Networks of Knowledge:

An Appraisal of Research Themes, Findings and Implications

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Abstract

This chapter presents an overview and appraisal of the literature on knowledge networks. The analysis is carried out by taking into account three ways in which network approach is undertaken in the literature. In the first one, the network topology is used to describe, analyse, or understand the evolution of certain knowledge domain, where the focus is not on revealing a causality mechanism. In the second one, the network position is taken as a possible cause to explain a certain outcome. The third one focuses on the formation and evolution of networks. These ways of taking networks are largely complementary to each other, and sometimes overlapping, forming an interdisciplinary context where economics, management, sociology and physics meet. The chapter addresses these three domains by taking into account the theoretical and methodological challenges which are deemed to be most critical in network research, including the problem of endogeneity, tie definitions and data sources, and the discussions around structure and agency. Based on the review, the paper points out several weaknesses of existing literature on knowledge networks. The chapter suggests some future research areas that might be valuable in resolving these weaknesses.

Introduction

A network is essentially a way of seeing relationships in a system. In the social sciences, the network approach is undertaken to explain how the social structure shapes individual behaviours and performance. The rise of the network approach can be linked to an increasing interest on open systems in many fields of science during the last half a century. Open systems emphasize interrelations between parts of a system (Scott and Davis, 2007).

It is possible to trace the roots of the network approach in sociology to Moreno (1934) who first used a sociometric configuration, and Simmel's sociological theory (Simmel, 1950). [1]More recently, the understanding that economic action is embedded in a social context (Granovetter, 1985) has been embraced by an increasing number of subfields in the social sciences. This embeddedness can be represented in different network configurations, and can deepen our understanding about the relation between social connections, and behavior and performance (Powell and Smith Doerr, 2005). Knowledge networks are particularly important in this context; the patterns of knowledge and information flow between people are important for behavior and performance. Consider the role of contacts in knowing about opportunities, or diffusion of an idea, or innovation diffusion through social contagion.

During the recent decades industries are increasingly composed of firms who form alliances with each other; universities are becoming more connected through collaborating scientists, and civil societies are becoming more integrated through NGO networks. Firms are giving more and more attention to the social networks between inventors, and the role of intra-firm communities in fostering creativity is frequently emphasized. Moreover, immense improvements in information and communication technologies have also contributed to increased networking between actors, as well as our capabilities to analyse them. In short, networks have become the main means

[1] See Freeman (2004) for the history of the field.

through which public and private knowledge is generated and diffused in the economy at various levels.

Networks both store knowledge, and also diffuse this knowledge. They provide a context in which learning takes place, and depending on their structure, they shape organizational routines that enable (or constrain) knowledge creation. For example, dense networks are efficient in diffusing tacit knowledge as shown empirically in many studies. Networks formed of diverse actors and bridging / brokerage positions are usually associated with novelty and creativity.

In the organization of this chapter, I prioritized the current debates in social network research, so as to highlight those areas which most merit contributions in the future. For this purpose, I categorized the studies according to the following:

1. Network as a knowledge map, network as a cause, network (or tie) as a consequence

2. Secondary network data (archival) and primary network data use

3. Inter personal and inter organizational network

Each of these categories has some implication for the debates in social network research. Consider an example: there is a debate on the structure and agency problem, claiming that network research leaves little space for understanding individual action, since success or failure is explained only through the social structure (Emirbayer and Goodwin, 2004). This debate underlines the importance of studies exploring the role of individual in network evolution, presented in section 5: network as a consequence. Nonetheless, not all studies on network evolution necessarily explain the role of the individual action; data constraints can present important barriers, especially the use of archival data, which is largely ex-post and highly aggregated. Considering similar constraints, the survey is further divided into secondary network data and primary network data, because they contribute to the literature in different ways. In addition, the distinction between inter-organizational and inter-personal is significant, especially in the following sense: it is possible to collect data on an interpersonal network through surveys and interviews. Then the researcher has access to both the structure of the network (if sufficient number of interviews are made), and also the qualitative aspects of ties between people (emotional intensity, frequency of meetings, affection, dislike, etc.). This permits understanding links between the structural and the relational. Are bridging positions characterized by ties that "coordinate" the knowledge of people, for example (Obstfeld, 2005)? At the inter-organizational level, this is more of a challenge, in terms of data constraints. Qualitative aspects of ties are inferred, or assumed, by large-scale data. For example, the number of times that two inventors have published a paper together is usually taken to imply that they have a strong tie. There is in general no problem with such assumptions, as long as the research questions are designed accordingly. Nonetheless, when the theoretical framing of the study lies in social psychological theories, such inferences may risk undermining the precise mechanisms and causalities in relations.

Overall, such a categorization of research permits to see how studies are distributed among the three levels above, and highlights the following observations. First, the nature of questions addressed largely depends on the sources of data. Among others, one of the implications of this is to put a divide between the precision in measuring the structural network positions, which is easier with large scale data (especially for inter organizational networks) and qualitative aspects of ties, which is more readily collected through interviews.

Secondly, and largely as a result of abundant and accessible large scale data sources (like patents), some questions are over studied, leaving other, and possibly more problematic areas under studied. Third, there is a gap between analytical models on one hand, and empirical ones on the other. The analytical results obtained through simulation studies, and models are not reflected in empirical research for more rigorous testing. Fourth, measuring networks in a certain way reflects certain assumptions about how knowledge is taken by the analyst. More studies are needed to establish the links between the epistemological assumptions regarding knowledge, and how it is reflected in network studies. This link should be better understood so as to avoid misalignments between the results of network research, and its contribution to theories of knowledge.

The chapter is organized as follows. In the second section I focus on some important debates in the social network research area. In the third section I focus on knowledge network maps. The fourth section reviews studies that take the network as a cause. The fifth section takes network (or ties) as a consequence. The sixth section presents an overview of simulation models. Some concluding remarks and directions for future research follow.

2. Knowledge Networks: Definitions, Scope and Positioning in Network Literature in General

What is a knowledge network? It is difficult to find a unique definition in the literature. One of the reasons behind this difficulty is that networks are *constructed* by analysts, being largely shaped by their own perception of what knowledge constitutes. Nevertheless, a working definition is relevant in a survey article, to clarify the scope of studies covered. In this survey, a knowledge network refers to a structural representation of relationships between individuals, organizations, or artifacts, where these relationships have implications for the way in which our understanding about how knowledge is shared and disseminated (or blocked and retained), its institutional social and cultural context, its nature, cumulativeness, evolution, and its role in innovation is deepened. As such, knowledge networks are closely related with social networks. The social realm is about communications and influences between people, and it is through these that knowledge flows.

I focus on four areas of debate in network research, and review knowledge networks from the lens of these debates. These issues are not exhaustive, for further elaboration, excellent resources exist on social network research referring to recent issues (examples are Kadushin, 2012; Borgatti et al., 2013 ; Scott and Carrington, 2011). These areas are concerned with theoretical, epistemological and methodological considerations most frequently mentioned in knowledge network research, and they are presented in Table 1. Some of them point to some issues that are most problematic, and/or understudied in the literature.

Table 1: Theoretical and methodological issues in network research

Research axis	**Explanation**	**Implications**
Boundaries of research	Does the study utilize social network analysis as a methodology, or as a theory?	Implications for the disciplinary field of contribution.
Causality	Network as a source of (or reason behind) behavior /performance of an organization or individual, or,	Implications for the problem of endogeneity in network research.

