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Social Interactions Between Innovating Firms :
An Analytical Review Of The Literature

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Réseau social et performance des firmes innovantes : une revue analytique de la littérature

Résumé

L'objectif de ce papier est de proposer une revue de la littérature analytique se focalisant sur le lien entre collaboration et performance. Plus précisément, le papier analyse l'impact que peut avoir sa place dans un réseau de collaboration sur sa performance. Evoluer dans un réseau d'innovation implique que la firme est exposée à des flux de connaissances venant de ses collaborateurs. Elle s'expose aussi à la diffusion de sa réputation par le biais de ses partenaires. Ce document résume les différents facteurs qui ont un impact sur la manière dont la firme peut profiter de son réseau de collaboration et comment elle peut, à son tour, impacter le réseau.

Mots-clés : Réseau d'Innovation ; Performance ; Connaissances ; Collaboration

Social interactions between innovating firms: an analytical review of the literature

Abstract

The main objective of this paper is to offer an analytical review of the literature focusing on the link between collaboration and performance. More precisely, the paper analyses the impact the position of the firm in the network has on the performance of the firm. Evolving in an innovation network implies that the firm is exposed to knowledge flows from collaborators. They are also exposed to the diffusion of their reputation through their partners. This document summarizes the different factors that have an impact on the manner in which firms can profit from their network and how, in their turn, they can impact the network.

Keywords: Innovation networks ; Performance ; Knowledge ; Collaboration

JEL: L14 ; 032 ; 033 ; D83

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1 Introduction

The technological landscape evolves continuously. New technologies are discovered, others are recombined into new products. In this context of constant technological change, firms need to adapt in order to survive on the market. To ensure that firms will not fall behind their competitors, firms are required to continue researching and developing their products. This raises the question of how this technological progress is achieved, i.e how do firms innovate.
Broadly speaking, innovations are achieved through the recombination of existing technologies and ideas. This process of recombination of knowledge results in a complexification and cross-fertilisation of different technological domains. The increase in complexity of the technologies used in the innovation process have as a consequence that firms are no longer able to master all the required knowledge. Accessing external sources of knowledge then becomes part of the innovation process. Firms are incited to go beyond their bounds to access knowledge held within other firms (Hagedoorn, 1996; Narula, Hagedoorn, 1999). The knowledge held within the firm becomes its main asset (Penrose, 1959). In this Knowledge Based View (KBV) of the firm (Penrose, 1959), firms have to protect their own knowledge while gaining access to new knowledge held by other firms.
The need for firms to access new knowledge has become increasingly important (Duysters et al., 1999), making collaborations more widespread, changing the business landscape by a profound reconsideration of strategic decisions. Hagedoorn (2002) shows that collaborations have been steadily increasing in the 1980's, a trend that has continued ever since (Nesta, 2005).
The aggregation of these collaborations, whether at the level of a single technology, a sector, region etc., results in a collaboration network. The latter is viewed as an interconnection of collaborating firms with a common goal. A network is however much more than a mere sum of its parts. Each actor in a network influences, in one way or another, any other actor in the same network and the network impacts in return the performance of the firm.

The aim of this paper is to study how innovating firms can be influenced by their network and how, in turn, they can shape the network. The document is organized as follows; The first section will explain the functioning of networks and how they emerge. Section two will analyze the impact of the network on the R&D process of the firm. A third section reviews how knowledge diffuses through the network while the final section studies how these flows impact the efficiency of the network.

2 The genesis and basic mechanics of innovation networks

When compared to working alone or in bilateral cooperations, networks present numerous advantages for firms. Networks are designed for long term interactions that go beyond the scope of a single project, firms interact continuously through time on different projects (at the same time or one after the other) allowing for social links to become stronger and for firms to learn from each other.
Bilateral cooperations are known to have a low success rate (Barringer, Harrison, 2000; Masrurul, others, 2012), reasons are suspected to be (mostly) diverging interests and managerial disputes. Networks are less prone to these risks since they are build with a common goal, creating all the more incentives for firms to invest completely in the project.
Instead of collaborating in order to gain access to knowledge, firms have the option of buying information or knowledge on a market. The market for knowledge raises a certain number of problems. The market for information is indeed imperfect, the uncertainty about the quality or even the source of the information making it difficult to put a price on information. If the buyer on a market "knew enough about the information,

he would know the information himself" (Arrow (1962), p.946), the intrinsic risk that goes hand in hand with information creates imperfections in the market. Firms then cooperate and share their knowledge in order to overcome these imperfections. The social links that emerge from these cooperations allow for reputations to flow in the network resulting in an auto-regulatory environment that replaces market hierarchies. Networks are hence a stable form of industrial organization. Podolny (2001) summarizes the benefits of networks for participating firms by the use of two metaphors: tubes and prisms. Tuber refer to the potential of flow between connected firms, while prisms are a reference to the reputation that flows through the network.

2.1 Networks as an interconnection of tubes

Tubes refer to the links between firms. When firms cooperate a link is created between them, allowing for an exchange of knowledge, funds or any other resource they might be willing to exchange. Accessing other firm's resources is of vital importance for firms since with growing complexities in new technologies a firm alone can no longer master all the technologies needed for the production of a single product. Accessing different knowledge sources is thus beneficial for the firm (McEvily, Marcus, 2005), for innovation (Kogut, Zander, 1992; Tsai, 2001) as well as survival and growth (Fernandez, Castilla, 2001; Watson, 2007).
Working under the Schumpeterian hypothesis that innovations are achieved through the recombination of existing technologies, diversity is the key to new innovations (Dosi, 2000; Cowan, Jonard, 2007). By recombining different types of knowledge new knowledge can be created, if diversity in technologies runs out, the recombination process will become less productive and innovations will become more difficult to achieve.
Potentially, the more channels a firm has to different actors the higher the diversity of the knowledge a firm can have access to. The benefit of the network hence lies in the transfer of knowledge through the network.
Sampson (2007) found a similar conclusion in a an empirical analysis of 463 R&D alliances. The author found that the diversity of tubes had a significant influence on the innovative performance of the firms in her sample (measured by citation weighted patents).

McEvily, Marcus (2005) show, by studying joint problem solving projects between firms and suppliers, that learning from a diversity of partners increases the competitive advantage of the firm on the market. They argue that firms acquire capabilities through exchange more than alone, the better the relationship between the firm and the supplier the easier the transfer of capabilities. This transfer is important because technologies will reach a point where their returns become decreasing (Kogut, Zander, 1992). The authors argue that because of this decrease in returns, the firms must access new capabilities. Learning new capabilities or even finding them is difficult. Firms embed themselves into a way of organizing their production, they will have to go out of their comfort zone in order to achieve better returns, learning from other firms is one possible solution. Tsai (2001) supports the view that in a network firms can learn from each other and hence increase their innovative performance but does point out that the success of such transfer depends upon the ability of the firm to absorb the knowledge (as proposed initially by Cohen, Levinthal (1990)). The influence of networking on industrial performance should thus be visible and Watson showed that it is (Watson, 2007). Through a survey of Australian firms he was able to find a significant influence of networking activity on the survival of the firm, growth however was less influenced by network activity. Growth is shown to be influenced by collaborations by Szulanski (1996) and Duanmu, Fai (2007). The latter showed that Chinese suppliers learn from the routines of multinational firms significantly increasing their R&D productivity. Networks hence allow firms to interact and influence each other over time by the exchange of knowledge.

