarding the behaviour of economic agents. Firstly, agents are boundedly rational, and accordingly all complex contracts become unavoidably incomplete (Williamson 1998). Secondly, they are opportunistic. Indeed, firms are formed for 'attenuating the *ex post* hazards of 'opportunism by *ex ante* choice of governance' (Williamson 1998, 31).

From a TCE perspective, the network-based firm appears to be a hybrid type of organisation between markets and hierarchies (Thorelli 1986; Williamson 1991). However, there are some problems with this way of thinking. Some authors have emphasised that the network organisation has distinct characteristics regarding the feature of the items exchanged which can be knowledge, or the behavioural attributes of parties involved in transactions, which makes them theoretically infeasible to handle with the market *vs.* hierarchy approaches (Larson 1992; Powell 1990). In a world of rapid economic and technological change, TCE is a static cost trade-off analysis and cannot be used to explain the dynamic gains from networks, which are knowledge creation, diffusion and innovation (Langlois 1989; DeBresson and Amesse 1991; Nooteboom 1992; Powell, Koput, and Smith-Doerr 1996).

One may categorise the criticisms to TCE into three broad categories; the first one is concerned with opportunism, the second one with the need for a more dynamic approach to understand networks in environments of rapid change and the third one the lack of social processes in TCE. In this way, it was the basic assumptions of TCE that were being questioned, and this was why another framework needed to analyse network governance.

One of the central questions about the issue of opportunism is, whether the central behavioural assumption of opportunism in TCE can be reconciled with the development of mutual trust underlying long term relations in network organisations? According to Nooteboom, Berger, and Noorderhaven (1997), there is a polarisation in the literature, since some scholars tend to focus on opportunism whereas others on trust, with few exceptions taking both into account. However, for a coherent approach to the network based organisation, a reconciliation of the two poles is needed. This also relates to the lack of a dynamic perspective in transaction cost approaches, as well as to undermined social contexts in which most economic relations are embedded in (Jones, Hesterly, and Borgatti 1997). The need for a dynamic approach stems from the fact that, as the transaction relation proceeds there can be a change in the perceived risk of opportunism and *ex ante* expectation of opportunism may be replaced by mutual trust (or mistrust) as individuals accumulate experience in a social context (Nooteboom, Berger, and Noorderhaven 1997). The central role of opportunism in TCE shifts the attention away from the trust as a product of embeddedness of economic relations in social contexts (Johanson and Mattson 1987; Larson 1992; Noorderhaven 1996; Jones, Hesterly, and Borgatti 1997; Uzzi 1997). One of the driving forces in network forms being the mutual trust among parties, it is likely to reduce transaction costs (Jarillo 1988; Noorderhaven 1996; Uzzi 1997; Gulati, Nohria, and Zaheer 2000; Dyer and Chu 2003 for a direct empirical test among US, Japanese, and Korean firms), and improve performance (Carson et al. 2003).

Notwithstanding the need for a different approach than TCE, several researchers have carried out studies to incorporate social mechanisms within a TCE framework (Jones, Hesterly, and Borgatti 1997; Ybarra and Wiersema 1999). From a transaction cost

perspective, the selection of a partner is a trade-off between the costs of the risk involved in finding a reliable partner (so that the risk of opportunistic behaviour is reduced), versus the gains from access to new opportunities. But essentially, the idea of a network of firms reduces the costs of opportunistic behaviour. In the case of informal know-how trading systems, decisions to trade proprietary know-how are made by individual and knowledgeable engineers, no elaborate evaluation of relative rents or seeking of approvals from firm bureaucracies are involved thereby involving less transaction costs (Von Hippel 1989). In this way, network forms mitigate transaction costs, making opportunism more costly due to reputation effects in a tightly bounded social environment (Uzzi 1997; Walker, Kogut, and Shan 1997; Gulati, Nohria, and Zaheer 2000).

Finally, the exclusive focus of TCE on minimisation of costs disregards the strategy and organisational learning aspects of networking as well as social contexts (Eisenhardt and Schoonhoven 1996; Powell, Koput, and Smith-Doerr 1996). Kogut (1988) underlines the difference between a TCE approach and a strategy approach to joint ventures. In particular, strategy is related with the positioning of the firm vis-a-vis its rivals, whereas TCE focuses on the costs of transactions solely. Most of the time the motives underlying the formation of alliances are more complex than mere cost considerations and factors like transfer of know-how among parties, accessing other firms' capabilities, and/or improving the firms' own capabilities via organisational learning can be very important motives.

3. Network formation: which firms? Why? With whom?

There are many studies which explore the underlying motives for firms to collaborate with each other, and with whom they collaborate. In the circular flow of Figure 1, these studies are referred as studies on network formation (Box 3 in Fig. 1). In the literature, these questions are addressed by referring to various mechanisms. One can summarise these as the effect of firm-specific characteristics, the effect of external conditions, and the effect of the network of the firm.

3.1. Firm-specific motives and external effects

One of the leading papers explaining why organisations collaborate belongs to Oliver (1990). She mentions six motives: (1) necessity in the sense of meeting legal or regularity requirements, (2) asymmetry, referring to the potential of an organisation to exercise power or control over another organisation, (3) reciprocity, referring to the collaboration, cooperation rather than the exercise of power (horizontal linkages rather than vertical), (4) efficiency, referring to the effort of the organisation to increase its internal input–output ratio, (5) stability, as an adaptive response to environmental uncertainties, (6) legitimacy, to improve reputation, image, prestige. The importance of each of these varies according to the type of collaborative activity and relatedly the industry conditions. For example, in uncertain and competitive environments, reciprocity and stability are important whereas for the case of joint ventures in biotechnology there is for sure the effect of asymmetry, where larger firms exercise organisational control over smaller firms (Kogut 1988).

3.1.1. Resource interdependence

The earliest and the most widespread approach to explain why firms form collaborations is the resource-based approach. The resource-based view (Wernerfelt 1984) explains collaborations among firms with respect to the complementarities in firm resources. According to this view, the firm is a bundle of resources and the most common motive for collaborative

relations is the interdependence in resources. This means that firms form alliances with other firms because they are not self-sufficient, and they collaborate to reduce uncertainty as well as to access each others resources (Pfeffer and Salancik 1978) especially in technologically intensive industries (Hagedoorn 1993).

Hagedoorn (1993) explains why firms collaborate by referring to market and industry conditions. Specifically, in sectors where interrelatedness and complexity are high, technological complementarities is a significant motive. Other motivations include, access to markets, and reduction of the innovation period which is more valid for relatively mature industries.

In a leading paper Eisenhardt and Schoonhoven (1996) analyse the semiconductor industry and find that firms in vulnerable strategic positions (emergent or growing firms, or firms facing many competitors) tend to form more alliances as well as firms with a socially strong management team. In a more recent study, using community innovation survey for French firms, Miotti and Sachwald (2003) adopt a resource-based perspective to investigate the effect of complementarities in resources among collaborations formed by a wider range of actors, including academic institutions, firms, rival firms, clients, etc. They find that seeking technology is the main motive behind R&D alliances. A review of resource-based literature can be found in Das and Teng (2000).