	Network as the result of a process, an attribute or a previous state of network.	
The role of agency	To what extent can network formation be explained by the deliberate actions of the actors which constitute it, by foreseeing the broader network picture?	Implications for role of structure – agency, strategy and policy
Tie definition	Is the network constructed by using secondary data sources, or through direct interactions with individuals who constitute it?	Implications for research questions addressed.

2.1 Boundaries of Research

Is the network research paradigm predominantly a methodology or a theory? (Barnes, 1979). While the social network analysis methodology (SNA) is common in addressing a wide range of questions in various disciplines, only some of these have a direct impact on the field of social network theory itself. But then, what do we mean by "social network theory"?[2]

Kilduff et al. (2006), define the four core concepts of the network research program, from a Lakatosian perspective (Lakatos, 1970). The first one refers to the primacy of relations, where the focus is "away from the individualist, essentialist, and atomistic explanations, towards more relational, contextual and systematic understandings" (Borgatti and Foster, 2003: p. 992). In other words, the network research program prioritizes relations between actors as a main force behind change and economic action. The second is the "ubiquity of embeddedness", where economic action is taken to be embedded in interpersonal relationships and a social context (Granovetter, 1985). The third core concept is taken to be, the social utility of connections, which refers to the economic well being conferred (or the opposite) by network relations. Finally the fourth core concept is "structural patterning of social life", where the apparent complexity of social life can be explained in terms of relationship *patterns*. They state that the hard core of network research program is largely level free, as it applies to individual as well as organizational networks. In addition, they state that in network research, irrespective of the unit of analysis, it is the *structure* of relations that should be the focus of organizational research program.

[2] Borgatti and Halgin (2011) distinguish between social network theory and theory of social networks. The former refers to the impact of social network structure on behavior or performance, the latter refers to the formation and evolution dynamics of networks.

In other words, “studies that fail to incorporate structural thinking and analysis are outside the boundaries of network research, even though the term network can be used” (Kilduff et al., 2006). One of the essential features of network perspective is its rejection of “all attempts to explain human behavior or social processes solely in terms of the categorical attributes of actors, whether individual or collective” (Emirbayer and Goodwin, 1998, p. 1414).

In the literature on knowledge networks, it is not uncommon to find studies that take the network as a mathematical object to illustrate, describe, or analyse a knowledge domain and its evolution. In these studies, the use of archival data, like patent documents and publications are common, which gives the possibility to trace the long term developments in a particular knowledge domain, through constructing networks of citations, co-authorship, or through key word analysis. Most of the times, it is *not* the network itself which is the main subject of analysis as a cause, or a consequence, but rather the network representation is used to describe, evaluate, or understand the nature (or the evolution) of a particular knowledge system. Although these studies utilize social network analysis, their scientific impact is more on science and technology studies, rather than social network theories. This distinction is highlighted between the studies in section 3, which use network analysis as a methodology.

2.2 Direction of Causality

Is the network the cause, or is it a consequence? In this review, sections 4 and 5 distinguish between these two broad questions. In the former, the network itself, or the positions of actors in the network is associated with performance, behavior, or attributes of actors that constitute it. These studies imply some sort of consequence that is conferred by a certain network position. These relations, especially when they are inferred by using large-scale data, point to correlations between positions and performance, rather than direct impact. The latter on the other hand, explores the mechanisms that give rise to networks. In other words, they are concerned with how and why certain network positions come to be occupied by certain actors, and how a certain network structure emerges. Borgatti and Halgin (2011) call these two broad fields of inquiry as *network theory*, and *theory of networks*, respectively. These are covered, respectively, in fourth and fifth sections of the survey.

It is important to note that network theory and theory of networks are not always easily separable. For example, one of the most famous, and an initial study on intra-organizational knowledge flows in an R&D organization, carried out by Cohen and Allen (1969) analyse both the attributes of inventors who occupy central positions in the network, as well as the impact of such positions on the occupants. In addition, most of agent-based simulation studies take network evolution as a dynamic and continuous process, through which agents learn and adapt to changing network environment, which further modifies their network positions (Ozman, 2008), modeling a feedback mechanism between individual and the network. Other empirical studies in this nature are rather rare in the literature on knowledge networks (see for example, Stam, 2010 and Zaheer and Soda 2009).

This causality issue lies at the root of the endogeneity problem in network research. Endogeneity problem refers to the problematic nature of correctly predicting the effect of a network, without investigating how the network got there (Borgatti and Haldin, 2011). To put it differently, those factors which are seen as causing the outcome can themselves be dependent on the outcome.

Endogeneity problem in network research highlights the potential value of studies which examine the dynamics of networks. However, a word of caution here: not all studies which focus on network dynamics necessarily explain network evolution. As Doreian and Stokman (1997) point out, *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.

During the recent years there has been an increase in the studies on network evolution. In general, three mechanisms are usually referred to explain change. The first one explains the evolution of the knowledge network by the state of the network in the previous periods[3], emphasizing path dependent processes behind network formation. The second one explains network evolution through common dyadic attributes of network members, being mostly a measure of proximity; geographical, cognitive, technological, organizational, ethnical, gender, etc. These studies are rooted in Festinger's (1964) social comparison theories which underline the importance of

[3] See for example the "rich get richer" phenomenon which underlies preferential attachment mechanism (Barabasi and Albert, 2000).

social comparisons between people as the main driver of connections. The third approach highlights the role of individual attributes in explaining the network positions that they occupy. Examples are, self monitoring behavior (Sosavova et al., 2010) or scientific success (Lou et al., 2009).

Finally, while these studies may explain network evolution through an *understood mechanism*, this does not mean that they highlight the role of deliberate action (or strategy) of actors in shaping their network positions, giving their decisions initially by overseeing the broader network picture. This question brings forth the third debate in network research. To what extent do actors intentionally manipulate network structure? This dimension is explored in the next subsection.

2.3. Structure, Agency and Networks

Historically, network analysis was borne as a reaction to the individualistic explanation of social systems which dominated the methodology of sociology in 1950s. As explained by Coleman in this period (cited in Emirbayer and Goodwin, 1998, p. 1416):

> "There were no comparable tools of development for analysis of the behavior of interacting systems of individuals or for capturing the interdependencies of individual actions as they combine to produce a system level outcome. The far greater complexity required of tools for these purposes constituted a serious impediment to their development.... The end result [was] extraordinarily elaborated methods for analysis of the behavior of a set of independent entities (most often individuals) with little development of methods for characterizing systemic action resulting in the interdependent actions of members of the system (Coleman, 1986 p; 1316)"

While the essence of the network approach underlined the effect of relationship structures on performance or behavior of actors, later on, it was precisely this aspect of networks that received criticisms. In particular, some authors have criticized structure-oriented explanations, questioning the lack of individual action to guide network evolution or the manipulation of specific positions by individuals who make up the network (Emirbayer and Goodwin, 1998). Consequently, network research, they claim, leaves little space for individual action.

One of the areas which is yet to be developed further in network research is concerned with understanding the deliberate and strategic manipulations of networks by actors who constitute them (Baum and Rowley, 2008). Yet, the literature is developing only slowly in this area (see for example, the works by Baum et al., 2005 and Dantas and Bell, 2009, and for a focus on network strategy Baum and Rowley, 2008). Most likely reason is that organizations rarely have deliberate network strategies, and most network strategy is emergent in nature (cf. deliberate and emergent strategies by Mintzberg()). Therefore there is a need in the literature to fill this gap by taking an emergent strategy perspective in understanding what factors contribute to organizational decision making mechanisms in organizations' occupying certain network positions.