Knowledge is a powerful motivation for firm cooperation. There are however other motivations. Table 1 gives

a list of different motivations that go beyond the benefits of knowledge exchange.
Other resources might be interesting to a firm, especially when these resources are rare. We can take the example of the large hadron collider. A network might emerge for the purpose of the exploitation of such a resource, to regulate its use and creation.
Firms can decide to cooperate with other firms for internalization purposes. Some firm might be brought to consider cooperations because it knows that other firms might profit from it's innovative activity without it's consent. In order to avoid being victim of this externality the firm can cooperate and hence internalize the externality.
Firms can also decide to enter a network for the aim of the network, for a specific cause. Firms in an industry with high pollution can decide to enter a network for the development of cleaner technologies purely for ecological reasons. It is however possible that this interest for cleaner technologies is motivated by new government regulations. This is the case in the aerospace sector for example, where cleaner engines are required by the european commission. Firms then cooperate in order to make this technology as efficient as possible. The advantage of this kind of cooperation resides in the fact that the technology cannot be used for a competitive advantage by any of the firms (or consortium). This facilitates the emergence of industry standards since the technology is developed by a large number of firms which can come from all stages in a supply chain. This means that during cooperations firms will be able to be more aware of the different requirements and problems they might face. In addition, they can find common solutions increasing the efficiency of the technology. This also implies that during cooperation firms learn about each other's technology resulting in an increase in efficiency of the innovation process.
Not only do firms learn about the technologies of other firms, they also learn about the trustworthiness and value of a collaborator. The network is not only a catalyst for the exchange of knowledge relative to technologies but also for reputational aspects. From this point of view networks act as prisms.

Collaborations between firms allow for more than just the exchange of ressources between firms. Since collaborations are risky endeavors, and prone to failure (Masrurul, others, 2012), the search process for new collaborators is influenced by the reputation and trust of prospects.

2.2 Prisms and the diffusion of reputation

Repeated cooperations between firms allows trust to form. Information about the trustworthiness of agents then flows through the network (mainly by social contacts). A collaborator that slows down projects or behaves as a free-rider should at all cost be avoided. The choice of partner is both difficult and of paramount importance. Problems of moral hazard and adverse selection can be reduced by basing partner choice on repetitional effects. Un-cooperative behavior will result in firms having a bad reputation, keeping them from collaborating again in the future. Increased trust allows for a decrease in the failure of cooperations as shown by Zaheer et al. (1998). The authors show that there is even a direct link between trust and the performance of the firms (as measured by competitive price, quality of goods delivered and respect of deadlines). These results were obtained by studying dyadic exchange relationships of electrical equipment manufacturers. Even though the object studied was not a network this is only because the authors did not define their cooperations as a network. There might not be a common goal for the actors here but their reputation can still flow through the social network of the firms with whom they work. As such the social network of the firms influences the performance of the firms through the creation of trust that result from dyadic cooperations.
Each agent inside the network sheds light on the other agents, either illuminating their positive reputation and capabilities or their un-cooperative behavior. From a dynamic point of view, the network allows firms to better select their partners by increasing available information about their knowledge. The flow of this information increases allows firms to better understand the functioning of other firms (either their routines or

Aim	Definition
Specific goal of the network	Networks can be created for a specific goal; greener technologies, healthier products, computer standards etc. Firms might decide to enter a network purely because it believes in the cause of the network.
Internalize externalities	A firm can anticipate that other firms will benefit from its efforts. The creation of a network will allow the firm to limit the free rider effect.
Standards and labels	Using standards is beneficial for a firm since it allows to cut cost and might result in a larger user base (for electronics: wi-fi, usb). ISO standards , controlled designations of origin and other labels.
Access to rare resources	Firms might require the use of a specific resource (technology,natural resource etc.). A network of entities might manage the resource, in which case a firm can decide to join the network with the sole purpose of gaining access to the resource in question.
Access to a new market	Entering a new market is risky, collaborations with incumbent firms can reduce the risk factor since the firms can share their knowledge of the market.
Access to complementary knowledge.	Firms might find that it is more cost-efficient for firms to collaborate in order to use knowledge mastered by other firms rather than invest in R&D in order to master the same knowledge.
Access to funding	Policy makers can put conditions on the distribution of funding for R&D which can include collaborations.

Table 1: Motivations for collaborating

the employees they have to cooperate with). The more firms cooperate, the better they are able to exchange and combine their knowledge (Cowan, Jonard, 2007). Gulati (1995) shows that firms look for partners with whom they have a high cognitive embeddedness and who can provide them with new knowledge. The prism metaphor explains that in a network it is easier for firms to identify which potential partners possess the knowledge they are looking for and hence increase their efficiency.
This shows us that there are different dimensions to a network: we can find social links, informal links, contractual links and even invisible links. These links all play an important role in the innovation process as we will see later in this document.

Leung (2013) notes that networks resemble sponges, they absorb information from its components, recombines these elements to create new knowledge which is send to the actors in the network, the process can then start over again. The network hence evolves, and not only because of the knowledge it created but also by the structure. The agents in the network rewire themselves to cooperate with firms with a better reputation or better knowledge enhancing once again the performance of the network. The strength of the network resides in its ability to evolve over time, getting rid of bad elements and innovate continuously by sending relevant knowledge to the firms composing it.

Networks can however have a negative impact on the firms. Pippel (2013) points out three potential technology-push disadvantages of networks, they mostly stem from what we initially considered to be advantages.

When a firms has identified indispensable resources for its R&D project that it does not possess itself, a partner needs to be found. The search for a fitting partner is costly, not only is it time consuming, gathering information about trust and quality of a potential partner is difficult to obtain and hard to verify. There is hence an inherent risk in choosing a partner.The network helps to reduce the cost and the risk. Working in a network implies that firms know each other and communicate on a regular basis, this allows for them to discuss behavior of other firms and judge the quality of their work.
This means that a firm searching for a new partner will be inclined to activate it's social network for this search rather than take the risk of cooperating with a firm it knows little about. As a result networks tend to become more locally clustered, phenomenon that is observed empirically (Hanaki et al., 2010). This phenomenon is amplified by social pressure. Firms that tend to cooperate often have close social ties, asking another firm rather than a socially close one is decision that becomes increasingly difficult, resulting in a specific type of lock-in, a social lock-in. Instead of choosing a new partner, (with potentially new, more valuable knowledge a firm will continue to cooperate with the same firms. In fine the social lock-in can result in a technology lock-in because of the absence of new knowledge in the innovation process.

