CRANFIELD UNIVERSITY

C. BASILE

Circumstances and Paths of Change and Stability in Knowledge Network

SCHOOL OF MANAGEMENT
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Academic Year: 2011 - 12

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ABSTRACT

To cast light on the impact of knowledge on economic growth, performance and innovation is a highly sought-after research endeavour that keeps triggering interest across different disciplines. This in turn calls for the need to explain how processes of knowledge creation, transfer and use occur. A fast-growing body of research argues that the characteristics of social relationships and the network they constitute may provide a better understanding of knowledge processes. However, the great majority of empirical works in the field has concentrated on static analysis, addressing the effect that structural and relational properties of social networks exert over knowledge outcomes

In this work I aim to extend the current understanding on knowledge network research by conducting a systematic review of longitudinal knowledge network research. I believe that it is by looking at longitudinal empirical investigation that we can get a grasp of dynamic processes such as those related to knowledge.

I propose therefore a framework to organize knowledge network research, highlighting points of conflicts and coherence across different levels of analysis, network elements and constructs adopted.

Emerging themes and future areas of research are explored.

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1 Executive Summary

To cast light on the impact of knowledge on economic growth, performance and innovation is a highly sought-after research endeavour that keeps triggering interest across different disciplines. Ever since the contributions of pioneers such as Kuznets (1966), the production, rise in stocks, distribution and use of knowledge are increasingly acknowledged as the essence of modern economic growth (OECD, 1996; Foray, 2004; Powell and Snellman, 2004). To this extent, evidence has been found to support economic performance of individuals, organizations and countries as progressively relying upon knowledge production (e.g. Furman et al., 2002; Roberts, 1999). Moreover, the shift of attention to knowledge as a primary source of value creation and competitive advantage has spawn new ways of theorizing organizations and even new field of enquiry in academic research. Of particular relevance is the knowledge-based view of the firm (Grant, 1996; Spender, 1996; Nonaka, 1994) positing, at the expense of the resource-based one, that the services rendered by tangible resources owned by a firm depend on how they are combined and brought to bear. This in turn relies upon the knowledge rooted in and carried through multiples entities such as organizational culture and identity, routines, activity systems, repositories and individuals (Grant, 1996; Nelson and Winter, 1982; Spender, 1996). The proponents of this perspective argue that since knowledge-based resources are socially complex and difficult to imitate they may constitute the main source of long-term competitive advantage.

Parallel to such theoretical position, the field of knowledge management, including its IT counterpart, addresses the development of organizational and managerial practices which are more knowledge-focused and may therefore generate a greater economic impact.

Thus, according to the knowledge-based perspective the relationship between knowledge and its economic impact involves first an understanding of ‘what knowledge is’ and then dealing with the ability of individuals or higher collectives to search for, acquire, retain, transfer and utilize knowledge (Alavi and Leidner, 2001). With regard to the latter, a fast-growing body of research indicates that the characteristics of social relationships and the network they constitute affect the ability

of individuals or collectivities to access, transfer, absorb and apply knowledge thus increasing their efficiency and efficacy in creating knowledge (Phelps, 2012). This strand of research has been referred as knowledge network research, with '*knowledge network'* defined as (Phelps, 2012: 1117):

"a set of nodes- individuals or higher level of collectivities that serve as heterogeneously distributed repositories of knowledge and agents that search for, transmit, and create knowledge- interconnected by social relationships that enable and constrain the acquisition, transfer and creation of knowledge".

By revising almost 40 years of research in *knowledge network* so conceived, Phelps et al. (2012) found, among others, that the great majority of empirical works in the field is cross-sectional and addresses the effect that observable structural and relational properties of social networks exert over knowledge outcomes. In detail, about 90% of all the studies reviewed by these authors assumes that the network configurations investigated are not correlated with unobserved characteristics of individuals and not caused by those knowledge-related dependent variables they explain (Phelps, 2012:1154). Moreover, it is surprising how knowledge network research has mostly overlooked so far the cognitive capabilities or internal knowledge structure of actors involved in a network of social relationships, which clearly influence their ability to access, absorb and create knowledge. The same happens for intentionality and strategic motives of actors, or similarly agency, which are as well not accounted for in examining the effect of their patterns of interaction on knowledge outcomes.