In biotechnology the complexity and multidisciplinary character of the knowledge base are considered to be the main factors that draw firms into external collaboration (Hagedoorn 1993; Arora and Gambardella 1994). The knowledge base is widely dispersed and the collaborations are mostly characterised by the alliances among the large and established pharmaceutical firms, which offer market access opportunities, and small firms' scientific and technical contributions (Arora and Gambardella 1990; Shan, Walker, and Kogut 1994; Walker, Kogut, and Shan 1997). Arora and Gambardella (1994) find for the biotechnology that scientific capabilities reduce the number of collaborative agreements, while technological capabilities increase the number of them.

In another paper, Gulati and Singh (1998) examine how the choice of alliance type is influenced from coordination costs and appropriation concerns. They find that the more are the coordination costs related with interdependence, and when there is a technology component in an alliance in an industry with weak appropriability regime, the more likely to have structures with high hierarchical control. Ahuja (2000a) finds that link formation is influenced by the social, commercial and technological capital of the firm. Another study is by Mowery, Oxley, and Silverman (1998) who find support for the resource-based view by explaining alliance formation through similarities in technological capabilities of firms.

To summarise, the literature on resource-based view reveals that firms form alliances for various reasons, like having access to complementary knowledge and skills and to new markets. The knowledge base of the industry, uncertainty in the environment, similarity in knowledge bases, the stage of the firm in its life cycle are factors which effect the choice to enter into an alliance.

3.1.2. Organisational learning

There is a very rich literature which takes organisational learning to be an incentive to form alliances. As it is taken in these studies firms collaborate to learn.

The pioneering paper in this literature has been that of Powell, Koput, and Smith-Doerr (1996). They state that firms network with each other not only because they lack resources and need to access others, but because they seek to explore and exploit knowledge bases. In particular, their seminal work in biotechnology places the concept of organisational learning at the heart of the networks literature. Distinguishing between exploration

and exploitation in organisational learning, the former refers to experimentation with new alternatives, and the latter to the exercise of refinement and extension of existing competencies, technologies, and paradigms (March 1991, 85). Viewed in this way, organisational learning is both a function of access to new knowledge, and the capabilities for utilising and building on such knowledge (Powell, Koput, and Smith-Doerr 1996). Networking enable firms to effectively explore new knowledge. Still, external collaboration is complementary to internal capabilities in the sense that they facilitate exploiting and building upon existing knowledge (Mowery 1989). Collaboration between firms not only enhances learning about new developments, but also strengthens internal competencies and thus the locus of innovation is found in the networks of learning (Powell, Koput, and Smith-Doerr 1996).

Some recent studies examine in detail the motivations for exploration versus exploitation alliances, in the context of life cycle of the firm (Oliver 2001), industry life cycle (Rothaermel and Deeds 2004) effects of uncertainty and industry life cycle (Nesta and Mangematin 2002; Beckman, Haunschild, and Philips 2004). The general idea behind this strand of research is that, whether a firm collaborates for the purpose of exploring or exploiting depends on the external conditions, like the stage in the industry life cycle, or the growth phase of the firm. Lavie and Rosenkopf (2006) investigate how the firm balances exploration and exploitation alliances and they underline the role of organisational inertia and absorptive capacity.

Some others examine the effect of negative consequences of knowledge transfer on collaborations, mainly because of unintended leakages. For example, Oxley and Sampson (2004) underline that when firms are competitors, the unintentional leakage in valuable technologies can also be a barrier to an R&D alliance. In the case of electronic and communication equipment companies, they find that a response to this risk can be to limit the scope of the alliance and to regulate the knowledge flow. Mohr and Sengupta (2002) investigate this dual character of organisational learning, between benefits and unintended transfer of knowledge. Dutta and Weiss (1997) examine the relation between partnership type and innovativeness of the firm, and find that technologically innovative firms are usually involved in diverse range of partnership types so that transfer of tacit knowledge is restrained.

3.2. With whom do firms collaborate? Effect of networks on partner selection

This strand of research looks into partner selection decisions of firms, and the majority of studies explain partnership selection through the effect of network of the firm. For example, do central firms have different rules when selecting partners? Here, the main idea is that firms form alliances not only because they lack resources, organisational learning or because of strategic considerations, but also they are embedded in social networks which influence the way they select partners.

3.2.1. Embeddedness and social connections

The idea in this strand of research is that social networks of firms are decisive on their partner selection. In this sense interdependence in resources is a necessary but not sufficient condition for collaborative relations (Gulati 1998; Gulati and Gargiulo 1998). In other words, not all opportunities for collaboration result in success, and one should take into account the social networks of firms in investigating collaboration patterns. There is a growing body of research to verify this postulate. For example, Gulati (1995) studies the collaboration patterns of firms in various industries, and finds that the likelihood of collaboration between two firms increases as the commonly known third parties between two firms is more. In this

case, the network is a vehicle to carry information among the members about the reliability and capabilities of others (see also Shan, Walker, and Kogut 1994). In another paper Gulati (1999) develops the concept of a network resource of the firm (measured by the centrality of the firm in its network), and he investigates how this influences the collaboration patterns of the firm. He finds out that the firms which are more central in their social networks are more likely to enter into alliances. Huggins (2000) also finds that social relations are significant in the decisions of firms to enter networks. In a recent paper, Baum et al. (2005) find that Canadian investment banks prefer risky connections with partners previously unknown to them especially when their performance levels are different than the social and historical aspiration levels. Here social and historical aspiration levels refer to the performance feedback of the bank in comparison to other banks, or based on its own history.

Other studies include Stuart (1998) who uses patent data to place the newly established firms on the technology space (the more overlapping competencies firms have, the closer they are), and investigates how distance influences future alliances. According to his results prestige and closeness increases the possibility of future alliances. It is found in another study by Hagedoorn, Roijakkers, and van Kranenburg (2006) that firms who are strategically selective in partnerships are more likely to enter into future partnerships.

Another branch of research investigates how managers' behaviour is influenced by their social network in which they are embedded, and find that social networks of managers have an effect on partner selection. McDonald and Westhpal (2003) find evidence among the CEO of American companies that in response to a poor performance of the firm, managers tend to seek advice from executives of other firms who are their friends, or who are in similar positions as theirs. Findings by Rosenkopf, Metiu, and George (2001) also support this argument. More precisely, they emphasise the importance of communication among mid-level managers within technical committees in cellular service providers. They state that when firms have less prior alliance experience, interpersonal communications among technical committees forge knowledge flow to a large extent, especially in formation of future alliances and in partner selection. Gulati and Westphal (1999) investigate the effect of type of CEO board connections and find that links based on strategic decisions develop trust and thereby they promote future alliances.