Pippel (2013) also points out that knowledge flows are difficult to control and some flows can be involuntary. Even in networks, specific knowledge still is a competitive advantage. Through cooperations knowledge can flow further than an initial dyadic cooperation resulting in a possible decrease of the competitive advantage.
Firms thus have to make sure they protect their knowledge and what they send throughout the network. This will greatly depend on the type of cooperations a firm has as the next section will show.

Networks are build up from tubes between agents.These tubes allow firms to access resources inside other firms that are needed for the accomplishment of their R&D process.
Alongside the tubes that connect the agents, networks act as prisms that allow information on firms to diffuse inside the network. Firms will be able to chose partners based on their reputation. It is not always possible for firms to know which firm detains which resource, information about these resources flow in a network and will allow for firms to know with whom they can cooperate.

We have shown here the general conceptualization of networks and their functioning with a specific aim on innovation networks. The time has come to go into more detail on the functioning of the network by looking into the manner in which the different flows inside the network influence the R&D process of the firm and enhance their performance.

3 Networks and their influence on the innovation process of the firm

Dosi (2000) gives a detailed description of the innovation process that underlies the majority of innovations[1]. In his paper he reminds us that there are two theories describing the innovation process. These two theories, demand-pull and technology-push, explain where ideas come from and are hence the starting point of the innovation process.
What we will recall from these theories (for our purpose) is that one theory suggests that the market sends information about it's needs to the firms and that this information should be used by the firms for new

[1] With the exception of innovations that are created purely by accident

ideas. The other (technology-push) suggests that firms innovate without consulting the market, pushing an innovation without there being demand. We can illustrate the difference with the example of the iPad. The iPad was created by a company without there even being a market for it. The firm created the product and pushed it on the market. Hybrid cars on the other hand are the result of a reply to a consumer demand for the reduction of cleaner cars and a reduction of fuel consumption.

3.1 Demand-pull theory

Demand-pull theory suggests that the consumers reveal their preferences regarding innovation by their behavior on the market. If goods with certain characteristics have a higher demand, firms should include these characteristics in their new products.

The question we have to answer here is how does the network influence this first step of the process. The demand-pull theory suggests that firms have information about consumer preferences. It should be clear that this is valuable information since innovations based on this information have a high probability of finding demand on the market. Firms that posses this valuable information do still have an incentive to collaborate. A single firm is unable to master all the technologies needed to create a product. Working with firms that have the reputation for providing high quality products can only increase the quality of the end product that they develop together. Disclosing their information might not seem as a viable decision in the short run, because profits will be shared and the competing[2] firms in the network might become more capable. It is however a viable strategy in the long run. Sharing valuable information allows a firms to show it's value as a collaborator.

The same reasoning applies for firms sharing their productive capacities. By showing what one can do to other firms one ensures future cooperations and thus opportunities to learn and access more information. This information is valuable in its own right because it can result in an increase inefficiency for the firms.

3.2 Technology-push

Technology-push implies that firms create innovations without knowing if there will be a demand for the product on the market.

Cooperations between numerous firms allows an exchange of ideas an expertise in various domains. If no information on demand is available, the risk that an innovation will find demand is higher. The reason why firms still engage in technology push innovations lies in an information asymmetry between the market and the firms. New discoveries (by universities or labs for example) can open the way for a large number of new products that consumers had not yet imagined to be possible.

Once again it is the diffusion of information that allows for ideas to emerge. Only experts can see the potential of new discoveries and estimate their impact in their industry. Allowing this information to spread as widely as possible is hence positive not only for the consumers but also for the agents developing the technology. A network provides agents with contacts whom they can trust (their reputation has been established by their previous accomplishments in or outside the network), which allows firms to bypass the market with all it's imperfections. The discussions between the agents, and hence the combination of their expertise will allow for a development under optimal conditions. By contrast, a firm working on it's own would have to acquire abilities by itself, requiring important investments. A network allows direct access to agents who can share their experience and reduce the risk of failure.

[2] Firms that compete on the same market

One special case of a technology-push is worth mentioning here, the development of a new industry standard. Standards in an industry influence the efficiency of both the production process and the innovation process. In any cooperation time is needed for firms to adjust to their work methods and organize the compatibility of technologies. The use of an industry standard allows these efforts to be drastically reduced and the efficiency of the cooperation increased. In the french aerospace sector for example the whole supply chain uses software designed for the sector. The software makes sure that all parts are in stock. As soon a an order is placed it immediately updates stocks and orders for all the other firms in the sector.
As we discussed before, the instauration of such a standard can be a motivation for network creation, showing the importance of standards in an industry. The advantage of the development of a technology in a network resides in the fact that it will be adopted by all firms. If standards emerge from a market there is a possibility that we observe competition between standards resulting in a loss of efficiency until one of the two competing standards wins.

Until now we have mostly discussed knowledge exchange between firms. Firms are however not the only source of knowledge. Research institutions such as laboratories and universities can be the epicenter of new technologies that might initiate new technologies and products. Indeed, it is in these research centered institutions (RIs) that fundamental research is developed that will define the technologies and materials of tomorrow. The research provided by these institutions results mostly in codified knowledge (by patents or publications). The difference with the knowledge provided by firms resides in the application of the technology. Firms develop their technologies and routines with the specific aim of making them operational inside the firm. The research institutions (RIs) do not have this aim, they are only motivated by the performance of the technology they are developing. As such, if no cooperations exists firms would not be able to efficiently exploit new technologies (or not at all).
Networks then allow firms to help RIs to find an application for their developed technologies. The objects of the exchange hence are far beyond the transfer of tacit information, the firms have to develop new routines and methods with the knowledge provided by the RIs.

The network then influences greatly the generation of new ideas at the beginning of the innovation process and how they are developed. Firms are no longer shielded from technological progress in other firms nor from the development of fundamental research (through cooperations with research institutes). This makes it easier for other firms to learn who masters which technology in the network and hence facilitates the second step of the innovation process.

3.3 The search for resources

The second step in the innovation process is the identification of resources needed for the development of the technology. Resources such as new technologies, patents, machines, expertise and know-how are identified. Taking into account the cumulative nature of knowledge, firms that wish to innovate need to master the existing technologies that incorporate this knowledge (Cowan, Jonard, 2007).
The identification of firms that master the needed technologies is not easy. Indeed, it is not simple to find out which firm uses a certain technology, who hold vital patent that need to be licensed etc. For firms in network this step is greatly simplified.
The search for partners will be accomplished in part through the "prisms" of the network, as time flies by and collaborations begin and end more is known about which firm knows how to do what. This information will flow through the network and should converge to a perfect information scenario. This is only possible of

course if no new firms enter the network which is not necessarily the case.
A firm working on its own would have much more difficulty and also be confronted with hostility from the other firms who might not want to diffuse any of this information.
For example, Airbus wants to use composite materials instead of aluminum in order to reduce the overall weight of its aircrafts. The technology is relatively new and it has no in-house knowledge on the subject. By searching through its collaborative network it has been able to identify swiftly which of its suppliers was already working with the technology and which firms owned strategic patents on the technology that needed to to be licensed for the development.