In light of the above, I argue that current knowledge network research is not consistent with most of the theoretical arguments around knowledge and some related empirical evidences available in literature. Kogut (2000), for example, builds on a set of network studies (Kogut & Zander, 1996; Walker, Kogut & Shan, 1997) to propose a network theory that looks at the network of social relationships as the outcome of organizing principles, generative rules of coordination which are nothing else but knowledge residing in organizations. Similarly, Birkinshaw et al. (2002) has demonstrated how knowledge characteristics of individuals involved in a network of social relationships predict its structural configuration. Indeed, it is intuitively unreasonable to see patterns of interaction or any form of interdependence among

agents as entirely disentangled from the knowledge they carry along with them, whatever knowledge stands for. Grand social theories (Giddens, 1984; Bourdieu, 1977; Sewell, 1992), but also well-respected works in the development of the knowledge-based perspective (Brown and Duguid, 2001; Nonaka and Toyama, 2003; Spender, 1996, Tsoukas, 2009) and as well some empirical evidences (e.g. Berends et al., 2003) have argued the knowledgeability of actors as deeply involved onto recursive or dynamic processes of interactions occurring in a particular context, and so resulting in observable structural and relational configurations. These in turn enable and constrain the ability of individuals to intervene in the course of events, or in other words their agency. What is at issue is then a more clear understanding of how the knowledgeability of network members and the structure of social relationships in which they are embedded combine overtime in a context, yielding particular outcomes.

The aim of this review is therefore to extend the current understanding of knowledge network research by reviewing empirical studies of knowledge network over time. In particular, focussing on both change and stability of the structure of knowledge networks over time it is believed to provide insights concerning variation, mechanisms and cause which are knowledge-based.

1.1 Aim of the Review

The aim of this review consists of systematically exploring the literature in order to extend the current understanding of knowledge network research. This will entail identifying significant points of coherence and conflict among empirical results, gaps and promising areas for future research. In so doing, I am going to focus in this review on longitudinal studies in knowledge network research so as to uncover mechanisms of change and stability: I argue that a longitudinal network perspective can provide deeper insights on knowledge processes and how these could be managed effectively. The great majority of studies in network research rely upon cross-sectional corroborations while they indeed attempt to cast light on dynamic processes such as knowledge creation, transfer, use and adoption.

Overall, a similar review is purported to enhance the current understanding of:

- Mechanisms underlying change or stability in the structure of knowledge networks.
- Knowledge conceptualizations adopted so far in the literature and implications that choosing a particular conceptualization of knowledge entail.
- Current limitations in explaining the mutual relationships among the structure of social relationships and knowledge variables.
- Possible avenues for future research.

2 Positioning the field of enquiry

In this section I am going to discuss relevant bodies of literature which underpin two concepts: “Structure” and “Knowledge Network”. The purpose is to provide an appreciation of the major debates and identify key streams of research that may inform this systematic review, leading to a well-formulated review question.

“Structure” and “Knowledge Network” are indeed two concepts for which a great deal of contributions can reasonably be assumed as relevant and worthy to be examined.

Therefore, in the first section I will provide a historical overview of the main research traditions around *Structure*. I will retrace the origin and fundamentals of structural-functional anthropology and sociometry schools of thought, touching upon key conceptual debates typically overlooked in the seminal treatises of the subject. Yet, I will briefly point out their main theoretical and empirical developments and sketch future directions of inquiry. A discussion concerning the main arguments of structural thinking will follow.

Following this, I will examine a set of relational construct that have been used to investigate knowledge-related phenomena. While it is common in literature the adoption of a network perspective addressing knowledge processes (to a limited extent the other way round), their mutual relationship or, let’s says, their co-evolution is still lacking.