One of the difficulties involved in analyzing the role of deliberate actions of individuals is about collecting network data. The use of archival data, and also large alliance databases which are commonly used to analyse knowledge networks, hardly permit fine grained information on the specific mechanisms through which actors make decisions. There is too much aggregation, which runs the risk of imprecise generalizations ex-post. For this purpose, surveys, detailed interviews, and long term anthropological studies in the field of interest are necessary, to pinpoint clearer causality mechanisms.

The issues of network data and the boundary specification problem are explored in the next part, as the fourth dimension of network research.

2.4. Knowledge Networks, Boundary Specification and Data Gathering

In this section, I focus on two related issues in network studies; the boundary specification problem, and network data collection.

Boundary specification is concerned with specifying the limits of network data to be collected. To illustrate the significance of this issue in network research, one can imagine how the overall network analysis would be rendered meaningless, if only one actor (who forms a bridge, for example) is omitted from the network, which would result in a significantly different network topology. Boundary specification problem is a challenging one, since one can take networks to be endless, unless the limits to inclusion are set by the analyst, or the network members themselves. Laumann et al. (1983) distinguish between realist and nominalist approaches to boundary specification. In the realist approach, "the network is treated as a social fact only in that it is consciously experienced as such by the actors composing it" (Laumann et al., p21). In the nominalist approach, on the other hand, the analyst "self consciously imposes a conceptual framework constructed to serve his own analytic purposes" (ibid, p 21-22). As such, most of the knowledge network literature, in the economics and management disciplines, adopts a nominalist approach. [4]

Boundary specification problem is also related with the kind network data to be used. In the case of secondary network data from archival resources the limits of data depend on either availability of data or the conceptual interest of the researcher. For example if one studies the evolution of technology for LEDs (light emitting diodes) only the patent classes related with this technology can be included, but this would miss the underlying knowledge which LEDs draw upon, and also the fields which it influences. Therefore if the researcher were analyzing knowledge flows, she would include the forward and backward citations of these patents to obtain a network. At which level to stop, depends on the analyst and the aim. If the researcher is interested in knowledge diffusion in an R&D lab, network data on the engineers who are part of the lab can be focused upon. But, considering the importance of boundary spanners who carry information from the external to the internal (or vice versa) , possibly their external links should be collected as well, especially if the sources of knowledge flows is analysed. Therefore it is extremely important to have clear and objective criteria to set the limits of network data, especially in knowledge networks considering the highly fluid nature of knowledge.

The second issue is related with the network data. Theories of knowledge are based on two alternative conceptualizations of knowledge. In the first one, knowledge is regarded as an "objective" entity. According to objectivists, knowledge can exist outside the individual, by being embedded in an artifact, for example, or flowing between people and organizations. Accordingly knowledge can be in tacit, or explicit form, which implies that it can be fully, or partially transferred between actors. This implies that knowledge can be taken separately from the actors who create diffuse, or

[4] I refer the reader to sources such as Carrington, Scott and Wasserman (2005), Knoke and Yang (2008) for further reading about these problems.

process it (Hislop, 2013). The practice based approach to knowledge, on the other hand, emphasizes that knowledge is not unique and it is not independent of interpretations; people have different understandings of it, depending on the context, language, or history, culture. In other words, according to the practice based approach, knowledge is not either "tacit or codified", contrarily, it is both "tacit and codified" (Hislop, 2013) .

This distinction is important as far as researchers define and measure ties in a knowledge network. An objectivist perception of knowledge manifests itself clearly when knowledge is assumed to be embodied in a network of artifacts, for example in using bibliometric data, or when it is assumed to flow between actors during an event (like an alliance between two firms). The use of secondary data in studying knowledge networks separates the context within which knowing takes place, and the tangible events and artifacts which accompany the process of knowing by actors. For example, by analysing the network of artifacts a social tie is *assumed* between actors who create knowledge, although this tie may not be properly defined as a "social tie", but a "proxy for unobserved social ties" (Borgatti and Haldin 2010).

In addition to the risk of missing important actors in knowledge diffusion who are not included in secondary network data, there is also the risk of omitting multiple relations between the same actors (like geographical proximity, and friendship at the same time). [5] Moreover, studies show that there are systematic biases in network perceptions (Kilduff and Krackhardt, 2008), which can prevent the extent to which we can compare, and harmonize studies based on bibliometric data, and survey based studies. It should be noted that some of the problems of secondary data sources are valid as well for primary data collection techniques, especially if some crucial actors do not participate in a field survey (Knoke and Yang, 2008) or are excluded by the researcher. Considering such impacts of data sources, in this review, each section is subdivided according to data sources.

Although the detailed and long-term observations of members of the network is more suitable to address majority of these problems, such anthropological studies on networks are relatively less in economics and management studies. [6]

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[5] See Ter Wal and Boschma (2009) for a detailed survey of social networks in economic geography, where they discuss the advantages and disadvantages of the use of patent data.

[6] An excellent exception is Barley (1990).

2.5. Overview

Table 2 provides a summary of the above debates, and the categorization used in this chapter. Few notes about the rules of inclusion in the study are useful. Unless necessary, the studies since 2005 are covered. In addition, those studies which incorporate network structure explicitly into their analysis are included. Therefore, the review excludes literature on management of dyadic ties (as in alliances), and those that take the network as essentially a group (or agglomeration) of actors, without an emphasis of structure. Studies that take knowledge as the essential feature of the network are included. The principal aim of the survey is to present a “bird’s eye view” of research on knowledge networks. In this sense, the survey is broad in its inclusion of various perspectives rather than being deep and detailed in a particular one. Finally, the research on networks has become a very intensively studied research field and the studies included are obviously far from being exhaustive.

Section of the survey	Implications for theory	Data and Questions/themes commonly addressed
3. Network as a mathematical object	• Impact predominantly on science and technology studies.	• Evolution of a knowledge domain, critical patents in knowledge flow maps, impact of and source of knowledge flows, comparison of networks in different industries
4. Network as a Cause	• Problem of endogeneity	Analyzes the impact of a network position on performance and / or behavior of actors
4.1. Secondary Data	• The risk of omission of important actors in knowledge networks • Objectivist notion of knowledge, higher risk of omitting the context of knowing by distancing the context and artifact • When networks of individuals are derived from network of artifacts (or events), issues like clustering can arise (Lissoni et al., 2013)	• Inventor networks derived from patents (2-mode data) • Strategic alliance networks • Under which conditions do brokerage, centrality, and cohesion influence performance? • What are the moderating factors? (emphasis on past performance, individual attributes, exploration / exploitation, environmental change, strategy, absorptive capacity, heterogeneity).
4.2. Field Research	• Increased opportunity to take into account actor perceptions in networks • More opportunities for collecting fine grained information, and multiple relations • Risk of non participation of important actors • Limited in its capacity for long-term observations, generalizations, static analysis.	• What is the nature of ties that bridging actors form? • How does network position and information seeking relate in an organization?
5. Network as the Consequence	• Potential to explain the role of intentional manipulation of networks by network members	
5.1. Secondary Data	• The risk of omission of important actors and events which derive network change in knowledge networks	• How do patent citation networks evolve? • How do brokers emerge? Emphasis on past performance and past network structure, proximity • What governs overall evolution of networks in different industries?
5.2. Field Research	• Contributions in terms of addressing the agency problem, since field research permits a fine grained analysis of individual / organizational strategy (more so than databases) and additional knowledge that may be difficult to infer by large scale data • More possibility to take into account actor perceptions in	• How do brokers emerge? Emphasis on personal traits that are hard to capture with large databases (self monitoring, close friendship, social status). How does proximity influence tie formation between organizations? How does past cohesion influence tie formation?

	networks	
6. Simulation studies	• Permits analyzing co-evolution of networks with actors which constitute them, critical issue of empirical validity	• A wide range of questions on network dynamics and their effects

3. Knowledge Mapping

The network approach to study collaborative relations in science and technology has been increasingly used since 70s, with a shift of emphasis from "scientific maps" to "networks", which permit long term and detailed analysis of the development of fields (Maggioni et al., 2013). One of the areas in which the network perspective has been very fruitful, is in the analysis of knowledge flows in a geographical context (Breschi and Lissoni, 2009)[7].