3.4 The development stage

The research for resources being over, the partners with whom a firm is going to cooperate have been selected allowing for the research and development stage to start. Tubes are now created between the firms which opens the possibility for exchange between the agents. The firms start to work together and will hence be able to observe the inside of the firm. Hence, more than information, knowledge can be exchanged during this stage. More specifically, two basic types of knowledge can be transferred through the tubes: Routines and technology specific knowledge.

Routines The concept of routines was first introduced by Nelson, Winter (1982) and refers to the way a firm is organized and accomplishes its tasks. Firms improve their routines over time, and can share their experience with other firms. For example Duanmu, Fai (2007) showed that Chinese firms, by observing how multinational firms organized their R&D, were able to better organize their own R&D procedures resulting in higher productivity. The links in their study are vertical but horizontally the exchange is possible as well. Even competitors can learn from each other's routines.
Networks allow for firms to exchange best practices (Szulanski, 1996) or even encourage it since it will allow for a smoother cooperation between firms. Converging work methods will allow for agents to speak a common language in the development process and avoid lost time due to inefficient organizational aspects. The firm that has the best practice will benefit just as much as the other firms from the exchange of routines. Firms are hence able to learn from each other and implement best practices that increase the efficiency of the organization of the production (and/or R&D) process. The network influences the R&D process by the means of gaining access to best practices from other firms which would not be willing to exchange this knowledge in a more competitive environment.

Technology specific knowledge Technology specific knowledge is the know-how that is needed to operate a machine or the knowledge to understand how a technology works. In the case of a network (or a simple cooperation) firms might benefit from both mastering a technology. Some technologies are however not easily operational without the help of an expert (Comin, Hobijn, 2004). Think for example of a firm that masters composite materials and uses it to make wings for an airplane. If it has to work with a firm that wants to use the materials to make nacelles, then for the sake of having a motor that is correctly fastened to the wing, the first one might want to teach the second one about composite materials. This exchange of knowledge is beneficial for both parties because it increases the quality of the components. Considering that firms in networks work towards a common goal they are concerned with the quality of the objective the network and not only they part they supply.

Networks then, incite firms to exchange knowledge and broaden the range of the technologies they master in the process. In the case of a technology that was not unknown by the firm the exchange can have implemented a better knowledge of the technology. For example firms could now be aware of other applications, or have more ease in the resolution of problems with regards to the technology. Working in a network setting allows firms to learn new technologies, increase they level of comprehension or even solve existing problems.

The network influences the R&D process of the firm in each of the stages of the process. Networks make it easier to access knowledge and information that allows the firms to be more efficient in the choices it makes but also in the development of the technology that has been chosen.

However, the diffusion of knowledge as we just described is not an easy process and is subject to many factors that influence the efficiency of the learning process through a network. The efficiency of the transfer will depend on the channel through which it has to travel but also on the type of knowledge.

4 The diffusion of knowledge in a network

4.1 Forms knowledge may take and the influence on its diffusion

So far we have identified two types of knowledge that were of vital importance in the R&D process: Routines and Technology Specific Knowledge (TSK). These terms are general, they contain in fact various types of knowledge with different characteristics. These characteristics define the transferability of knowledge and hence how it flows through the network. Polanyi (1966) and Nelson (1990) made a first distinction between different types of knowledge. Polanyi defends the opposition between implicit and explicit knowledge, where explicit knowledge is a physical aspect of a technology (machine) and the know-how to operate the machine is referred to as implicit knowledge. It is obvious that the machine is in many cases easy to transfer from one firm to another, yet acquiring the know-how to operate a machine takes more time and effort.

Nelson draws our attention to the fact that implicit knowledge itself can be decomposed into two major components, a 'private' and a 'public' component. The private component refers to technology specific knowledge, i.e knowledge that is only of use for a certain technology (system adjustments or specific problem solving).

The other component is the public component, which englobes all general knowledge used to render the machine operational. An example of general knowledge could be that the machine should be plugged in, and in order to make it work one has to turn it on. This distinction is still valid if we take into consideration information without a physical component. For example, if one wishes to compute the maxima of a non linear system, one will need basic algebra skills involved that would be considered to be common knowledge, but there are also other more complex methods necessary that are more specific to the task at hand, which would be the private component (the programming of algorithms). The use of a machine is only one side of the story. Nonaka (1991) makes a similar observation but uses the terms "explicit" knowledge and "tacit" knowledge. This distinction has lead to what is nowadays referred to as the "Knowledge Based Vision" of the firm (Penrose, 1959). Nonaka uses the analogy of an engineer who tries to develop a new bread making machine. The engineer tries to learn how to knead the bread with one of the top bakers of the country, and discovers that the knowledge the baker has about kneading is tacit. It has no physical form and thus the only way to learn it is through practice. While the two work together the tacit knowledge of the baker is transformed into explicit knowledge for the engineer (Nonaka, 1991), who can then transform his knowledge into a machine, that can be easily be transferred from company to company. This becomes even more obvious in Rogers' theory of diffusion (Rogers, 1982) who makes the distinction between hardware and software.

Hardware is useless without software, and more importantly hardware can only be optimally used if the software is efficient.
The underlying hypothesis here is that the knowledge of a firm is held by the employees of the firm. Some authors have however noted that in the knowledge base vision of the firm, the firm as an entity can also posses know-how which can be tacit Kogut, Zander (1992). This vision relates to Nelson and Winter's theory of routines, in which routines are not only established by the employees but also by the firm.

In fine, two distinction should be retained for the analysis of diffusion of information, whether knowledge is tacit and whether it can be codified. Codified knowledge is the possibility for information to be passed down on a written support (patents, manuals, publications etc.). This allows us to organize all information into two categories. Information that has to be exchanged by face-to-face interaction and information that can be transferred directly between two agents without face-to-face interactions being a requirement.
Clearly, the flow of knowledge is faster in the case of codified information. The quality of the transfer will however depend on the absorption capacity of the firm.
What these descriptions show is that the tacit, implicit, private or codified dimension of knowledge need specific conditions under which they can be transferred. According to the type of cooperation chosen by firms certain types of information may transfer, other may not. Let us hence take a look at the different channels that may be created between firms and the objects they might carry.

4.2 The diversity of channels

Channels between firms can take a large variety of forms, from a simple discussion between employees to a joint venture or even a buyout. Table 2 gives a number of "tubes" that allow for knowledge exchange between firms. The differentiation is important because each tube (or channel) allows for different types of knowledge to flows through the channel and defines what firms may learn from one another. For instance, through a social interaction between employees only general problem solving can be transferred (Breschi, Lissoni, 2001), the influence on the productivity of the firm is only marginal.