In first instance, a review concerning an epistemology of knowledge, the shift from individual and collective knowledge and the contextual and dynamical nature of knowledge are pinpointed. Whereas there are some attempts in literature to define “knowledge networks”, these constructs rely upon the particular conceptualization of knowledge, the types of relationships considered in building a network (network construct) and the contexts of investigation undertaken.

Overall, the analysis of the different perspectives adopted in this area of study suggests that a longitudinal standpoint is necessary in order to merge in a meaningful way these two concepts.

Furthermore, being structure here understood as the formal meaning of a network construct and being knowledge the basis of the aimed construct, this scoping study suggests a review question centred around patterns and contexts according to which the structure of knowledge network change or remains stable overtime.

In fact, a review of how and in what contexts change or stability occurs in knowledge networks' structure may offer insights concerning knowledge-based causes and mechanisms underlying the variation or stability of patterns. This in turn may cast light on the way knowledge flows and diffuses along structure. A similar review of the literature is thought to build awareness of how knowledge networks can be built and analysed from a dynamical standpoint.

The advantage of similar findings could have great significance for the design of organizational structures, inter-organizational relationship platforms and generally to inform the literature in Innovation and creativity studies.

In figure 1 a schematic representation of the two domains investigated, plus the temporal dimensions these two concepts require for their meaning association is provided.

2.1 Structure

2.1.1 Introduction

Structure, more than a concept, can be considered a metaphor that both social and natural sciences scholars have extensively used in scientific discourse, making its adequate definition nearly impossible (Sewell, 1992).

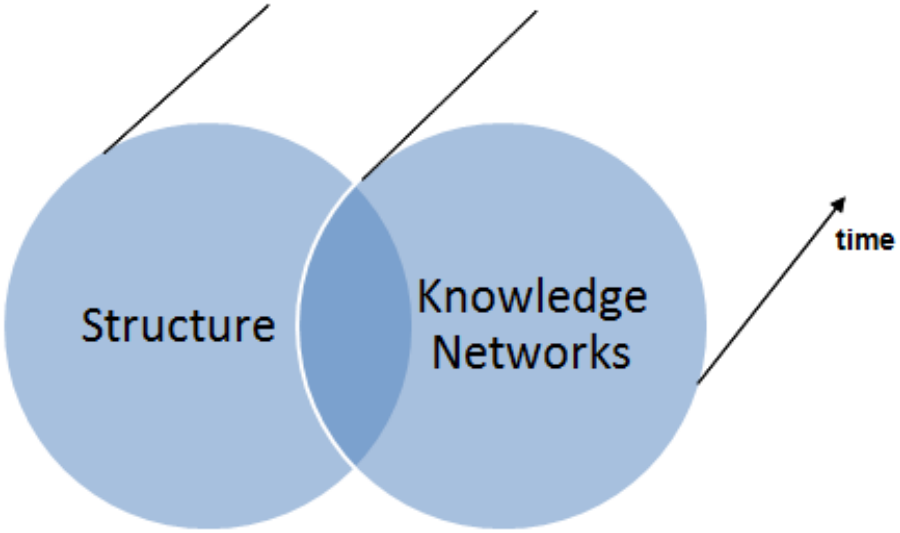

Figure 1: The two domains for the scoping study overtime

However, one may expect that by a) narrowing down the avenues of enquiry for a meaning of structure to a particular school of thought and b) looking for the most relevant definitions of structure available in recent literature, can sort out things. Unfortunately, this is not the case for structure. In fact, clarifying the aim here to address a social network perspective on knowledge processes does not help to significantly reduce the critical sources of meaning attached to structure, rooted in anthropology, sociometry and graph theory, and later developed in a multidisciplinary setting. Furthermore, looking for available definitions within recent literature in social science for structure reveals how it closely overlaps with network, triggering confusion.