The studies covered in this section -by no means exhaustive- take the network as an instrument, which represents relations between entities in a knowledge, technology or scientific domain, so as to address questions related with its nature and evolution. In this sense, the questions posed are not concerned with networks per se.

The field of medicine is one of the areas which have been studied widely in network studies. Barbera et al. (2011) utilize patents in artificial spinal disc and present evidence that patent connectivity analysis (see below) is a promising methodology to study the evolution of science. For example, Mina et al (2007) show the emergence, growth and transformation of medical knowledge in coronary artery diseases, through network representations of patent citations and complementary interviews. They present evidence of the uneven, uncertain and often diverging evolution of knowledge domains. Consoli and Ramlogan (2007) carry out a similar study of glaucoma, investigating the evolution of medical knowledge by analysing scientific publications.

Science and technology studies, social sciences and innovation are other domains which have been studied intensively by using network analysis. Dolfsma and Leydesdorff (2010) analyse the positioning of the Journal of Evolutionary Economics and the interdisciplinary knowledge that it produces using citation network analysis. Bhupatiraju et al. (2012) analyse three fields by using social network analysis; they find a cumulative nature of knowledge evolution in science and technology studies, whereas a shift to business oriented research in innovation. In addition, they detect that the three fields have developed in relative isolation from each other, rarely citing each other, with weak links between them.

[7] see Maggioni and Uberti (2011) and Ter wal and Boschma (2009) for a review of this field).

Gossart and Ozman (2009) analyse the national and international co-authorship networks in Turkey, and present evidence of segregation among researchers, which inhibit diffusion of knowledge.

In the field of telecommunications, Martinelli (2012) uses patent connectivity analysis to designate the paradigmatic changes in technology in telecommunications switching, from a historical perspective. Connectivity analysis is used to generate knowledge flow maps, which are utilized to see the evolution of a knowledge base (Hummon and Doreian, 1989), by revealing patents which are deemed to be key in the future evolution of the technology (cf. Barbera et al., 2011). Ter Wal (2013) analyses the evolution of networks in life sciences and information technology in Sophia Antipolis through a patent based network analysis.

Another domain of interest has been environmental technologies. Verspagen (2007) uses patent connectivity analysis to explore the evolution of knowledge in fuel cells. Corrocher et al. (2012) reveal the evolution of the knowledge bases of green ICTs, by considering the actors involved in their development, as well as the persistence and cumulativeness of underlying knowledge.

Network analysis has also been used to compare different industries in terms of their networks, and how the structure of networks relate to the industries' scientific and knowledge bases. For example, Rosenkopf and Schilling (2007) explain the differences in network structure between industries, with respect to modularity and uncertainty characterizing industries. Cantner et al. (2010), for the case of three innovation regions in Germany highlight the association between knowledge base and network structure, underlining that broad knowledge bases are associated with fragmented networks. In a similar vein Broeker and Boschma (2011), by utilizing survey data, compare the differences between aviation and space industry knowledge networks, underlining that, although the technological bases are similar, there are marked differences in networks of market knowledge between the two industries. Cassi et al. (2012) analyse the differences between the old world and the new world wine producers in terms of the structural closeness between trade networks and scientific collaboration networks. They find that the association between the two is not strong for the case of new world wine producers.

Most of these studies do not directly aim at uncovering a causal mechanism between networks and knowledge domains. In the next section the focus is on those studies in which the network is the independent variable.

4. Network as a Cause: Implications for Knowledge

In this line of inquiry, it is the structural position of the actor in the knowledge network that is presumed to influence his/her performance or behaviour. The studies in this section are categorized into two, depending on the nature of network data used. In the first section, the networks are constructed through using secondary network data sources. For example, in some cases participation to an event, like an alliance, reveals a relationship between two actors. In a similar way, a relationship between two actors can be inferred by analyzing joint scientific publications or patents, or else, by analysing citations. In the second section, the focus is on studies in which surveys or questionnaires for network construction are used. In both sections, a distinction is made between inter personal and inter organizational networks.

One of the most fruitful areas in this field of research is rooted in the well known debate on network cohesion and structural holes (Burt, 1992). Briefly, the debate is concerned with what type of network structure is a better source of social capital for an actor. Network cohesion stresses the positive performance impacts of dense and clustered networks (Coleman 1988), arguing that interactions which are accompanied with intensive exchange of knowledge, which are frequent and face to face, helps to build trust among the parties, so that concerns for reputation mitigate possible opportunistic behavior. Such dense networks, in which an actor's partners are themselves connected, are characterized mostly by redundant knowledge flowing in the network, yet they facilitate transfer of tacit knowledge since a common language is developed among the actors, which increases efficiency in terms of time and costs of negotiation (Uzzi 1997).

On the other hand, proponents of structural holes argue that cohesive networks result in redundancy of knowledge exchange, since the same actors are linked through different intermediaries (Burt, 1992). As the proponents of non-redundant ties claim, actors should fill structural holes in the network, and act as "bridges" connecting otherwise disconnected alters (Burt, 1992). These ties are advantageous in terms of getting access to novel knowledge from diverse sources, thus beneficial for exploration purposes and when the knowledge being transferred is more codified (Rowley et al., 2000).

The debate between proponents of structural holes and cohesive networks has resulted in a very rich stream of research. Earlier on, some authors presented evidence of contingency on external environment (Rowley et al., 2000), and others suggested that these positions are not substitutes, but rather complementary and a hybrid of both positions is beneficial for performance (Uzzi, 1997). More recent research investigates in detail the contingent nature of this trade-off, highlighting the conditions under which, as well as the moderating factors, which shape the impact of brokerage positions on performance. More on this debate follows in the next sections drawing upon the latest developments in the field.

4.1. Networks from Secondary Data Sources

4.1.1. Inter-personal networks

In these studies an interpersonal network is usually derived from bibliometric data. For example, a joint patent between two inventors is taken as a link in the network. One of the most commonly addressed questions is related with the performance impacts of brokerage positions. Lissoni (2010) finds that, inventors occupying brokerage positions have usually a high number of publications and patents. Although brokerage is usually associated with novelty, and scientific success (Allen and Cohen, 1969), more recent studies examine the contexts in which this is so. Moderating factors are considered to be significant in most cases as far as the impact of brokerage is concerned.

Fleming et al. (2007a) use patent data and present evidence that while brokerage is beneficial for generating an idea, it is not well for its subsequent diffusion. In addition, the small world network structure, with high clustering and short path lengths due to brokerage positions in the network, are not found to be significantly associated with increased innovation (Fleming et al., 2007). According to Lee (2010), it is the actor level variables, like heterogeneity and past performance that moderates the relation between brokerage and performance. Controlling for past performance of inventors, which enhances brokerage positions, the positive effect of brokerage on performance reduces. Nerkar and Paruchiri (2005) look at the interaction between structural holes and centrality of inventors in determining the citations she receives from others. Paruchiri (2010) finds that the impact of intra-firm inventor centrality is moderated by the firm's centrality in the inter-firm network, as well as firm's span of structural holes. In addition, Soda et al. (2004), for the case of Italian TV production industry, find that it is the current structural holes, but past closure in networks which influence current performance.