Some links allow for bi-directional knowledge flow to occur, i.e Alliances, joint ventures, technology swaps and vertical links. These links will allow for the most valuable knowledge to flow. Indeed, these interaction are long term and hence allow for repeated interactions allowing tacit information to flow.
In the case of a buyer-supplier link the buyer might send employees to the supplier to teach them how to build parts up to their standards (cf. Airbus). This will have a significant impact on the performance of the firm, it will create a signal of quality and increase demand. Nike's supplier Mizuno was for example able to launch its own brand worldwide after learning from Nike.
Other links only allow for a unidirectional flow, Spin-outs, buy-outs, IP-transfers, R&D contracts and employee mobility. Even though these links allow tacit information flow, the flow only goes from one firm to another, there is no counter part. This is hence less valuable for the efficiency of the network as a whole. Innovating ideas and technologies will flow slower through the network.
Table 3, shows the different tubes and the types of knowledge they might carry.
The choice of the type of link depends on the knowledge flow that might result from the interaction. The structure of the network that results from these decision is hence partly defined by the type of knowledge pursued by the firms in the network.

This means that according to the needs of the sector in which the network evolves it is possible to find

Tube	Definition
License	A firm pays another for the use of a patented technology
Joint Venture	Two or more firms create a new firm for a specific purpose
Alliance	The pooling of resources by several firms
Social	Any contact between employees of a firm that may take place inside or outside the firm
Spin-Out	Employees of a firm create their own company
Externalities	Knowledge flows between firms or employees
Buyout	One firm takes ownership of another firm
Supplier	One firm supplies an intermediary good to another firm
OEM	One firm has an exclusive contract with another firm for the trade of an intermediary good
Technology swap	Two or more firms allow each-other to use a technology
IP transfer	The passing of hands of Intellectual property
R&D contract	One firm is contracted to perform R&D for another
Minority Investment	One firm buys less than 50% of the shares of another firm
Employee mobility	The knowledge stock of a firm is held by the employees of the firm. When employees switch firms they take part of the knowledge with them.

Table 2: Diversity of tubes

actors that generate fundamental knowledge. In technology intensive sectors such as biotech and aeronautics, research conducted by universities and laboratories is the only mechanism that allows for radical innovation to occur. The research provided by the Research Institutions (RI) cannot be completed inside firms, they lack not only the knowledge but often enough the research provided by RIs is void of any marketable application. Cooperations between firms and RIs allows for firms to help RIs to orient their research and market it efficiently.

I will make a second distinction between channels that occur between firms and channels that involve RIs. The RIs typically provide codified, scientific knowledge that has to find an application. This application is in most cases provided by firms. Where RIs are involved, the transfer of knowledge is relates to fundamental knowledge which has a general nature. Transfers between firms are mostly transfers of technology specific knowledge. The transfer of knowledge between RIs and firms is different from knowledge flows between firms.

4.2.1 Channels between firms

Firms can interact in a variety of ways as shown in table 2. Not all of these tubes allow for the same type of knowledge flows. Some of the tubes allow for bilateral knowledge flows (RJV, technology swaps) while other only allow for knowledge to flow in one direction. The distinction is important for strategic purposes. Firms aim to protect their knowledge base, unilateral transfers protect firms from losing a competitive edge. Bilateral flows imply that firms need to share some of their knowledge base which can result in losing part of their advantage. In addition, when collaboration results in the requirement of receiving knowledge, the firms become dependent on the other firm. The choice of the type of collaboration is hence of vital importance.

	Alliance	Licence	JV ou RJV	Social	Spin-out	Externalities	Buy-out	Vertical	OEM	Technology swap	Ip-transfer	R&D contract	Employee mobility	Investment
Routines	■		■		■		■	■	■				■	■
TSK, explicit	■		■				■	■	■	■		■		
TSK, implicit, tacit	■		■		■		■	■	■	■	■		■	
TSK, implicit, codified	■	■	■		■		■	■	■	■	■	■	■	
Solutions	■		■	■	■	■	■	■	■			■	■	

Table 3: Tubes and the objects they may carry

IP transfers for instance are simply the transfer of a patent from one firm to another, the direction of the flow of knowledge unidirectional. A spin-out keeps the same spirit since a new firm is created while taking knowledge from another firm, without sending anything back. The case of R&D contracts is more complexe since the direction depends upon the nature of the contract. Research that is accomplished for the account of another firm cannot be considered to be bilateral knowledge flows. One of the firms creates the knowledge while the other receives it. The receiving firm does not transfer any knowledge to the other firm. Table 2 can hence be classified to account for the direction of knowledge flows.

Tube	Bilateral	Unilateral	Both
License		■	
Joint Venture	■		
Alliance		■	
Social			■
Spin-Out		■	
Externalities	■		
Buyout		■	
Supplier	■		
OEM	■		
IP transfer		■	
R&D contract			■
Employee mobility		■	

Table 4: Direction of knowledge flows per tube

Table 4 shows this classification. Just as the direction of the flow depends on the tube, so does the type of knowledge (tacit, implicit, public or private) that an transfer. For instance a social link, which is a discussion between employees can never allow for a transfer of physical capital, it allows information on problem solving to flow. An IP transfer is a transfer for codified knowledge only. Tacit knowledge needs repeated face-to-face interactions to be exchanged (Von Hippel, 1987). We hence have to understand which type of knowledge can be transferred through which channel to judge the potential importance of the transfer on the innovation

process of the firm. Let us take a look at the channels and the objects that they might carry.
Table 3 allows us to see that some channels only allow for a specific type of knowledge to flow. For example in the case of social interactions only solutions to problems may flow. We have to emphasize here that an interaction between agents can imply different channels at the same time. A social link might exist at the same time as a licensing agreement, or the creation of a licensing agreement might lead to a social link. This does not change the information in our table. The different types of links are separate and transfer knowledge in their own right.

4.2.2 Channels involving research institutions

Many of the channels involving firms can also involve research institutions. The channel itself is not affected but the motivations are. Research institutions are typically at the pinacle of scientific knowlegde. A collaboration between a firm and a research institution is motivated, from the firm side, by a need for fundamental research and the expectation of radical innovation (Tödtling et al., 2009).
The RIs objective is different since it is less market oriented. A RI is motivated by the need for funding. Reputation is therefore important, the better the reputation the more funding a RI will be able to gather. Finding applications for the technologies that are developed and forming students to use them is hence of paramount importance. The reputation of a RI depends upon the quality and usefulness of the research conducted, a point where firms can play an important role. After all, firms have expert knowledge on market trends. In a collaboration network, RIs have a central role in the sense that they add new knowledge to the knowledge base of the network ensuring that technological diversity does not decrease to a level where innovations would only be incremental.

Conclusion Networks are build up from linked agents. Even thought in the vast majority of analyses and models all these links are considered identical, in reality they are all different.
The diversity of channels is important because they each carry different types of knowledge that influence the R&D process of the firm in a different manner. Indeed, some of the links impose no particular restriction to the knowledge that may flow between collaborators others allow only specific types of knowledge to flow. This is due to fact that tacit knowledge needs time and regular interactions to be transferred. Channels that do not have this characteristic hence restrict the flow of tacit knowledge while it has an important impact on the productivity of the firm.