3.2.2. Imitation and influence

Networks provide a feedback mechanism among the firms through time, which facilitates the spread of certain organisational forms. The concept of mimetic isomorphism was put forward by DiMaggio and Powell (1983), which might be an explanation in the case of alliances (Kogut 1988). This phenomenon has been studied systematically by various scholars in relation to network structure. For competitive advantage, firms imitate the behaviour of other firms, so that the emergence of certain organisational structures happens through a positive feedback mechanism conferred by networks (Garcia Pont and Nohria 2002). Kenis and Knoke (2002) apply the idea of the organisational field to network of firms, and analyse how various measures of network structure influence the patterns of tie formation among the members.

At the same time, firms' position within the network give an insight into the structural similarities among them. More specifically firms are more likely to be influenced by other firms having similar structural locations, as revealed by their position in the network; like membership to the same clique, or having similar centrality measures in the network. In their dynamic analysis of the automotive industry Garcia Pont and Nohria (2002) find support for the hypothesis of local mimetism as an important motive for alliance formation. As the

number of prior alliances increase, the competitive pressure on similar firms to do the same also increases and so is their likelihood to be involved in collaboration. Partitioning the firms in the network to strategic groups (as in Nohria and Garcia Pont 1991), they measure the effect of similarity by the local network density of strategic groups.

4. Firm performance: the effect of networks

The bulk of the research on interfirm networks tries to unravel the effect of networks on performance of firms. The origins of this rich literature date back to Granovetter, who was among the first to underline that economic exchanges are embedded in a social context. Today the embeddedness perspective tries to understand performance differences among firms in relation to the social networks in which they are embedded in. In this strand of research, social network analysis tools are increasingly being used to gain an insight into the network position of a firm. How this can take place is investigated in a unifying way by Gulati, Nohria, and Zaheer (2000) who postulate that differential profitability of firms may be explained by the structure of firms within the network.

4.1. Effect of embeddedness on performance of firm

The effect of embeddedness on performance has been widely explored in the empirical literature. Part of this literature is on industrial districts and is taken in a separate section below.

Most of the studies find a positive effect of embeddedness on various measures of performance (Anderson, Forsgren, and Holm 2002; Uzzi and Gillespie 2002; Echols and Tsai 2005). On the other hand, some studies cast doubt on the positive effect of embeddedness. For example, Uzzi (1997), in a study of the New York fashion industry highlights the paradox of embeddedness: the same processes by which embeddedness creates a requisite fit with the current environment can paradoxically reduce an organisation ability to adapt mainly by decreasing diversity, reduction of non-redundant ties and sometimes causing over-embeddedness. Over-embeddedness can also be caused by the inability of the firm to change its network portfolio, which is termed to be network inertia by Kim, Oh, and Swaminathan (2006).

As a result of the above views, Uzzi (1997, 1999) postulates that ties composed of a mix of arms length and embedded ties are more conducive to increased performance in the apparel industry (Uzzi 1997) and commercial banking industry (Uzzi 1999). However, Shipilov (2005) finds that the combination of embedded and arms length ties is not beneficial in the Canadian investment banks. This is mainly because of the nature of investment banking, where adopting a mixed relational strategy may increase the competitive pressure, and may provoke confusion about the network strategy of the bank.

4.2. Social capital, structural holes and performance of the firm

Recent years have witnessed an extensive amount of research effort devoted to the concepts of structural holes (Burt 1992) and social capital (Coleman 1988), how these are reflected in the networks surrounding the firm, and how they influence performance. Burt (1992) argues that the competitive advantage of firms rests on their ability to fill structural holes between dense groups of firms. Low structural holes, and therefore high level of redundancy in ties make information exchange inefficient and thus not beneficial for competitive advantage. Therefore in the structural holes perspective, the critical importance of filling structural holes to avoid redundancy in knowledge flow is underlined. Conversely, Coleman (1988) argues

that taking place in a dense network with cohesive ties confers competitive advantage to the firm, because coordination is improved through repeated exchange with stable partners which facilitate the transfer of tacit knowledge.

Walker, Kogut, and Shan (1997), in their seminal paper on biotechnology, translate the ideas of structural holes and social capital into network language, and express that it is the firm's position in the network which determines its access to social capital. They identify high levels of social capital with dense networks, and as for the structural holes they state that network positions with the highest income lie within dense regions of relationships (Walker, Kogut, and Shan 1997). In the case of biotechnology, they find that the social capital is a better predictor than structural holes in the pattern of relationships.

Social capital versus structural holes are analogous to the strong ties versus weak ties conceptualisation of Granovetter (1973), respectively. Strong ties are usually associated with thick information exchange, efficient and effective transfer of tacit knowledge, and connote trust among partners. In this sense, strong ties are better to exploit existing knowledge, and to deepen the knowledge of the firm in specific areas (Uzzi 1997; Rowley, Behrens, and Krackhardt 2000). On the other hand, weak ties are associated with exploration, which is access to new areas of knowledge (Granovetter 1973; Dyer and Nobeoka 2000; Rowley, Behrens, and Krackhardt 2000). These two opposing views on the structure of networks have provoked increased empirical attention in the last decade as it is reviewed below.[9]

One of the research in this field was carried out by Ahuja (2000b) where he examines how the network position of the firm influences its' innovative output with a longitudinal study in the international chemicals industry. There are two kinds of benefits that a firm acquires through networks. First of all firms access the resources (physical, skills, knowledge) of other firms, and second networks enhance firms access to outside developments, like a major technological innovation, or failures through knowledge spillovers. His findings suggest that structural holes have a negative impact on innovative output; indirect ties (enhancing knowledge spillovers, without costs of maintaining links) and direct ties (enhancing both access to resources and knowledge spillovers) have a positive effect on innovative output of the firm.

Hite and Hesterly (2001) analyse how the changing resource needs of start-ups matches with the cohesive ties or structural holes in various stages of evolution of the firm. In particular, they state that as the firm passes from the emergent to a growing stage, the network shifts in response to changing resource needs. In initial phases, the network structure conducive to success is more cohesive and as the firm grows filling structural holes becomes more critical for success. McEvily and Zaheer (1999) study metal working workshops and find evidence in favour of bridging ties for competitive advantage, which are non-redundant, infrequent, and geographically dispersed.

Other studies focus on different aspects of the debate. Among these, Gargiulo and Bennassi (2000) stress the trade-off between the safety conferred by cohesive ties and the flexibility conferred by filling structural holes. Inkpen and Tsang (2005) focus on different networks (cluster, intracooperation, and strategic alliances) and investigate how knowledge transfer can be facilitated in different types of networks with respect to different dimensions of social capital. In the case of global steel industry, Koka and Prescott (2002) outline different dimensions of social capital and demonstrate that each dimension has a different impact on firm performance (information dimensions, like volume, diversity, and richness).