Beaudry and Schiffauerova (2011) find that the effect of central inventors, and stars have a positive impact on patent quality and repeated ties has a negative impact for the case of Canadian nanotechnology inventor networks. For the case of Italian microelectronics sector, Balconi and Laboranti (2006) stress the importance of collaborations between universities and the industry, where they find that strong connections are associated with higher scientific performance and border-crossing relations are driven by cognitive proximity, face to face interactions and personal acquaintances. Stressing the role of knowledge diversity in innovation, Cecere and Ozman (2013) find that the impact of strong ties between inventors on technological diversity follows an inverted u-relationship. Cattani and Ferriani (2008) analyse the role of social networks in the individuals' ability for creative outcomes in joint movie production networks. They emphasize the importance of intermediate positions between the core and periphery of networks.

4.1.2. Inter-organizational networks

The most commonly used data sources are strategic alliance data (Schilling, 2008) and patent data for constructing networks. While direct effects of certain network positions (like centrality, brokerage, or repeated relations between firms) have been studied intensively, during the recent decade or so attention has shifted to unraveling contingency factors in this relationship.

Shipilov (2009) finds that the performance effect of structural holes depend on firms' capacity to absorb heterogeneous knowledge, bargaining power and ability to protect against non-cooperation, for the case of mergers and acquisitions. In another study (Shipilov and Li, 2008) the effect of structural holes is found to increase status accumulation, but to dampen market performance of firms. Yang et al. (2011) find that, joint brokerage and centrality of two firms moderates the relation between learning strategy of the firms, and their acquisitions. An exploration strategy is more likely to result in an acquisition, with the joint brokerage with the other firm strengthening this relation. For the case of steel industry, Koka and Prescott (2008) find that, performance effects of different network positions, as entrepreneurial and prominent, depend on environmental change, and the strategy of the firm. Strategy of the firm is also found to be a moderating variable between environmental change and network change (Koka et al. ,2008). Whittington, Owen-Smith and Powell (2009) find that the impact of centrality in the local network depends on firm's connections in the global network. Min and Mitsuhishi (2012) analyse the disappearance of brokerage positions, underlying that their persistence is not good for performance in the airlines industry.

While the use of secondary data can be useful for observing broad patterns, over long periods and involving a large number of actors, there are also potential disadvantages. Firstly, missing relations between actors can pose risks. The constructed knowledge network is confined to what is implied by the artifacts produced or events which analysts have access to, thus running the risk of undermining the social ties, communities and "silent designers" (Gorb and Dumas, 1997) in understanding the evolution of a knowledge system (see for example, the work by Meyer (2010) on airplane communities), which may not appear in the data. On these issues, Nelson (2009) explains the problems of using patent data, licenses and publications for the case of DNA recombinant technology. He underlines the importance of using multiple indicators, or complementary data sources. Despite these problems, Fleming et al. (2007) present evidence that co-invention patterns found on patent data do reveal technically close interactions between inventors.

A second possible problem is related to deriving "one-mode" data from "two-mode" data (Balconi et al, 2004; Borgatti et al., 2013). In this case, a direct relationship between inventors is assumed, which is derived from a network of patents. More precisely, if three inventor names appear on a patent document, ties between these inventors are constructed. One of the technical issues associated with this process can be an unusually high values of clustering, which will mathematically increase the possibility of observing, for example, a small world network (see Lissoni et al., 2013). Another possible problem that may arise with secondary data is to miss possible multiple relations between the same actors. In this case, the use of primary data is statistically more robust (Ter Wal and Boschma, 2009).

4.2. Networks constructed through surveys and interviews

This section reviews research where the network data is collected based on individual interviews and surveys. It is important to note that, as different from secondary data, surveys and questionnaires permit collecting more fine-grained information on the characteristics of the network, to reveal causality mechanisms. In fact we will see that the qualitative aspects of ties are particularly important to consider when knowledge transfer is concerned. Such qualitative aspects cannot be revealed by secondary data sources, as effectively as direct interviews.

4.2.1. Inter-personal networks

One of the initial studies on knowledge networks and communication inside organizations belongs to Allen and Cohen (1969). Their research was carried out in two R&D laboratories. In exploring how technical and scientific knowledge flows within and across the organizational boundaries, they highlighted the critical role of gatekeepers as those who maintain close relations with the outside sources of knowledge, and who are better acquainted with the technical and scientific literature.

More recent research focuses on information seeking in organizations. Borgatti and Cross (2003) address the determinants of probability of seeking information from another. They find that physical proximity and information seeking is mediated by knowing and valuing what the other person knows, as well as ability to access his/her thinking in a timely way. Singh et al. (2008) investigate the effect of network position on individual search behavior. People who are out group, because of social status, tenure, or centrality access people like themselves (homophily) and get further away from knowledge. Another study by Hansen et al. (2005) investigates how existing networks between teams and subsidiaries within a large organization, influence the perceived costs of knowledge seeking and transfer.

How do interpersonal networks influence innovation performance? Commonly, the advantages conferred by bridging ties are emphasized, in fostering creativity and innovation, and by enabling access to diversity. While bridging position is a structure-based measure, the qualitative aspects of the bridging ties are also important to understand knowledge transfer. For example, strong ties, as revealed by frequent meetings and emotional intensity, are commonly associated with the transfer of tacit knowledge (Smith et al, 2005), and bridging positions, while beneficial in terms of accessing diversity, can be insufficient when creative ideas are being put to practice (Obstfeld, 2005; Perry Smith, 2006, see also Fleming et al. (2007a) above for a similar result).

Obstfeld (2005) distinguishes between "tertius iungens" and "tertius gaudens" positions. His case study among the engineers in a large automotive manufacturing plant shows that, it is not tertius gaudens but tertius iungens which explains involvement in innovation. Tertius iungens refers to brokerage position that prioritizes coordination between the diverse actors connected to, rather than obtaining brokering advantages through "playing off" partners as in tertius gaudens (Burt, 1992). In a similar way, Tortoriello and Krackhardt (2010) find that bridging positions have no effect on innovation, unless they are Simmelian. Here a Simmelian tie is taken as a bridging position with ties to a common third party. These studies reveal that, mere bridging is not enough for innovative performance; successful bridging positions are usually accompanied by strong ties and coordination capabilities between diverse actors.

Smith et al. (2005) find that strong ties between members are critical in the knowledge creation capabilities of firms, and they find that the number of alters (network range) is not significant. They confirm these findings by studying the management teams and knowledge workers in 72 high tech companies. On the other hand, according to the findings of Perry Smith (2006) in a university research laboratory, strong ties are neutral, compared to the positive impact of weak ties on creativity. Gargiulo, Ertug and Galunic (2009), using data on investment bankers, find that the effects of network closure depend on whether the actor is a knowledge acquirer or a knowledge provider. For the case of managers, Moran (2005) finds that the impact of structural and relational embeddedness in a network depends on the type of task considered; while structural embeddedness is good for routine tasks, it is relational embeddedness which confers advantages when innovative and new tasks are considered. [8] Bjork and Magnusson (2009) find that more connected employees come up with more innovative ideas.