We can hence summarize channel's characteristics by 2 factors, the breadth and the length of the channel. The breadth would define the amount of knowledge that a firm is willing to exchange (which it reveals by offering a contract of a certain type) and the length defines the amount of knowledge that actually flows through the channel. In such a framework codified knowledge only needs a narrow and short channel (social link suffices) whereas mastering the large hadron collider needs a very broad and long channel for employees to learn a technology.

The diversity in channels also teaches us that several networks might exist at the same time. We refer here mainly to the social and the formal network. Formal interactions imply social interactions. The exchange of information through the social network is however different from that that transfers in the formal network. Information relative to trust and reputation flows through a social network that will have a different structure than the formal network of cooperations.
In any case the diversity of both channels and agents in the network defines the quality of the knowledge flow

in the network and as a result defines the performance of the network as a whole.

5 Network efficiency

The strength of the network resides in its ability to evolve over time, getting rid of bad elements and innovate continuously by sending relevant knowledge to the firms composing it. The efficiency of a network can be understood in two ways: the speed and quality of the diffusion of knowledge, and the optimization of social surplus generated by collaborations through market interaction. In this section we will review elements that impact the efficient diffusion of knowledge through the network as well as more market oriented measures of efficiency (profit, utility, return on assets). Since the structure of the network has a vital role to play, one would wish to identify efficient structures for networks. Since efficiency is very difficult to measure empirically, theoretical models are often used to assess efficiency.

5.1 Equilibrium structures

The previous sections have discussed factors that impact the transfer of knowledge in a network. The structure of the network itself also impacts the efficiency of knowledge flows. In a sparse network structure knowledge needs more time to diffuse while a more dense structure allows for faster diffusion. Models of knowledge diffusion understand efficiency as the speed and quality of the transfer of knowledge through a network. The previously discussed elements hint however to the idea that diffusion highly depends upon the abilities of the agents transferring the knowledge. In order to have a better understanding of the effects of the structure of the network on network efficiency one is required to include other elements such as profit (König et al., 2012; Jackson, Wolinsky, 1996), utility (Jackson, 2003) or R&D expenses (Goyal, Moraga-Gonzalez, 2001). The latter calls for models that include market interactions between firms. Firms evolve on a market and face the same demand. They instigate collaborations that result in a reduction of their production cost (through knowledge flows), making them more competitive on the market. Firms continue to add links as long as the marginal benefit from a link exceeds that of the marginal cost. In order for a link to exist both firms need to accept to maintain it. If one of the firms decides the link is not beneficial it can unilaterally cut it. When no firm wishes to sever a link or add a link, the network is called stable. This specific concept of stability is called "pairwise" stability (Herings et al., 2014; Jackson, Wolinsky, 1996; Bala, Goyal, 2000; Jackson, Yariv, 2007). Different papers identify different stable structures (stars, complete graphs, empty graphs). The question is then wether any of the identified stable structures are efficient (according to a particular criteria). When it comes to the diffusion of knowledge, the small world structure has been identified as the most efficient (Verspagen, Duysters, 2004). When one includes the industrial dimension, i.e how firms use the knowledge they receive in order to make a profit, results are much more ambiguous. König et al. (2012) show that the efficient network structures (as measure by the total profit of the network) are not necessarily the stable network structures. It turns out then, that firms are not able to organize themselves in manner that maximizes social surplus, due to their myopic, short-term, profit maximizing vision.

It turns out then that the role played by the structure of the network is more than ambiguous. Maybe, it is not so much the structure that is important but more the agents one is connected to. Network efficiency might simply be a question of efficiency of partner selection. A small world, identified as efficient in terms of knowledge flow, might be much less efficient if certain firms with strategic positions do not transfer knowledge efficiently.

We would hence be interested in models that allow for a more strategic partner selection mechanisms coupled with more clearly defined knowledge transfer mechanism. These considerations will however only show their fundamental importance if heterogeneity is introduced in the model. As we have seen previously the value of the network lies in the diversity of agents and the diversity of channels that connect them, allowing them to innovate.

The literature shows us that the structure of the network is highly dependent upon the partner selection mechanisms as well as sectorial aspects. The latter point is influenced by the presence of different types of agents present in the network. When public research institutions are present, they usually take a central position in the network impacting the average distance of the network. Some sectors rely more on these research institutions than others. High technology sectors will for example rely more on the presence of universities than would the manufacturing sector. The differences in the network should hence be visible through sectoral differences in which the networks evolve. The characteristics of the sector of activity will define the types of agents present and even the channels that are created between the agents. Some sectors will rely more on joint ventures because of high competition between firms, others will rely more on long term cooperations with suppliers and universities.

5.2 Obstacles and accelerators of efficient knowledge diffusion

5.2.1 Absorption capacity

When exposed to new knowledge a firm will want to absorb all knowledge that is useful to it. Even though the quality of the information it has access to is high, it might only be able to learn a small fraction of it. This inefficiency in the transfer stems from a low absorption capacity; the ability of the firm to learn. This means that it is completely dependent upon the technology level of the firm. The more technologies a firms already masters the easier it is for the firm to learn a new technology.
Tsai (2001) shows that the absorptive capacity of the firm is directly related to the business performance and innovation of the inter-firm units in a study covering a petrochemical company and a food manufacturing company. Østergaard (2009), for example, shows that the absorption capacity increases the probability of knowledge acquisition, this is reinforced by results from Giuliania, Bella (2005). Giuliani et al. find that firms with a higher absorption capacity are more likely to create links. The more links a firm has, the more (potential) access it has to knowledge. This capacity not only increases the innovative performance of the firm, it also reinforces the competitive advantage of the firm (Chen et al., 2009).
When studying the efficiency of innovation networks the absorption capacity is often casted aside because of the heterogeneity it introduces when researches want to focus on a specific aspect of innovation networks. Using an agent based model in which firms create alliances based on absorptive capacity rather than social capital, Egbetokun, Savin (2013) show that the resulting networks have a similar structure as the networks that result from social capital considerations. They also found that there was a positive correlation between the position of the firm in the network and the absorption capacity of the firm. In order to use all the available information in the network (either through tubes or by spillovers) firms need a high absorption capacity (Camisón, Forés, 2011).
Firms with a low absorptive capacity in a central position in the network can hence stop the diffusion of ideas and technologies, or slow it down significantly as happens with Chinese whispers. A network is hence only truly efficient if the agents composing it are indeed able to learn from each-other.