The conflicting results of these studies which predict different structures for different industries reveal that the effect of strong ties and weak ties on firm performance depends largely on the conditions surrounding the firm (Burt 2000). One of the studies which confirm this finding has been that of Rowley, Behrens, and Krackhardt (2000) who investigate the conditions under which strong/weak ties and close/sparse networks are associated with

firm performance. Their findings for semiconductor and steel industries reveal that weak ties are beneficial for exploration especially in uncertain technological environments, and that strong ties are beneficial for exploitation, where uncertainty is low and competitive pressure is high. Dyer and Nobeoka's (2000) detailed study of the Toyota network also supports this argument.

4.3. Other studies on the effect of networks

In this subsection other studies which focus on effect of networks on performance are presented. There are a wide range of factors that are focused on, and various criteria are used to measure performance of firms. Examples are the effect of partner composition and type of alliance, the effect of diversity of partners, effects of the size of the firm and its social ties. In addition to empirical research, an overview of literature which uses simulation analysis is given.

A strand of literature examines the effect of partner portfolio and type of alliance on performance. Bae and Gargiulo (2004) analyse the effect of alliance network structure and partner substitutability on firm profitability in US telecommunications. When the focal firm has a large proportion of powerful partners, its control over resources can also be costly for the firm, which might outweigh the benefits of an alliance. When this is the case, a dense alliance network structure is better for firm profitability. Gulati and Higgins (2003) examine the young biotechnology firms and their Initial Public Offering (IPO) performance and find that the linkage benefits of venture capital and investment banks depend on the stage of market, while for strategic alliances there is no contingence. Park, Mezias, and Song (2004) find a positive effect of alliances on firm value in market type alliances compared to technology alliances.

One question that has been the subject of debate is whether diversity of partners is good or bad for performance? There seems to be a consensus in the literature that a diverse portfolio of partners is better. Beckman and Haunschild (2002) find that firm's acquisition performance increases when its network partners are diverse in their experiences. Similarly, Hoang and Rothaermel (2005) find that organisational learning through diverse range of partners results in higher performance then repeated alliance experience with a single partner in biotechnology, but the R&D performance exhibits diminishing returns. Baum, Calabrese, and Silverman (2000) analyse the performance of start-ups with respect to their alliance formation with others, having defined network efficiency by the diversity in the firms partners (universities, research institutes, rivals, etc.). Their results indicate that diversity in the partners competencies increases start-up performance in most aspects. Wuyts, Dutta, and Stremersch (2004) report a similar finding where technological diversity among partners and repeated partnering increase ability to generate radical innovations. In a similar context, the results of Phan and Peridis (2000) underline the importance of conflict between partners in the successful knowledge transfer in an alliance. However, the findings of Goerzen and Beamish (2005) contradict with these studies in the context of multinationals. According to them, multinational performance is lower when the alliance network is composed of diverse partners. Results of these studies show that whether diversity is good or bad for performance depends on the type of firm analysed.

About the effect of firm size, there are some studies which conclude that the effect of collaborations on firm performance depends on the size of the firm. Among these studies are, Singh and Mitchell (2005) who find out that both entry and post-entry collaboration contributes to superior performance, the extent of which is dependent upon who the collaborator is and upon the size of the firm in hospital software industry. Rogers (2004) for the

case of Australian firms find that effect of networks on innovation is significantly positive for small firms in manufacturing industry.

There are also some studies which focus on the effect of social ties in networks. For example, Bowles and Gintis (2004) look at the economic effects of ethnic and religious sharing of identity in business networks and find support for the idea that these networks can solve economic problems that are resistant to market or state based processes. Kale, Singh, and Perlmutter (2000) investigate how the development of mutual trust facilitates transfer of know-how and also forms a basis to overcome the effects opportunistic behaviour.

There is a strand of literature focusing on the effect of networks on learning. This literature is quite diverse, but a general consensus seems to be that networks have a positive effect on learning, depending on the type of networks. Hagedoorn and Duysters (2002) find that the effect of networks on learning depends on the type of network, where learning through exploratory networks is better for innovative performance than learning through exploitation networks. Anand and Khanna (2000) look at the effect of learning to manage alliances through experience for different types of alliances, and they find that the effect of learning on value creation depends on the type of alliance. Dyer and Nobeoka (2000) study how the structure of Toyota network enhances the organisational learning of its members.[10] Mowery, Oxley, and Silverman (1998) find that regardless of the initial motives underlying alliance (whether for market access or technological), the level of technological overlap increases after alliance formation. Larsson et al. (1998) analyse the effect of alliances on learning through learning strategies adopted by firms. Tsai (2001) finds that it is the interaction between absorptive capability of the firm and its' network position that has a significant effect on innovative performance. For the case of Italian manufacturing firms Medda, Piga, and Siegel (2006) find that collaboration with other firms in conducting R&D increases productivity.

Some other studies in this field are theoretical and simulation analysis of knowledge diffusion, which examine the relation between the structure of the network and the extent of knowledge diffusion in the industry (Cowan, Jonard, and Zimmermann 2002; Cowan and Jonard 2003; Cowan and Jonard 2004) as well as how value is distributed among the firms in a network (Kogut 2000). In a simulation study, Cowan and Jonard (2003) demonstrate that small worlds outperform regular and random structures in the extent of knowledge diffusion. In a different framework, one in which the collective invention phenomena is related to the network structure, Cowan and Jonard (2004) find that small world produces highest knowledge growth, yet the most uneven distribution of knowledge among the actors. Cowan, Jonard, and Ozman (2003) explore the effects of interaction in networks compared to no-networks (no structure in communications). Their simulation results indicate that regular structures generate higher knowledge growth in industries with tacit knowledge and high technological opportunities; whereas when knowledge is codified and technological opportunities are lower, communication without any structure performs better. Their model demonstrates that the type of network conducive to higher performance depends on the features of the industry. This result has been confirmed in another simulation model by Cowan and Jonard (2006) where they find that in the beginning of an industry life cycle where knowledge is relatively abundant, rather than local clustering, scarce networks are better for performance so that firms have access to distant firms. When knowledge is relatively scarce, like when a dominant design has emerged in the later stages of industry life cycle locally clustered networks are better for performance. These results are in accordance with the findings of Rowley, Behrens, and Krackhardt (2000) as explained above.

There is a field of research using patent data to test for knowledge flows. In a recent study, Gomes-Casseres, Hagedoorn, and Jaffe (2006) show that knowledge flows are influenced positively by technological, geographical and business similarity among firms, and that

knowledge flows between allied firms are greater than knowledge flows between non-allied firms. Some of the other examples on the use of patent data for knowledge flows include Mowery, Oxley, and Silverman (1998), Sorenson, Rivkin, and Fleming (2006), Balconi, Breschi, and Lissoni (2004), Singh (2005), and Fleming, King, and Juda (2006).