For instance, according to Doreian and Stokman (1997, pg. 1), a fundamental definition of structure is “a set of social actors with a social relation defined over theme”. For Brass et al. (2004) “a network is a set of nodes and the set of ties representing some relationship, or lack of relationship, between the nodes”. Their similarity is striking.

These are obviously not the only definitions available, especially concerning networks, where, as highlighted by Provan et al. (2007), several definitions and a tangle of meanings co-exist in literature.

While an exhaustive examination of the multiple meanings of structure is impossible here, I will nevertheless provide a brief historical overview of the different research traditions addressing this concept. This is necessary to convey an understanding of structure and highlight how these different streams of research around structure can serve my purpose of research.

2.1.2 A historical overview of Structure

2.1.2.1 *Structuralist thinking*

Freeman (2004) in his book "The development of social network analysis" identified Comte's positivism as the first structuralist thinking for the way this philosopher looked at society in terms of interconnections occurring among social actors. Borgatti et al. (2009) emphasized his attempt to establish the field of "social physics", moving explanations about the order[1] of social systems away from the metaphysical and towards the rational and scientific method of the natural science. This shift, in Comte's view, will not only allow explaining the past progresses of mankind but also formulating predictions about its change overtime. Along with this emphasis towards achieving predictive capability in the social realm, Comte's primary concern was to unfold the conditions responsible for social stability. These two distinct but interrelated endeavours, known as social statics and social dynamics, were the basis of his sociology. Social statics (which is really about the condition and precondition of social order) consists of principles (e.g. division of labour) governing the action and reaction of the different parts of a social system while maintaining its stability. By conceiving society through an analogy with a biological organism, Comte argued that *'there must always be a spontaneous harmony between the whole*

[1] Social order, in sociology, refers to a set of linked social structures, social institutions and social practices which conserve, maintain and enforce "normal" ways of relating and behaving.

and the parts of a social system' (Comte, 2009:226). Nevertheless, the order of society changes according to laws of human progress, and their study constitutes for Comte the foundation of social dynamics. These concepts, as developed by Comte, have had a major role in developing modern sociology, making his work basilar for any attempt to describe what structural thinking is about.

To this extent, Scott's (2000, 2011) work is enlightening. He accurately describes the roots and development of social network analysis, putting particular emphasis on the role played by graph theory and matrix-based approaches, while touching upon crucial theoretical and conceptual groundings and advances. Social network analysis has undoubtedly roots in the structuralist thinking and has decisively contributed to the operationalization of structural concepts through mathematical lenses. However, conceptual lines and views about *structure* are only sufficiently addressed in the aforementioned contributions. The most relevant among them deserve some further attention if one's aim is to convey a satisfactory account of what structure means.

Figure 2 illustrates the lineage of the different strands of research which have contributed to the development of *structural analysis* (see Scott, 2000 for an in-depth examination)

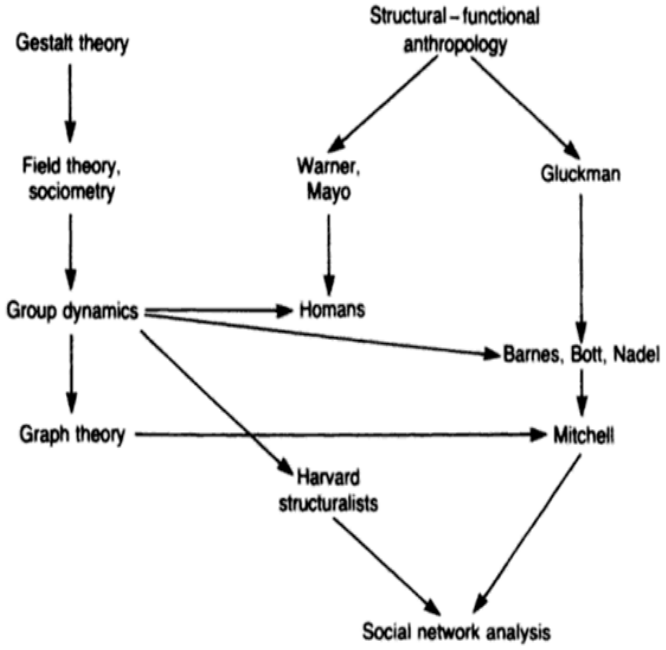

Figure 2: Lineage of social network analysis (source: Scott, 2000)

Social network analysis stems from an emphasis, shared among structural-functional anthropologists and followers of the Gestalt psychology, on formulating a different approach to social structure for studying social phenomena (Scott, 2000).