Figure 1: Brokerage and Closure illustration

5.2.2 Cognitive distance convergence

As I discussed before, knowledge exchange is one of most important motivations for the emergence and efficiency of innovation networks. In order to be able to learn from each other firms need a low to average technological overlap or short cognitive distance. When firms collaborate, they exchange knowledge which increases their overlap. The more they exchange the less unique knowledge they have, decreasing the diversity of knowledge. When this diversity becomes too low or disappears, the return to innovation then decreases. Wuyts et al. (2005) show that the technological overlap is a decreasing function of the frequency of cooperation. This highlights once again the importance of the presence of RIs in the network that allow firms to learn new technologies and diversify their abilities and, through recombination, find new technologies to avoid the convergence to a network in which all firms master the same technologies and innovation eventually dies.
Granovetter shows this in his seminal work in 1973 Granovetter (1973) in which he argues that the strength of a tie is positively correlated with the time spend between actors, showing how socially close they are. Granovetter applies the idea in sociology but the idea can be directly translated to the analysis of the firm. The higher the strength of a tie in this case the more efficient the transfer, at the same time the repeated interaction also means that firms have less to learn from each other and will eventually master the same technologies as we pointed out before. The weak ties hence play an important role since they bring this diversity to the neighborhood of the firms. The channels we enumerated previously hence have to be taken into account in a dynamic vision as well. One alliance at time t cannot be compared to a continuous alliance over time, the possibility for exchange is high but the risk of a lock-in is high. Lock-ins can occur not only at a technological level but also on a social level, firms might be afraid to select a partner.
This shows that if firms are too embedded in their network, their connection to the rest of the network is restricted. New ideas and technologies will take time to reach the firm because knowledge needs to travel to a dense network.This phenomenon, called overembeddedness, is a risk for firms in a network configuration.

The structure of the whole network and that of individual firms, hence plays a vital role in the diffusion process and thus the efficiency of the firms evolving inside the network. To complete the picture of the efficiency of innovation networks we will now see how the structure of the network influences the performance of innovating firms.

5.2.3 The theory of strong and weak ties and the importance of structural holes

The study of the structure of the network structure will allow us to assess the efficiency of information flow and hence the efficiency of firms inside the network.

We have stressed the importance of diversity of knowledge in a network. Some structures allow for this diversity to exist others do not. For instance suppose the networks in figure 1.

Even though the structure is simple the difference between these two structures highlights a vital point in

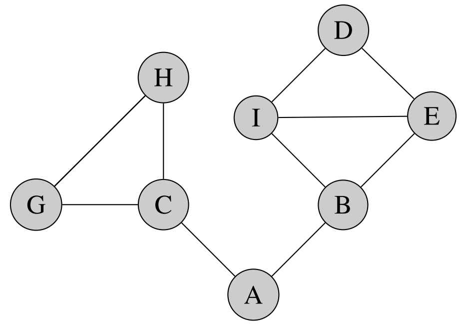

Figure 2: Structural hole illustration

terms of efficiency in cooperations. The structure of network 1 is very advantageous in terms of diversity of knowledge. Since A and C do not communicate they have different technologies and hence will improve the potential result of the R&D procedure. Firms B is in a very important position, B allows knowledge to flow from A to C indirectly.Without B there would only be two separate clusters in the network. This very advantageous position is referred to as a brokerage position or the bridging of a structural hole (Burt, 2004). A firm in a brokerage position connects different components of a network together. Not only is this position advantageous for the firm in terms of network importance, it also allows the firm to have first hand knowledge of new technologies or ideas. In a purely social context Granovetter (1973) shows that such a bridging link can only be a weak link. A weak link is a connection between agents that do not interact on a regular basis, they are mere acquaintances. Consider figure 2.

Agent A is in a brokerage position, if A had strong ties with C and B (socially close, they know each other well and interact often) then there is at least a weak link between C and B. The presence of this link results in the disappearance of the brokerage position of firm A. Hence if a firm is in a brokerage position it can only have weak links. The theory of weak links and brokerage focuses on the positive impact of diversity. Hargadon (2002) show for example how brokerage positions held by consultants allow them to introduce new techniques in different sectors. At the antipode of this theory we find the theory of closure and strong links. In network 2 we observe closure, or the absence of structural holes. Granovetter suggests that closure allows for firms to better cooperate through the creation of norms between the agents. This idea can be translated to the analysis of the firm. When firms cooperate often and with the same firms or people there will be convergence in their methods and routines. This advantage of redundancy is counterbalanced by a positive influence of brokerage though the advantage of diversity in knowledge.
Empirically both theories are supported, however, one has to be careful when using the terminology weak and strong ties. Throughout the literature on networks and the literature on knowledge exchange a weak tie does not follow the definition of Granovetter. Notably we find the definition of Hansen (1999) for whom a weak link between firms is a unidirectional link between firms while a strong link is a bidirectional link. With this definition he found that weak links speed up projects in which knowledge has a low complexity while strong links sped up projects in which knowledge was complex.

Empirical evidence on the importance of structural holes does however exist in the literature on inter-firm networks. Ahuja (2000) found a negative influence of diversification on firm performance (measured by patent count) while Cohen, Levin (1989) found a positive influence. An analysis adjusting for the strength of the ties could here be of use. It is possible that the reason why redundancy in Ahuja's case does not have a positive effect comes simply from the fact that firms have weak ties and hence norms have not emerged yet.

Another explanation might reside in the fact that one has to distinguish between social links and formal links between organizations, as I have shown, the transfers are not the same when one considers a social link or an alliance and hence the influence on the performance of the firm will be different.
Shan et al. (1994) show that in the case of start-ups social capital is a better predictor of cooperation, they theorize that structural holes are efficient in the case of market transactions since there is no need for extensive cooperation over time. In contrast, by analyzing on the level of the individual, Burt (2004) find by the means of interviews with managers that there is a correlation between the brokerage position of managers and their productivity in terms of coming up with good ideas. Promotions and compensation were disproportionally given to managers that found themselves in a brokerage position in the network.

Overall the theory on strong and weak ties teaches us the importance of redundancy in the innovation process. It enhances the ability to cooperate by the creation of norms between firms while at the same time reducing the efficiency of new innovations by the reduction of diversity. This then shows the importance of structural holes. When we try to connect this theory to standard network theory (in the mathematical sense) we find that the problems surrounding redundancy are similar to the concept of clustering. The clustering of a graph is indeed the propensity of a graph to have triangles. The higher the clustering of a graph the more triangles, the higher the redundancy. The clustering coefficient of a graph can hence be interpreted in terms of redundancy or in terms of norm emergence.

The influence of structural holes on the performance of the network as a whole is however not clear. However, brokerage positions have shown to be beneficial for agents. They appear to be able to exploit their favorable position.

5.2.4 Overembeddedness

The existence of structural holes shows us the risk of their absence and the negative effects that this absence might have on firms' performance. Firms might become too embedded in their network which puts them in a position far away from new sources of information.
Consider for instance figure 3. The network is somewhat stereotypical, but is serves as a good example. Firm A is in a very central position in the network, the disadvantage of this position is that it is 5 links away from any new knowledge, moreover that knowledge will be recombined by knowledge it has in common with other firms reducing it efficiency in terms of diversity. A firm in such a position can be caught in a network lock-in meaning that it will not be able to find new partners to work with and will hence always work with the same firms which will result in a convergence of technologies used and reduce the efficiency of the innovation process of the firm significantly.