How is the existing local institutional context interwoven with the processes of knowing in a community? Studies in this nature are relatively lacking. An exception is the work by Arora (2012), who carries out a detailed network analysis of the adoption of agro ecological methods by farmers in India. He presents evidence of how the established knowledge networks reflecting hierarchical status of certain actors restricts the participation of farmers in knowledge circulation networks. Giuliani (2007) analyzes the difference between business networks and knowledge networks in wine clusters in Chile, finding that diffusion on the knowledge network is uneven, owing to the asymmetric knowledge bases between firms.

4.2.2. Organization Level

Few inter organizational network studies exist, which is based on primary data sources (normally, since one cannot survey organizations but people within organizations). One of the most famous case studies was made by Hargadon and Sutton (1997) about the design company IDEO. This work highlights how brokerage positions can bring competitive advantage, when firm uses the knowledge obtained for one case, to other, possibly unrelated design problems. They mention how being a broker company, which accesses a diverse range of industries, can facilitate such analogous thinking.

[8] Structural embeddedness emphasizes commonly known parties (and network position), while relational embeddedness emphasizes the qualitative aspects of a relationship.

In these studies, usually few alliance agreements of a firm are investigated in detail. McEvily and Marcus (2005) look at the qualitative features of ties between firms, and find that, it is joint problem solving activities, rather than trust, which explains the transfer of tacit knowledge. Molina Morales (2009) detects an inverted-u relation between the strength of ties between firms and their innovation performance, and Tiwana (2008) highlights the importance of complementarities between strong ties and bridging ties for knowledge integration. Vanhaverbeke et al (2009) find that the impact of partner redundancy on innovation depends on what type of innovation the firm aims, distinguishing between exploratory and exploitative innovations. In addition, network embeddedness is not only taken in relation to innovation; Echols and Tsai (2005) find that it moderates the relation between offering distinctive products and performance of the firm. Finally, surveys and questionnaires also permit observing the perception and interpretations of actors concerning their networks. Tsai, et al. (2011) analyse the role of the firms' network in shaping its perception of how rivals prioritize competitors.

One of the weaknesses of studies analyzing the impact of networks on performance or behavior is concerned with the endogeneity problem mentioned in the first section. In short, endogeneity problem becomes a concern when the factors seen as causing the outcome are in some part dependent on the outcome. For example, if the emergence of networks can be explained by the behavior or intentional actions of actors, can we say that it is the network structure which leads to benefit?

In the next section, we turn to studies in which the network position is taken as the consequence of a mechanism which the study aims to explain. The factors most commonly analysed are actor attributes, past network structure, and dyadic similarities (or proximity) between actors.

5. Network as a Consequence: Formation and Evolution

While in the earlier phases of network research, the attention has been predominantly on their performance effects, recent years have witnessed a surge of interest in how networks form and evolve. Before presenting a review of this literature, it is better to note that earlier social psychological theories has been largely influential in the development of this field, especially with regard to the question of how interpersonal networks form. Some social psychological theories have been "imported" to the network research program (Kilduff and Tsai, 2003) to address this question. For example, balance theory posits that individuals prefer balanced to unbalanced relations, and focus on two network mechanisms as transitivity and reciprocity (Heider, 1958). The transitivity argument refers to the preference of actors to make their acquaintances friends themselves. In other words, it refers to the preference of actors to form cliquish[9] network structures. Another widely adopted social psychological framework in the network theory is the social comparison theory (Festinger, 1964). It posits that social comparisons with similar others can have important behavioral and attitude effects. In the homophily argument, for example, people like to associate themselves with similar others. Consequently, a range of studies investigate how similarity or difference between actors influences the probability of a tie between them. This framework has been one of the most studied in network research, where similarity can be taken broadly, as proximity in one or more dimensions. However, a largely unresolved problem is related with the network autocorrelation: we tend to form ties with similar others, but at the same time, we become similar to our partners as relations proceed (see Steiglich et al. (2010) on this).

It is possible to distinguish between three mechanisms that are most commonly employed in the literature, to explain network formation and evolution. The first one is related with individual attributes. In short, can we distinguish individual or organization level factors that shape partner selection? The second one uses a dyadic measure of homophily between two actors, like their similarity/proximity. In this area, a wide range of similarity measures are used, like technological, cognitive, geographical, social or organizational proximity. Finally, the third one focuses on the overall structure of the past networks as shaping current ones, underlining a path dependent process at work. The second and the third approaches are largely similar, since a path dependent process implies that the network proximity of actors today influence their proximity in the future. The difference is important when we consider the level of analysis, the former focuses on dyads, and the latter on overall network structure.

In the first subsection, the focus is on the studies about the emergence and evolution of knowledge networks that are constructed through secondary data sources. While these studies are valuable in the sense of understanding the mechanisms behind network

[9] Cliquishness of a network measures the extent to which friends of an actor are friends themselves (as in closure).

evolution ex-post, explanation of tie formation through direct interviews about individual motives, or intentional actions is lacking in secondary data sources. The second section overviews these studies.

5.1. Network Formation and Evolution using Secondary Data Sources

5.1.1. Evolution of a Network of Artifacts and People

What determines the probability that a patent will cite another patent? In other words, how do patent citation networks evolve? These questions have implications not only for understanding the evolution of knowledge domains, but also for exploring the diffusion of knowledge among inventors. According to Singh (2005), interpersonal networks between inventors are important in explaining citation patterns and the characteristics of knowledge play an important role (Sorenson et al. 2006; Hansen et al., 2005). Another question of interest is concerned with the emergence of brokers in a network of inventors. Most of the studies in this domain explain brokerage by the past performance or specific attributes of actors. For example, Lissoni (2010) finds that brokers have high publications, patents, and many of them work with companies (see also Kirkels and Duysters (2010) for a similar result, by using surveys)[10]. According to Lee (2010) actor level heterogeneity and past performance enhance brokerage positions. For the case of Italian TV series production networks, Zaheer and Soda (2009) also emphasize the importance of attributes, yet they find a significant impact of past centrality and structural holes spanned by the actors. Stam (2010), also emphasizes the importance of prior career experience, in explaining the antecedents of brokers in the open source software.

Preferential attachment refers to a mechanism in which popular actors attract more ties, which can result in a scale free network structure (Barabasi and Albert, 2000). It has been used to explain a wide range of networks, both at the individual and organizational level. Wagner and Leydesdorff (2005) in analysing international co-authorships, find that preferential attachment explains network formation, but there is no power law distribution, possibly because of institutional context. Another factor which explains network formation has been underlined as labour mobility by Casper (2007), who explores the formation of social networks inside regional clusters for the biotech in San Diego.

[10] Note that these studies do not imply a causal relationship, but rather they highlight correlations.

Some other studies compare the interrelations between two networks, associating the change in one network with changes in the other. For example, Breschi and Catalini (2010) find that for inventors, filling a central position in a scientific network comes at the cost of filling central position in inventor network. De Stefano and Zaccarin (2013) on the other hand, find that co-invention and co-authorship tend to occur together to a large extent. D'Amore et al (2013) detect a similar tradeoff between geographical proximity and institutional proximity in inventor networks. They explain this tradeoff by the type of knowledge concerned, distinguishing between basic and applied research.