On the one hand, Gestalt (standing for '*pattern'* in German) theory, though has particularly contributed to the understanding of perceptual phenomena, has had significant impact on learning and, most relevantly here, on social psychology. The central tenet of this tradition relies on the idea that 'the whole is different from the sum of its part' (King et al., 1994). In detail, wholes are the means whereby people structure their perceptions or thoughts, and these are not merely the sum of the constituent parts but rather 'configurations' that result from their mutual, complex interaction. Parts have to be seen in terms of their places, functions, roles on the whole which they form. Furthermore, perception of wholes are driven by grouping principles (e.g. proximity, similarity, closure and good continuation among parts) and governed by dynamic processes of

organization (tendency toward simple *Gestalten*), which in turn depend on the context as well as on cognitive structures and values of the perceiver (King et al., 1994). By stressing the social determination of cognitive structures and values, social psychologists have broadened the Gestalt's argument, moving from individual minds to embrace group structure and its influence on social perception and action. Moreno (1934) was a key contributor of this renewed interest towards social configuration and its network characteristics as both constraining and enabling people actions and thus affecting their psychological development (Scott, 2000). While social configuration in Moreno's view were still grounded on collective psychological processes (e.g. feelings and beliefs towards one other), he paid particular attention to the formal properties or *structures* (e.g. central positions of actors) of such social configuration and how these impacted social phenomena such as flow of information and social influence. He coined the term *sociometry* to denote this field on enquiry. For Moreno, social configurations meant the *"concrete patterns of interpersonal choice, attraction, repulsion, friendship and other relations in which people were involved, and they are the basis upon which large-scale social aggregates are sustained and reproduced overtime"* (Scott, 2000, pg.9). In this sense, Moreno's concern for the form of social interactions and its relationship with large scale aggregates can be said to represent a clear expression of Simmel's sociology (Scott, 2000). It can be further argued that Moreno breakthrough consisted of applying Simmel's (1908) ideas by devising the *sociogram*: a technique which allows mapping the formal properties of social configurations so as to infer their influence on social phenomena. Sociometry further developed through 'the group dynamic' approach developed by Cartwright and Harary (1956), aiming at extending the Heider's cognitive balance theory to interpersonal balance in groups. According to this theory people involved in a close relationship tend to develop similar feeling towards third persons or events. By building network of affect relationships and applying graph-theoretical methods, the authors demonstrated that triadic interpersonal relationships yield particular macro structure, consisting of two cohesive (positive relations) clusters with negative relations occurring among them.

On the other hand, and parallel to sociometry, a stronger development of structural thinking began with the structuralist and functionalist school of thoughts, mainly drawing on Durkheim's idea (Scott, 2011). Similarly to Comte and to some extent akin to the Gestalt's view, Durkheim (1938) believed that societies are entities *sui generis* and therefore the study of social wholes must avoid their reduction to constituent parts by means of individual psychological explanation. In detail, Durkheim considered functional and historical analysis, though separately, essential for explaining *social facts* and how social order is brought about, while probing individual motives and purposes was only of marginal importance for sociological inquiry. 'Social facts', the subject matter of sociology according to Durkheim, are in fact things, concepts, expectations which cannot be attributed to the individual but they are instead elements of the collective life exerting constraining influence over actors.