If network structure influences the performance of the firm, one thinks about whether firms might use their collaborations as a strategic move to achieve better network positions which was a question addressed by Baum, Shipilov, and Rowley (2003). In this paper, the authors study Canadian investment bank networks to highlight the extent to which the structure of the network is emergent, and to what extent it is shaped by strategic decisions of core and peripheral firms to improve their network positions.

4.4. Networks and firm performance in geographical districts

The literature on innovation in industrial districts has been growing impressively in the last two decades. This has partly been the result of a coinciding between two literatures; one is evolutionary and rejects a linear view of innovation (Nelson and Winter 1982), and the other is the literature on local and regional development economics. In this strand of research, learning has a localised nature (Malmberg 1997; Maskell and Malmberg 1999; Antonelli 2000); institutions have a central role in shaping regional innovation performance (Cooke and Morgan 1998; Amin 1999) and innovation is viewed as a dynamic collective learning process which essentially takes place within local milieux (Camagni 1991; Capello 1999; Keeble et al. 1999).[11]

When the theme of inquiry is geographical districts and innovation, networks can be taken as a central mechanism through which knowledge spillovers occur. This necessitates covering the whole literature on geographical districts and innovation. However, this literature is so rich that it requires a survey on its own. Taking into account this difficulty and limitations of space, instead of providing an exhaustive survey only the main themes of inquiry in this literature is summarised, which refer explicitly to the concept of a network in investigating innovative performance.

4.4.1. Trust and social networks in industrial districts

One of the most important mechanisms underlying the innovation process in regions is trust among parties. It can be defined as a cumulative product of repeated past interactions (Ring and Van de Ven 1994). According to a strand of research, because knowledge is tacit and only partly codifiable, face-to-face contacts is one of the most efficient ways to ensure its diffusion, which is accompanied by the development of trust among parties. These social networks have a positive effect on the extent of performance, and underlying them the most significant mechanism is trust (Jones, Hesterly, and Borgatti 1997). Indeed, many of the studies covered above incorporate trust as the main mechanism behind the dynamism of networks.

Lechner and Dowling (1999) stress that there is a distinction between an ‘industrial district’ and a ‘network’, where the former connotes mere geographical proximity and the latter is based on social ties among actors. For the success of an industrial district not only the existence of a regional infrastructure, pooled skill, common legal and financial services are adequate; important part of success stories arises from the existence of social networks among firms. The increased collaboration between firms in Silicon Valley and the sharing of a common culture and social context in the region enabled to better foresee market conditions, shaping the rate and direction of technological developments to a large extent. On the other hand, firms in Route 128 were mostly self-sufficient vertical hierarchies, largely

closed to external collaboration (Saxenian 1994). Indeed, it has been shown in other studies that informal contacts have important influence on knowledge diffusion in regional clusters. Dahl and Pederson (2004) confirm this for the case of regional cluster of wireless communication firms in Northern Denmark, Owen-Smith and Powell (2004) in their study of the Boston metropolitan area find support that informal transmission mechanisms strengthens the information channels among physically proximate firms, Cooke and Wills (1999), for the case of Denmark, Ireland and Wales finds that social capital has a positive effect on innovation in clusters.

4.4.2. Effect of proximity on innovation

Previous empirical research has confirmed that face-to-face contacts and geographical proximity are important factors facilitating the diffusion of innovations (Jaffe, Trajtenberg, and Henderson 1993), fostering some forms of knowledge exchange (Morgan 2004; Gomes-Casseres, Hagedoorn, and Jaffe 2006) and provide better access to information (Porter 1990). In a recent study, Bell (2005) finds for Canadian firms that locating in an industrial cluster and a central position of the manager network increases innovativeness. For biotechnology firms, Aharonson, Baum, and Feldman (2004) find that clustered firms are more innovative than geographically dispersed firms and clustering has a significant positive effect on innovation. Sonn and Storper (2003) also validate the positive effect of geographical proximity on innovation, looking at US patent citations. In another patent analysis, Almeida and Kogut (1999) find that regions are different from each other in terms of knowledge localisation, and mobility of patent holders is the main mechanism that localises knowledge in Silicon Valley. They also find that small firms explore new technology fields by taking place in local dense networks (Almeida and Kogut 1997). Audretcsh and Lehmann (2006) find for the case of German firms that locational spillovers and spillovers from universities are complementary for firm performance, and neither of them explains firm performance alone.

Despite the long established view that proximity increases innovativeness because of localised learning, a recent strand of literature cast doubt on this, questioning the postulate that mere geographical proximity is sufficient for learning and innovation. For example, Boschma (2005) stresses the importance of institutional and organisational proximity as well, in another study Boschma and Ter Wal (2007) show that it is not only local connections but also global connections that increases the innovative performance. The findings of Rallet and Torre (1999) also support this finding for the case of three French regions.

Some other studies reveal that social connectedness might be more important than the mere geographical proximity (Agrawal, Cockburn, and McHale 2006; Sorenson 2003; Balconi, Breschi, and Lissoni 2004). The increasing emphasis on social connectedness implies that it is the existence of networks and social relations, rather than mere geographical proximity that matters for innovation (Breschi and Lissoni 2003).

In some other studies, global connections are taken as complementary to local connections in firm performance. Bathelt, Malmberg, and Maskell (2004) question the mere sufficiency of localisation in transferring knowledge and emphasise the importance of both global and local interactions. Doloreux (2004) obtains a similar result for the case of Canadian firms where local Small and Medium Sized Enterprises (SMEs) rely also on their linkages with customers and suppliers outside the region. This result is also confirmed by Oerlemans et al. (2001) for the case of Netherlands, where external linkages had stronger effect on innovative performance in the face of complexity. Andersson and Karlsson (2004) underline the importance of accessibility rather than mere spatial proximity on innovation. Lissoni (2001) for the case of Brescia mechanical cluster finds that in a cluster, knowledge

can be highly codified, and even so it does not flow freely among all the firms in the cluster but rather within small communities. Love and Roper (2001) for the case of UK, German and Irish firms also find no significant effect of external links and innovative performance of firms in geographical districts.

To summarise the main results from the studies above, trust and social relations in industrial districts are important mechanisms which promote innovation. Moreover, the role of these mechanisms in fostering innovation is not confined solely to industrial districts. According to the recent literature on proximity, moving beyond the geographical definition of space in economics (Amin and Cohendet 2005) seems to be necessary as far as the effect of space on innovation is concerned.

5. Network structure

During the recent years, there is a growing attention in the literature to understand and explain the overall structure of networks. Theoretical work is developing only slowly, due to the difficulties inherent in studying networks. This is because most real world networks are characterised by some complications which Strogatz (2001) summarises as follows. For one thing, networks can be structurally complex. In most real world networks, there is high level of diversity in the type of ties in terms of their weight and content, and in the nodes themselves. In addition the state of the nodes and ties can change over time. Finally, various complications can influence each other (Strogatz 2001). Under these circumstances building theories to explain network structure is difficult since simplifications in their structure and focusing on relevant aspects (as determined by the context) of the network is inevitable, rather than covering all aspects within a unified framework. Despite all the difficulties, studying networks and how they evolve is valuable in many aspects, essentially because a dynamic network perspective enables to see how economic outcomes are influenced by relationships among actors (Kirman 1997)

5.1. Network structure: the role of external conditions

In this part, the papers covered focus on emergence of network structure as a function of external conditions, which refer to the knowledge base, technological conditions in the industry, as well as uncertainty and industry events.