5.1.2. Network of Organizations

There is significant evidence on the impact of structural embeddedness on the evolution of networks. The likelihood of collaboration between two firms increases the more they have commonly known third parties (Gulati, 1995; 2008; Gulati and Gragiulo, 1999). In this case the network is a vehicle to carry information among the members about the reliability and capabilities of others (Podolny, 1994). In addition to the existence of common partners in a network, repeated relationships between the same partners help develop trust and information sharing, especially in problem solving activities. Drawing upon the concepts developed within new economic sociology (Granovetter, 1973), proponents of this view stress that firms prefer partners with whom they were previously in relation with. Moreover, firms can seldom risk the certainty of continuation with existing partners for the sake of partnering with distant firms (Baum et al., 2005). However, there is a point in which decreasing returns set in to such cohesive relations (Molina-Morales et al., 2009; Uzzi, 1997). Over-embeddedness can be caused by the inability of the firm to change its network portfolio, which is termed to be network inertia by Kim et al. (2006). When firms are excessively embedded in cohesive networks, decreasing returns to performance sets in, whereby their flexibility in adapting to environmental shocks is reduced.

Among the studies which emphasize the role of past networks in explaining current network structure, are Hanaki et al. (2010) who analyse R&D collaborations in IT sector. They find that through time the network has become more clustered, and its growth is explained by preferential attachment. The aim of an alliance between two firms is also an important factor according to Li et al. (2008). When firms aim at radical innovations, they are more likely to partner with those with whom they have frequently collaborated in the past. However, when the past network constrains the current network, peripheral firms can find themselves at sustained disadvantaged positions in the network (Ahuja et al., 2009). These firms are more likely to be involved in ties of social asymmetry rather than ties of structural homophily (Ahuja et al., 2009). In other words, peripheral firms are more likely to be involved in alliances with more central firms, rather than others who occupy similar positions as themselves. Structural embeddedness is found to be another factor which sustains ties between organizations (Polidoro et al., 2011).

Some other studies emphasize a notion of proximity between firms in explaining tie formation. Here proximity refers to the similarity (or distance) between two firms, which can be defined in terms of geography, technology, cognitive, organizational or social (Broeker and Boschma, 2012). According to this literature, the impact of proximity largely depends on the type of industry and dimension of proximity considered. For example Cantner and Graft (2006), by analysing patent data for inventors in Jena find that, it is the technological overlap between firms which predict network formation. Balland et al. (2013) find that as the video games industry evolves, firms are partnering with more cognitively proximate firms. On the other hand, in the global satellite industry, the evolution of project network partnerships is governed by both organizational and geographical proximity, rather than cognitive and social proximity (Balland, 2012). Distinguishing between resources and markets, Mitsuhishi and Greve (2009) find that partnership links are more likely when there is high matching between firms in terms of complementarity in markets and compatibility in resources. Rosenkopf and Padula (2008) for the case of mobile communications, and using strategic alliance data, find that shortcuts in a network are governed by structural homophily.

As far as the third mechanism behind organizational tie formation is concerned, organizational attributes are highlighted, and how they shape partner selection. For example, Lou et al. (2009) investigate the impact of ratio of scientists in an organization, and find that it increases partner attraction. Rothaermel and Boeker (2008) find that the age of the partner is a factor explaining alliance formation between pharmaceutical and biotech companies.

A more recent theme of inquiry is concerned with the disappearance of certain network positions. In one of these studies, Rowley et al. (2005) find that complementarity and inequality predicts exits from network cliques better than social cohesion and similarity. They find that role diversity and cohesion reduces exit, while size diversity increases exit. In addition, withdrawal from alliances is influenced by similar factors as initiation of alliances; structural embeddedness tends to increase withdrawal, and relational embeddedness tends to reduce it (Greve et al., 2010). Min and Mitsuhishi (2012) analyse the importance of disappearance of brokerage positions, underlying that their persistence is not good for performance in the airlines industry.

Although majority of these studies investigate the formation dynamics of networks, few of them underline the role of organizational strategy, or intentional actions, in driving network change. Exceptions are, Baum et al. (2003) who find that it is both chance partnering, and control partnering by core firms which explains brokers and small world characteristics of firms in banking sector. Dittrich et al. (2007) analyze how the alliance network of IBM through time has been governed by changes in its leaning strategy from exploitation to exploration learning. They show that this strategy was reflected in their network strategy. Although there is obviously an association between a firm's innovation strategy and its alliances, the evidence does not permit us to conclude that firms have a deliberate network strategy in positioning themselves in a broader network structure. In other words, the extent to which firms are myopic in overseeing the network structure remains understudied.

While statistical analysis of large databases can highlight some broad regularities in network formation mechanisms over the long run, interviews, surveys and detailed case studies yield more fine-grained insights into the formation of networks, taking into account the participants viewpoint directly. This is especially valid considering the role of individual / organizational action and strategy, as well as the norms, culture, values in a certain context, which are difficult to understand by exploring statistical data. In the next section, the focus is on case studies carried out through field work through interviews and surveys.

5.2. Formation and Evolution based on Case Studies

5.2.1. Individual Networks

Surveys and case studies permit analyzing the impact of certain individual attributes that are impossible to measure through secondary data sources. For example, Sasovova et al., (2010a) show that self monitoring attributes of individuals have been shown to be a significant factor in brokerage. Analysing the friendship relations, they find that high self monitors attract new friends, and they are more likely to occupy bridging positions. Singh et al. (2008) investigate the effect of network position on individual search behavior. According to their results, people who are outgroup, because of social status, tenure, or centrality access people like themselves (homophily). Kirkels and Duysters (2010) analyse whether specific attributes are associated with brokers in SMEs, in southeast Netherlands. They find that most influential brokers are in science and non -profit sectors and have a long track record in their field. Jhe and Welch (2010) investigate the extent to which homophily influences multifaceted collaborations among scientists and find that close friendship and trust have a positive impact on collaborations in diverse areas. Concerning the network structure in a large project company, Kastelle and Steen (2010) observe that the small world characteristics of the network, accompanied by a largely hierarchical structure, are the result of a network strategy, rather than random occurrence. Network strategies can also reflect the power relations embedded in local formal and informal institutions, giving rise to knowledge networks which can benefit, or restrict the participation of some actors (Arora, 2012).

5.2.2. Organizational Networks

Case studies using primary network data at the organization level and analyzing network formation, are quite rare. Some of these studies are as follows. Broekel and Boschma (2011) analyse the dutch aviation industry and find that social, organizational, cognitive and geographical proximity explain network formation. Dantas and Bell (2009) analyse the long term evolution of a firm's network over 30 years, covering its alliances in 14 technologies. They analyse the objective of collaboration, kind of knowledge that each partner provided, and how tasks were divided and present evidence of the relation between the firm's strategy and the evolution of its network. Giuliani (2013), for the case of wine clusters in Chile, finds that a stable hierarchical structure in the informal network is attributable to asymmetric knowledge base between firms. In this paper, similarity between firms does not significantly influence new knowledge tie formation, but it is the cohesion variables, like reciprocity and transitivity which contributes to it.

Finally, the next section is allocated to the use of synthetic data, through simulation models in analysing knowledge networks.

6. Simulation Studies

In the social sciences the recent decades has witnessed a surge of interest in agent based simulation models (see Heath et al., 2009 for a survey). ABS models permit understanding how aggregate patterns *form*. This modeling exercise is fundamentally different from the top-down approach commonplace in economics, whereby equilibrium conditions are imposed on systems. Rather, complex adaptive systems (CAS) are concerned mostly with out of equilibrium conditions, through the self organization of microstate events into emergent aggregate structures.[11] The essential idea in these models is that, to explain aggregate patterns one has to take into account interactions among heterogeneous agents, how it evolves over time, and how it endogenously shapes the choices of individuals in return.