The question that is then raised is what structure is more efficient for knowledge transfer ? Different authors seek an answer either with a theoretical model or with a empirical analysis.
Empirically Innovation networks seem to be locally clustered (Geenhuizen, 2008; Valk van der et al., 2011), Asymmetric and sparse. Different canonical network structure have also been identified empirically: Small worlds and scale-free networks. Based on these empirical observations, models of knowledge diffusion have tested the efficiency of both the network characteristics and network structure. Small worlds are identified as the most efficient structure, both empirically and theoretically (Cowan, Jonard, 2007; Verspagen, Duysters, 2004; Gulati et al., 2012; Alghamdi et al., 2012). This observation can be explained by the fact that a small world structure is defined by a low average distance and a high clustering coefficient. The combination of

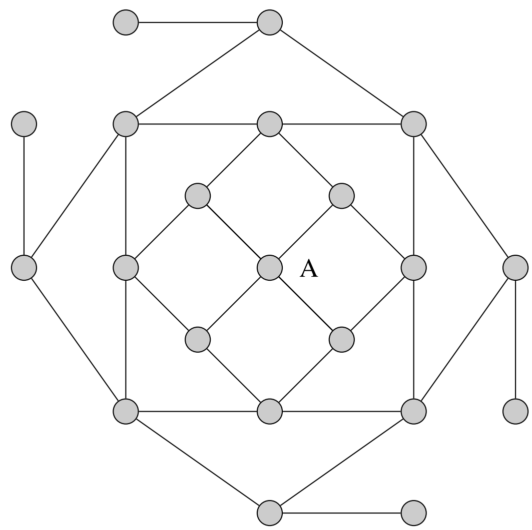

Figure 3: Embeddedness illustration

these two characteristics leads to a fast diffusion throughout the network.
The latter is however contrasted by a paper using a more complex method for the identification of optimal network structure. Using a genetic algorithm Carayol et al. (2008) find intermediary network structures to be more efficient.
When it comes to theoretical models studying the inception of networks, other structures are found to be optimal. Based on a cost-benefit analysis to link creation the first models (Goyal, Moraga-Gonzalez, 2001; Jackson, Wolinsky, 1996; Jackson, 2005) resulted in an equilibrium analysis with three possible solutions; empty network, star network or complete network depending on the cost of a link.
In most of these models firms select their partners at random. In reality however, the selection procedure can include different and more complex factors.

5.2.5 Partner selection

The structure of empirical networks are the result of strategic decisions made by firms and research institutions. The motivations of a firm or RI to collaborate with a specific firm or RI can possibly be explained by different factors. I exclude here projects that are financed by a government agency. In the latter case some agents might be included purely for reasons that are included in the contract and hence not the result of strategic decisions on the part of firms or RIs.

The most notable factors are:

- Social proximity (includes trust): starting a cooperation with a firm with whom one has not yet collaborated involves a high risk factor. First, the quality of the potential partner might not meet expectations. Second, on a social level, the employees that will be in contact with each-other might not get along well. And finally other firms might have different routines, converging to commun understanding might take time. For these reasons firms can prefer working with historic collaborators, reducing the risk of a failure.

- Technological proximity (Cognitive proximity): innovations are based on the recombination of technologies. The technological distance between firms place a vital role in the decision to collaborate. When this distance is too far apart firms will not be able to understand each-other and hence the recombination of technologies is inefficient. The relation between technological proximity and probability to collaborate has an inverted U-shape.
- Geographical proximity: In addition to being a possible condition in research contracts, geographical proximity has advantages for cultural and cost reasons. International collaborations can prove to be difficult because of cultural differences including work ethics and different practices. In addition, having one's collaborators close by allows for more frequent interactions and improve social proximity.
- Fitness / performance: When the previous factors are not leading to a decision, an agent would look at the performance of a potential collaborator. Technologically lagging firms can present a risk for the outcome of the R&D process. In the case of bankruptcy the R&D efforts would be lost.

The decision making process of a firm takes into account several of these factors. Which factor overrules another might depend simply on the project (and its aim) at hand. The efficiency with which knowledge flows through the network does depend heavily on the selected partners. When collaborators are chosen poorly, absorptive capacity as well as sending capacity might act as an obstacle to the flow of knowledge. Repeating collaborations with the same firms increases trust and the convergence of working methods, however this has the downside of reducing knowledge diversity for the network.
Despite the fact that firms are mainly not aware of their position inside innovation networks (or even social networks for that matter), their collaboration decisions alter the structure of the network in which they evolve. This is one of the manners in which the firms can themselves impact the network. Networks can have a stable structure if social interactions have a high impact on partner choice. The inherent risk factor can push firms to continue collaborating with historic partners rather than new ones (Gulati, 1995) . Trust hence place a vital role in the determination of the structure of the network (Ahlström-Söderling, 2003; Schrader, 1991). When interactions are repeated the cost of link maintenance can decrease while increasing the level of trust between firms. Human, Provan (1997) show that the structure of a network will not be the same when trust (or historic partners) or absent. The duration of these interaction does however not play an important role in terms of knowledge transfer Schrader (1991).

6 Conclusion

Networks emerge by strategic decisions of firms. Cooperations influence the innovative ability of the firms at every stage of the R&D process by the transfer of knowledge and information. Different channels allow for the transfer of different types of knowledge and information. The transfer of reputation allows for the selection of the optimal partner. The latter allows for increased knowledge flow and efficiency in terms of collaboration. In this sense the firm shapes the network. Efficient networks, measured theoretically, can take a large variety of forms and depend upon the definition of efficiency. In terms of knowledge diffusion the small world structure appears to be most efficient while in terms of profit the structure is ambiguous. These results are however based on models that do not fully take into account all the accelerators and obstacles to knowledge diffusion. It could then be possible that there is no such thing as an efficient network structure. The efficiency of a network is largely dependent upon the specific position of certain firms inside the network. Identical structures with differently positioned firms can behave differently. Of course, it might be that firms with better positions reached their position because they were more efficient to start with. The efficiency of

the network and its ability to survive hence depends upon the ability of the firms to learn from one another and on their ability to make optimal partner choices (by avoiding social lock-ins) to avoid the diversity of technology to run out. Context is of paramount importance when studying a network. The vast majority of network analyses oversimplify the complexity of networks and hence are unable to extract all the relevant information included in a network. A network is more than a simple aggregation of bilateral cooperations and this should be reflected in any conducted analysis. The firms, as a part of the network, are influenced by it, a symbiosis exists between the network and the agents that compose it.
The analysis of this symbiosis starts with an understanding of the dynamics of link creation. The decisions that brings a firm to collaborate with another specific firm shapes the network and informs us about the manner in which innovation is achieved. The decisions made by firms result in a particular position inside the network that could favor or hinder the performance of the firm.

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