Madhavan, Koka, and Prescott (1998) study how specific industry events shape the structure of the network in the steel industry. They measure structure by centrality and interblock relations, and focus on industry specific events like a major technological change, entry of a powerful competitor, a change in the regulatory infrastructure, and dramatic shifts in consumer preferences. In a similar context, Koka, Madhavan, and Prescott (2006) investigate how external effects and firm strategy shape the evolution of networks.

Orsenigo et al. (1998, 2001) construct a relation between the dynamics of the knowledge base in biotechnology and the evolution of the industry and detect a close relation between the two. More specifically, their findings point to the fact that the hierarchical structure of network of firms can be perceived as an adaptive response to the hierarchical structure of the knowledge base (with more generic theories on top of hierarchy, each leading to branches applicable to specific areas).

Other studies include Frenken (2000) uses Kauffman's NK model to model complementarities among technologies in the aircraft industry. Particularly in complex product systems, complementarities among the components render inter-organisational networking (or networking among the units within the firm) necessary for competitive advantage and timeliness. Ozman (2005) models the complexity of the knowledge base in two dimensions

as breadth and depth, and finds that the most dense networks among firms occur when the breadth and depth of the knowledge base is highest.

In a simulation model, Cowan, Jonard, and Zimmermann (2006) model an evolving network where knowledge carrying agents match with each other to combine their knowledge levels (and thus innovate). They investigate the resulting network structures as a function of type of innovation. They distinguish between two innovation regimes. In one of them diversity is important in innovation, in the other knowledge level is important. They show that different network structures emerge depending on innovation regime, and small world network is a possibility in a certain parameter space.

There are a few empirical studies that aim to detect the relation between uncertainty or stage in the industry life cycle and networks (Rosenkopf and Tushman 1998; Pyka 2000; Nesta and Mangematin 2002). Rosenkopf and Tushman (1998) examine the co-evolution of community networks and technology cycles in the flight simulation industry. They distinguish between eras of ferment, where technical uncertainty is high, and periods after which a dominant design emerges, which are the periods of incremental change. Their findings indicate that the intensity of the relations among actors increases during the former period, and they stress the mutual relation between technology and networks.

Empirical research in network evolution models is rather limited and one of the reasons is limited longitudinal data. Some of the research consists Powell, Koput, and Smith-Doerr (1996) and Walker, Kogut, and Shan (1997) who find evidence of a path-dependent learning process specific to biotechnology industry that shapes the network of relations among firms, Garcia Pont and Nohria (2002) adopt a dynamic perspective where networks form through mimetism in the automobile industry and Gulati (1999) studies partner selection in relation to social networks.

It is now accepted that interpersonal communication among scientists, engineers, or technologists play a vital role in the way knowledge diffuses. In this sense, individual inventors are the carriers of knowledge in their respective social networks. But detecting social networks on a large scale is not easy. One promising avenue in the detection of these networks is by using patent data, because it provides information on co-invention and citation patterns among patents (Balconi, Breschi, and Lissoni 2004).

5.2. Small world and scale-free networks

Watts and Strogatz (1998) have been the first to systematically explore in mathematical terms what was already known to many people: that the world is small. Since then, a vast amount of research has been conducted on the so-called small world networks. Small world networks are characterised by two parameters, clustering and path length. Watts and Strogatz (1998) demonstrate that the small world region lies somewhere in between a perfectly cliquish regular network with high clustering and high path lengths between nodes, and random networks with no clustering and short average path lengths. Small worlds, which lie in between these two extremes are characterised by high clustering (local connections, where nodes have ties with nearest nodes), but at the same time, via a few short cuts between distant agents, low average path lengths. As empirical work in many areas like the World Wide Web, scientific collaboration, movie actor networks reveal, most of the real world networks exhibit small world properties.[12] The application of small world phenomena in the economic sphere takes place along several dimensions. One of these is their relation with knowledge diffusion (Cowan, Jonard, and Zimmermann 2002; Cowan and Jonard 2003, 2004). Baum, Shipilov, and Rowley (2003) investigate the emergence of small world networks among Canadian investment banks, and Carayol and Roux (2005) examine the possibility of the emergence of stochastically stable small worlds in the face of

small perturbations in the rules of link formation. Bekkers, Duysters, and Verspagen (2002) find evidence of small world properties in technological alliances. A growing hypothesis in this line of research is that small world networks can increase innovative potential (see for example Baum, Shipilov, and Rowley 2003; Cowan and Jonard 2003; Verspagen and Duysters 2004; Schilling and Phelps 2005) while there are also studies which question this postulate (Fleming, King, and Juda 2006). In particular their study using patents reveals no significant relation between innovativeness and small world properties of the inventor network.

Barabasi and Albert (2000) provide a survey on complex networks, which incorporates the developments in the theoretical literature. The survey includes a detailed account of empirical work in topology of various real world networks, as well as recent theories on random networks, small worlds, percolation theory and scale free networks.[13]

According to Barabasi (2002), small world explanations have limitations in modelling real world networks in some important aspects. In these models the network size is held fixed, whereas in the real world networks grow, mostly following certain rules like preferential attachment. Basically preferential attachment means popular agents attract more agents. Indeed, they have shown in the case of the World Wide Web that, the degree distribution follows a power law, which means that there are a few nodes attracting majority of the nodes, and majority of the nodes have few connections. Underlying scale free networks are basically these two rules, preferential attachment and a growing network.

Following their paper, the network literature has been witnessing an increasing interest in scale free networks. Though yet limited in the area of economics, one of the studies was made by Riccaboni and Pammolli (2002), where they compare biotechnology and Information and Communication Technologies (ICT) industries. Their results reveal that in both ICT and life sciences the frequency distribution of firm links follow a power law, and thus they are characterised by a scale free structure.

5.3. Evolution of networks: game theoretical and evolutionary models

In this part of the survey, the studies on emergence and evolution of networks are covered. Most of these models explore the dynamics of networks, where self interested actors interact and result in the emergence of an overall network structure, under different mechanisms for interaction and different behavioural rules. These models conceptualise how the network forms and evolves, the feedback mechanism conferred by the network, and the relationship between stability and efficiency of the network. This literature has been developing rapidly in the last decade and a nice survey can be found in Jackson (2005) and Cowan (2005) on knowledge diffusion. In this literature, not all studies are related with inter-firm networks and innovation, but the literature offers theoretical guidelines about the modelling aspects of network evolution among firms. Therefore, a summary of the main themes is presented here rather than an exhaustive coverage of the literature.