Previously, it was stressed that the network approach in the social sciences is seen as largely structuralist, leaving little scope for individuals' choices, and treating the network as a separate entity which shapes the performance of its members (Emirbayer and Goodwin, 1994). However, the postulate that network position influences performance and behavior of actors does not imply that networks have independent and autonomous entities separate from the units which make them. This is why computational models are useful; particularly in understanding the gap between the individual attributes and the aggregate patterns which emerge from their interaction. Agent based simulation models enable modeling the feedback between the individual and the network, where the network surrounding the individual actors emerge and evolve as a consequence of actors' decisions, which in turn constrains and shapes their behavior and performance. In some of these studies, a network structure is taken as exogenous, yet there is a significant amount of models, incorporating this feedback mechanism between the individual and the network. Because the data is generated in computer environment, the empirical validity of ABS, which is the extent to which the model is an appropriate representation of the real system has become an extremely important point (Windrum et al, 2007).

Cassi and Zirulia (2008) analyse the impact of network structure on efficiency and equity where they find that small world is not the most efficient network structure. Chang and Harrington (2007) look at how attributes shape networks by exploring an evolving architecture of problem solving networks. They emphasize the dual role of individuals as innovators and imitators.

A range of studies examine the relation between knowledge bases and networks. Ozman (2010) models the co-evolution of networks and individuals, where agents learn through networks, which shape future partner selection processes. According to the findings, it is the knowledge base of an industry which impacts network structure, where broad and deep knowledge bases give rise to dense networks between flexible and small organizations.

[11] In this text, I use the term ABS, but it is important to note that different terms are used which connote this bottom up approach, for example, self organizing systems, computational economics, generative social science and so on.

In Ozman (2008) I explore through an agent based simulation study the evolving network structures when firms form alliances for the purpose of exploration or exploitation. The results reveal that, in an exploitation regime, networks are composed more of strong ties, where firms interact repeatedly with geographically close firms. In this regime, high technological opportunities and codified knowledge result in the emergence of locally star firms. As knowledge gets more tacit, local stars become global stars in the network and are more competent than other firms.

Cowan et al. (2006) explain network formation by characteristics of knowledge, taking into account the tension between similarities (common knowledge), and differences (complementarities) between agents. Cowan et al (2007), in a similar model of network formation based on knowledge complementarities, incorporate the role of subtasks in innovation. Cowan and Jonard (2009) show that it is the knowledge commonality between firms that give rise to certain network properties like skewed distribution, clustering and small worlds, rather than the structure of past networks. Llerena and Ozman (2013) model how the tacitness of the knowledge base and knowledge relatedness in an industry influence learning, depending on the level of commitment of partners to an alliance. At an intermediate level of knowledge relatedness, knowledge tacitness requires more committed relations, for increased knowledge flows between firms. However, this is not what firms are inclined to do, according to the model results. On the contrary, they change partners frequently. In Arora and Ozman (2008), users and producers networks are investigated. How do the co-evolution of these two networks, and the feedbacks between them, shape possible transition patterns to new technologies? The results reveal that the share of early adopters has a strong influence on the resulting producer networks, the total knowledge accumulated in both technologies, and the time period for full transition to a new technology to occur. The SKIN model (Gilbert et al, 2007) is a framework for simulating knowledge and network dynamics, in innovation based industries. Using this modeling framework, Ahrweiler et al (2011) investigate the impact of university and industry linkages. They find that incorporating collaborations with universities to networks significantly increase the quality and speed of knowledge flows, increase diversity, as well as the knowledge and competence of firms in the population. In an analytical model of tie formation, Letterie (2008) finds that uncertainty increases the propensity to ally and there is reduced incentive to ally when alliance partners are similar.

Conclusion

Based on this review, it is possible to make a few observations on the literature on knowledge networks. These observations are made in two spheres: methodological and content related.

One of the methodological issues is that the nature of questions depends on the source of data. While this is not a problem in and of itself, and it is what is expected in any scientific endeavor, in network research it is important in the following senses. The studies using large scale data sources are very rich in terms of observing multiple industries, long term developments over a large number of actors. But by focusing on the structure of the network, the precision of tie content is lost. Crude proxies for tie strength can and are employed, but the problem remains that the theoretical framework that they draw upon is rooted in social psychology. So there is a mismatch between the mechanisms that theory focuses on on one hand, and what the data measures, on the other. Given this situation, it is meaningful to come up with tie definitions that are specific to the nature of knowledge and innovation studies. For example, considering the knowledge complementarities between people or organizations is an important step in this regard (Schoenmakers and Duysters, 2006).

Another implication of this mismatch is related with the underlying assumptions about knowledge. Considering the two different conceptualizations of knowledge as objective and practice based approach, network studies have formed a platform in which both perspectives are used in analyzing the diffusion of knowledge. According to objectivists, knowledge can exist outside the individual, by being embedded in an artifact and flowing between people and organizations. Accordingly knowledge can be in tacit, or explicit form. An implicit assumption here is that, knowledge can be taken separately from the actors who create, diffuse, or process it (Hislop, 2013). According to the practice based approach, on the other hand, knowledge is not unique and it is not independent of interpretations; people have different understandings of it, depending on the context, language, history, and culture. An objectivist perception of knowledge manifests itself clearly when knowledge is assumed to be embodied in a network of artifacts, for example in using bibliometric data, or when it is assumed to flow between actors during an event (like an alliance between two firms). The use of secondary data in studying knowledge networks separates the context within which knowing takes place, and the tangible events and artifacts that accompany the process of knowing by actors. This separation is not necessarily problematic as long as the researcher recognizes the differences in the nature of questions that can comfortably be addressed in either of the approaches. Yet can pose problems when the two are confused.

Secondly, it is more convenient to collect data through interviews when analyzing inter personal networks. In this case, it is possible to focus both on the structure of the network, as well as the qualitative nature of ties. Moreover, as far as network formation is concerned, the researcher is more flexible to consider different independent variables other than what is available by data, which also leaves more space to uncover the role of individual strategy in network manipulation. Nonetheless, generalizations are more difficult across different organizational contexts. In this sense, it is important to be able to leverage the synergies between the results obtained from these studies and those that utilize large scale bibliometric data of inventors or scientists.

Above, I focused on some of the methodological issues that can be observed in the research. There are also some observations that can be made regarding the content of studies.

First, certain research questions are over studied, leaving others understudied. The impact of network structure on performance has been studied from various theoretical and empirical angles, analyzing the impact of moderating factors, as well as the idiosyncrasies between the actors in the network. More recently we are observing the increased importance given to network evolution and formation. In fact, this has been a longstanding field of inquiry within agent based simulation studies, game theoretical approaches, as well as analytical models. Empirical analysis of network evolution is more recent. Nonetheless, the "bridges" between formal models and empirical studies are still weak. There seems to be disciplinary borders between researchers working on networks. Although these borders have subsided to an extent during the recent years, a review of the current literature reveals that the borders between physics, sociology, and management and economics hardly disappeared. Efforts to bridge these gaps can be very useful, in terms of addressing many of the challenges facing network research today. This is especially valid for the studies on knowledge networks, considering that knowledge theories transcend disciplinary boundaries.

While the literature on the evolution and formation of knowledge networks has been evolving at full speed recently, the role of strategy and individual manipulations of the actors is hardly studied. There can be two reasons behind this lack of attention. The first is simply that actors do not manipulate their networks by overlooking the whole network structure; therefore this field has achieved less attention in the literature. The second is related to the cost and efforts necessary to collect data in this area. A significant proportion of network studies are based on large-scale data, which do not permit to infer individual strategic intentions, except when ex-post guesses are made. As far as the first explanation is concerned, this can be only understood by carrying out field studies at the organization level. In addition, whether it is better for innovative performance to have a networking strategy is another subject, which can be an interesting to study in the future.

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