Yet, Durkheim was concerned with unfolding factors responsible for holding the society together. He identified these factors as belonging to two main forms of solidarity, namely mechanical and organic solidarity. The first refers to shared beliefs and sentiments (indicated as *common conscience*) which act as a force binding groups together and are preserved by enforcing social norms. However, as societies develop, mechanical solidarity becomes ineffective, norms are broken and a complex organization of labour is made necessary: an 'organic' form of solidarity, based on interdependence, comes to replace that of collective conscience. Social order in this case entails differentiation - that is mutual dependence among the constituent parts of society, each of which performing certain functions in cooperation with the others so as to serve the societal needs.

Overall, by focusing on:

- the structural properties of social systems as independent from motives and purpose of individuals and constraining their action
- elements holding individuals together so as to ensure the stability of society

- social change as involving differentiation

Durkheim had a fundamental impact on modern-day functionalists, structuralists as well as anthropologists. There has been a great deal of contributions aiming to push forward his sociological enterprise, culminating in areas of overlaps and contrasting views both within and across these disciplines. It is neither the purpose nor an easy task to draw a clear conceptual lineage of how these different perspectives have converged or diverged overtime, but rather highlight dominant themes and key debates around structure. In so doing, it will be useful to outline one of the most enduring debates around the formulation of a notion of structure, that which have separated the structural-functionalism of Radcliffe-Brown and Levi-Strauss's structural anthropology.

The former has provided a notion of structure as real, observable, and concrete patterns of social relations. Yet, contemporary network theorists trace their own conceptual debt to such a *tangible* account of structure (Lizardo, 2010). Social structure as meant by Radcliffe-Brown concerns the 'whole set of actually existing relations, at a given moment of time, which link together certain human beings' (Radcliff-Brown, 1940:4). A human being, he further argued, is both an individual and a person: the individual includes physiological and psychological actions and reactions, processes and change and is therefore the object of study for physiologists and psychologists, while the person is a complex of social relationships. The study of social structure for Radcliffe-Brown is evidently concerned with the human being as person.

Moreover, Radcliff-Brown distinguished between social structure, as an actually existing concrete reality, and structural forms, in order to move from particular instances to general forms that persist overtime and that better serve therefore scientific purposes. Through a biological analogy very similar to that embraced by Durkheim, Radcliffe-Brown describes structural forms as stemming from the continuity of social structure overtime, a dynamic continuity as that of a living organism (Radcliff-Brown, 1940:4). This means that while change occurs in social structure overtime, some forms may remain invariant. These enduring forms may be discovered through observation, including statistical observation,

and offer ways of comparisons among different structural systems so as to learn more about their varieties and diversities. Yet, the continuity of structural forms is reasoned by Radcliffe-Brown as relying on the functions, the roles that the different parts of the system fulfil in interaction and through mutual adjustment so as to ensure the stability of the whole. Drawing again on Durkheim's organic analogy, change for Radcliffe-Brown entails differentiation of social roles.

Opposite to this conceptualization of social structure is that argued by Levi-Strauss with his structural-anthropology perspective. In line with the structuralist tradition, Levi-Strauss believed in a deeper stratum of reality and was therefore in search of underlying explanations for social phenomena as observed. With regards to a concrete notion of social structure such that expounded by Radcliffe-Brown, Levi-Strauss thought of it as nothing more than the whole network of social relations (Levi-Strauss, 1962). Rather, he argued that concrete and observable patterns of social relations might be simply the surface manifestation of a more fundamental, not observable bunch of structural principles (Lizardo, 2010:655). To this extent, Levi-Strauss did not disregard psychological traits of individuals as involved in the conceptualization of social structure. Indeed, his primary concern was to cast light on 'those universal, unconscious features of the mind which uniformly force a particular structure onto the world' (Baert and da Silva, 2010:28).

For Levi-Strauss, human beings have certain common features and one of this is the way they unconsciously interpret and construct their surrounding world through binary oppositions, as suggested by Jakobson's structuralist approach of language. In other words, we make sense of things depending not particularly on the meaning such things contain but by our understanding of the difference existing between a thing and its opposite. Levi-Strauss's ambitious project was therefore to scale, by successive abstraction, the social facts into binary opposites until reaching the human brain itself. This consists of breaking down practices, assumptions and beliefs of individuals into binary distinctions, finding recurrent patterns among them through comparisons and tracing such oppositions back to the structure of the human brain (Sewell, 1992:7).