The term network dynamics connotes the change of the network through time. As Doreian and Stokman (1997) point out, however, network dynamics and network evolution have different meanings. Network evolution refers to understanding the dynamics of the network via some understood process, so evolution of the network connotes understanding the rules governing the sequence of changes through time.

In network evolution models, the rules governing addition and deletion of ties for each node are imposed in the micro-level. These rules are usually based on the trade-off between the costs and benefits of forming a link. Therefore, the analysis is not being made from the planners' perspective, but from the perspective of individual incentives (Bala and Goyal

2000). Two approaches can be distinguished in this strand of literature; game theoretical models and evolutionary models.

Among the game theoretical approach, one of the earliest models is that by Jackson and Wolinsky (1996). They investigate the stability and efficiency of networks, when links are non-directed and there is a cost and benefit of forming links. They show that achieving stability and efficiency at the same time depends on the value allocation rules among network members, and need not always intersect. Other models of network evolution have investigated various issues, by defining efficiency in different ways (Jackson 2003), incorporating both direct and indirect links (Watts 2001), introducing small perturbations (Jackson and Watts 2001), introducing non-myopic agents (Watts 2002), learning (Bala and Goyal 2000; Goyal and Vega-Redondo 1999; Skyrms and Pemantle 2000; and for a nice survey, Goyal 2005), introducing different market contexts (Goyal and Moraga 2001; Kranton and Minehart 2001; Goyal and Joshi 2003; Zirulia 2004), stochastic stability (Carayol and Roux 2005), use of genetic algorithms (Carayol, Roux, and Yildizoglu 2005), and knowledge diffusion and network evolution (Cowan, Jonard, and Zimmermann 2006).

6. Concluding remarks

One of the results obtained from this survey is obvious to many scholars: networks have a very important role in innovation. However, more robust and refined results that are universally acceptable are yet difficult to achieve except in some areas. This is because most of empirical network studies are on different sectors, carried out under different conditions and they define networks in different ways. Such diversity makes it difficult to reach general conclusions supported by empirical evidence. The aim of this survey is to draw a general picture of where network research stands at the moment, what kinds of results in which areas have already been achieved with consensus, and also to highlight those areas that need further research in the future.

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Notes

1. Referring to a specific organisational form in which the boundaries of the firms are blurred and there is intensive networking among them.
2. For sure, actors of an innovation system are not confined to firms, but include customers, universities, institutions, government agencies, and others.
3. An exception where nodes are not firms is the case when patent analysis is made to construct firm networks (coinventor networks and citation patterns).
4. Also see Brass et al. (2004) for a survey of networks at the personal, departmental, and organisational levels.
5. For example, the literature on epistemic communities and their effect on innovation, or other studies which examine sources of innovation and knowledge diffusion inside the firm belong to this category.
6. The headings of boxes are the same as section headings of the survey.
7. The literature on emergence of industrial districts through agglomeration effects is not covered because it is related more with location decisions of firms rather than collaboration decisions.
8. At the same time networks can augment, or change external conditions. For example, perceived uncertainty can reduce with more dense networks.
9. See Borgatti, Jones, and Everett (1998) for various ways in which structural holes and social capital can be measured in networks.

10. They underline three knowledge sharing dilemmas (resistance to share proprietary knowledge, free rider problem, and maintaining efficiency at knowledge sharing provided in the network) and explore the specific processes set by the Toyota network to overcome these.
11. See also Sternberg (2000) and the special issue of European Planning Studies (2000) on empirical evidence concerning the network-oriented regional growth, based on European Regional Innovation Survey.
12. For other areas, including physics, see Watts and Strogatz 1998; Frommer and Pundoor (2003) for a review of three recent books on networks; Barabasi and Albert 2000; Newman 2000 for a review covering research on small worlds.
13. See Solla de Price (1965) for the initial foundations of scale-free networks.

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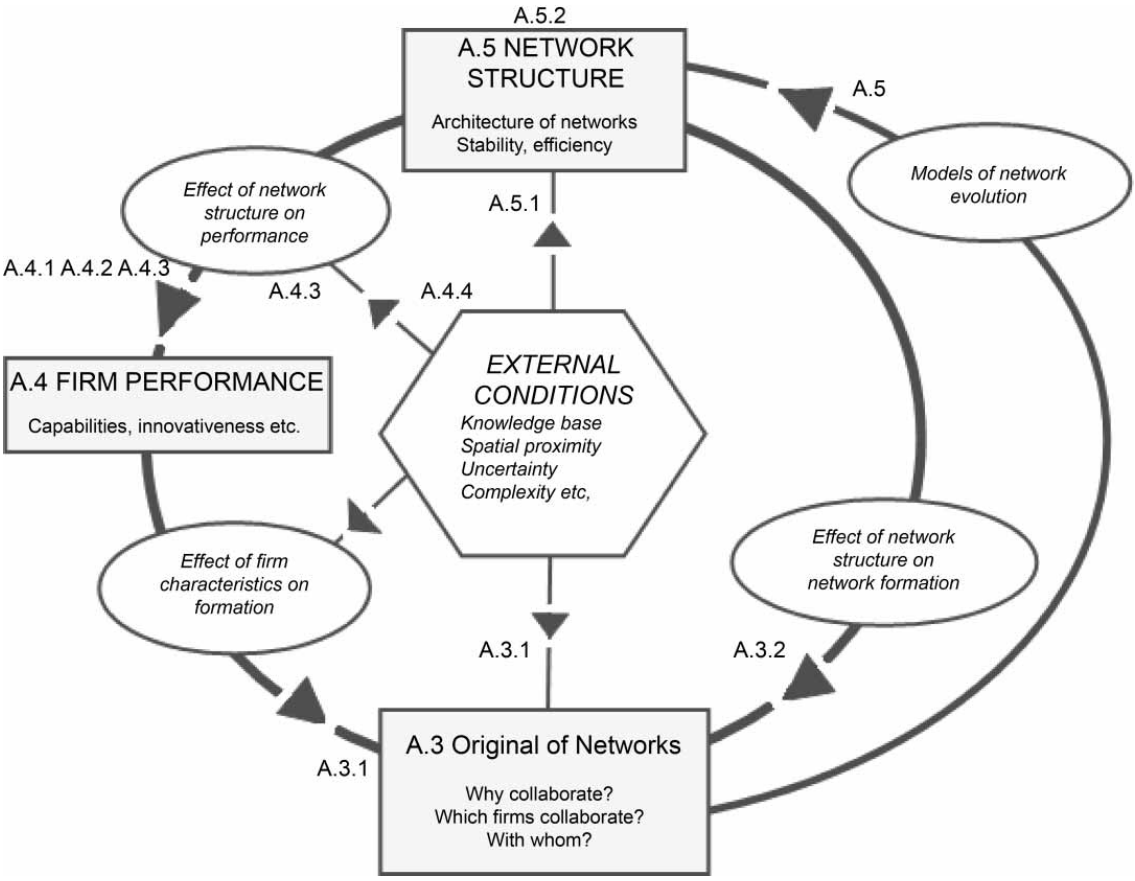
Appendix A

A.1. A mapping of network literature onto the circular flow (the numbers correspond to the sections of this survey)



A.3. Network formation: Which firms? Why? With whom?

A.3.1. Firm-specific motives and external effects

Oliver (1990), Kogut, (1988), Hagedoorn (1993), Beckman, Haunschild, and Philips (2004), Pfeffer and Salancik (1978), Hagedoorn, (1993), Arora and Gambardella, (1994), Hagedoorn 1993, Arora and Gambardella (1990), Walker, Kogut, and Shan (1997), Shan, Walker, and Kogut (1994), Eisenhardt and Schoonhoven (1996), Miotti and Sachwald (2003), Das and Teng (2000), Powell, Hesterly, and Borgatti (1996), Mowery, Oxley, and Silverman, Oxley, and Silverman (1998), Gulati and Singh (1998), Ahuja (2000b), Oliver (2001), Rothaermel and Deeds (2004), Nesta and Mangematin (2002), Lavie and Rosenkopf (2006), Mohr and Sengupta (2002), Dutta and Weiss (1997), Oxley and Sampson (2004).

A.3.2. With whom do firms collaborate?

Stuart (1998), Gulati (1999), Gulati and Gargiulo, (1998), Gulati (1995), Shan, Walker, and Kogut (1994), McDonald and Westhpal (2003), Rosenkopf, Metiu, and George (2001), Kogut (1988), Kenis and Knoke (2002), Garcia Pont and Nohria, (2002) , Huggins (2000), Baum, Calabrese, and Silvevman (2005), Hagedoorn, Roijakkers, and ńan Kranenburg (2006).

A.4. Firm performance: the effect of networks

A.4.1. Effect of embeddedness on performance of firm

Echols and Tsai (2005), Anderson, Forsgren, and Holm (2002), Uzzi and Gillespie (2002), Uzzi (1997), Uzzi (1999), Shipilov (2005), Kim, Oh, and Swaminathan (2006).

A.4.2. Social capital and structural holes

Burt (1992), Coleman (1988), Walker, Kogut, and Shan (1997), Granovetter (1973), Rowley, Behrens, and Krackhardt (2000), Uzzi (1997), Dyer and Nobeoka (2000), Ahuja (2000a), Hite and Hesterly (2001), McEvily and Zaheer (1999), Gargiulo and Benwassi (2000), Inkpen and Tsang (2005), Koka and Prescott (2002).

A.4.3. Other studies on effect of networks

Mowery, Oxley, and Silverman, Oxley, and Silverman (1998), Bae and Gargiulo (2004), Gulati and Higgins (2003), Beckman and Haunschild (2002), Hoang and Rothaermel (2005), Baum, Calabrese, and Silvevman (2000), Wuyts, Dutta, and Stremersch (2004), Phan and Peridis (2000), Goerzen and Beamish (2005), Anand and Khanna (2000), Park, Mezias, and Song (2004), Tsai (2001), Singh and Mitchell (2005), Rogers (2004), Bowles and Gintis (2004), Kale, Singh, and Perlmutter (2000), Larsson et al. (1998), Dyer and Nobeoka (2000), Hagedoorn and Duysters (2002), Cowan and Jonard (2003), Cowan and Jonard (2004), Cowan, Jonard, and Zimmermann (2002), Cowan, Jonard, and Zimmermann (2003), Cowan and Jonard (2006), Kogut (2000), Singh (2005), Gomes-Casseres, Hagedoorn, and Jaffe (2006), Balconi, Breschi, and Lissoni (2004), Sorenson, Rivkin, and Fleming (2003), Fleming, King, and Juda (2006), Baum, Calabrese, and Silvevman (2003), Medda, Piga, and Siegel (2006).

A.4.4. Networks and firm performance in geographical districts

Maskell and Malmberg (1999), Malmberg (1997), Antonelli (2000), Amin (1999), Cooke and Morgan (1998), Camagni (1991), Capello (1999), Keeble et al. (1999), Ring and Van de Ven, (1994), Jones, Koput, and Smith-Doerr (1997), Lechner and Dowling (1999), Saxenian (1994), Dahl and Pederson, (2004), Owen-Smith and Powell (2004), Cooke and Wills (1999), Jaffe, Trajtenberg, and Henderson (1993), Morgan (2004), Porter (1990), Bell (2005), Aharonson, Baum, and Feldman (2004), Sonn and Storper (2003), Almeida and Kogut (1997, 1999), Boschma (2005), Boschma

and Ter Wal (2007), Rallet and Torre (1999), Balconi, Breschi, and Lissoni (2004), Sorenson (2006), Agrawal, Cockburn, and McHale (2006), Bathelt, Malmberg, and Maskell (2004), Doloreux (2004), Oerlemans et al. (2001), Lissoni (2001), Amin and Cohendet (2005), Andersson and Karlsson (2004), Love and Roper (2001), Hite and Hesterly (2001), Audretcsh and Lehmann (2006).

A.5. Network structure

Strogatz (2001), Kirman (1997)

A.5.1. The role of external conditions

Madhavan, Koka, and Prescott (1998), Pyka (2000), Koka, Madhavan, and Prescott (2006), Orsenigo et al. (1998, 2001), Frenken (2000), Cowan, Jonard, and Zimmermann (2006), Rosenkopf and Tushman (1998), Nesta and Mangematin (2002), Kogut (2000), Soh and Roberts (2003), Powell, Hesterly, and Borgatti (1996), Walker, Kogut, and Shan (1997), Balconi, Breschi, and Lissoni (2004), Bekkers, Duysters, and Verspagen (2002), Ozman (2005).

A.5.2. Small world and scale-free networks

Watts and Strogatz (1998), Cowan, Jonard, and Zimmermann (2002), Frommer and Pundoor (2003), Newman (2000), Baum, Calabrese, and Silvevman (2003), Carayol and Roux (2005), Bekkers, Duysters, and Verspagen (2002), Verspagen and Duysters (2004), Schilling and Phelps (2005), Fleming, King, and Juda (2006), Barabasi and Albert (2000), Riccaboni and Pammolli (2002).

A.5.3. Network evolution models

Jackson (2005), Cowan and Jonard (2004), Doreian and Stokman (1997), Jackson and Wolinsky (1996), Jackson (2001), Watts (2001), Jackson and Watts (2001), Watts (2002), Bala and Goyal (2000), Goyal and Vega-Redondo (1999), Skyrms and Pemantle (2000), Goyal (2005), Goyal and Joshi (2003), Goyal and Moraga (2001), Kranton and Minehart (2001), Zirulia (2004), Carayol and Roux (2005), Carayol and Roux (2005), Cowan, Jonard, and Zimmermann (2006).