Underlying structure for Levi-Strauss is then that set of rules enabling binary opposition to be ordered. What differs linguistic from social phenomena is that the latter employ a dual time referent (Baert and da Silva, 2010:30). Using an analogy with myths, Strauss argued that cultural phenomena rely on events occurred long time ago, but they also operate outside of time since they somehow inform us about the meaning of the past, present and future.

It should be clear at this point how, in Levi-Strauss's view, social structure are models able to account for the phenomena as observed by showing their connections with pre-existing and unrevealed relationships (Lizardo, 2010:688). Posed this way, structure has to be distinguished from social relations: they are indeed models built up after it. In other words, *structures* are methodological devices; they do not bear any ontological position, do not refer to a particular level of analysis nor are they associated with constraining effects or problems of agency; rather they allow for the simulation of practices, cognitive operation or, more generally, they enable the reconstruction of unobservable mechanisms responsible for observable social facts.

The tension between the foregoing 'concrete' and 'abstract' views on social structure is evident. The first is culturally impoverished, refer to the whole network of social relationships disregarding psychological traits of the individuals, focus on structural forms stable over time and place social roles as a central concept in sociological enquiry. The latter instead proposes a cultural account of social structure, which, through experimentation, may offer mechanistic explanation for empirical facts as well as prediction concerning their occurring.

This tension is still persistent in recent sociological theory and practice, as will be briefly pointed out in the next section.

2.1.2.2 *Theoretical and empirical developments*

As I previously stated, Radcliffe-Brown's 'organicist' notion of social structure is still prominent in current network thinking. His conception of structure as the whole set of observable social relationships, as well as his emphasis on enduring forms and social roles, were indeed so central to Nadel's work, one of key influencer of structural analysis according to Scott (2000, 2009). Nadel's claim on the importance to analyse formal structures of roles through the use of algebraic and matrix methods has profoundly influenced the Manchester and Harvard turn (Scott, 2000; 2009). The arguments advanced by these schools of thought led to a blooming of formal methods for the empirical analysis of inter-personal and roles networks. Graph theory has provided means to formalize relational and structural measures, such as density and centrality, and evaluate their effect. Other matrix based approach has focused on social positions and roles, allowing for the organization of networks into hierarchical positions.

On the other hands, Levi-Strauss abstract conceptualization of structure has had significant impact on later theoretical developments. Levi-Strauss's structuralism can be regarded as one of the first attempt towards explaining the social by means of the tacit or unconscious layer of human knowledge. Different theories of culture has developed from such premises. Of particular relevance are that body of theories known as practice theories, such as those proposed by Giddens (1979, 1984) and Bourdieu (1977). With his conception of structure as tied to universal unconscious features of the mind , Levi-Strauss's structuralism has been criticized for neglecting human agency and showing limitation in explaining structural change. To this end, practice theorists opposed a view of social structure as consisting of routinized action performed by knowledgeable and situated agents. However, it is not the purpose of this review to offer a lineage of cultural theories. It is enough to note here that, even though with still limited empirical support, a long-standing turn in the social science sustain the sphere of the cognitive and symbolic structures as giving meaning to the social world.

2.1.2.3 *Complex thinking*

The increasing availability of both physical and social data has opened the possibility to investigate the structure of large networks and their dynamics overtime. Social networks such as co-authorships of scientists are the most popular examples. Recent highly cited pieces of research in networks are due to the work of physicists in the field of complex networks (e.g. Barabási, 1999, 2002, Newman, 2002, Strogatz, 2001, Pastor-Satorras, 2001). Andriani and Mckelvey (2009) provided a good description of the development of complexity science, particularly pointing to the third paradigm of this research tradition: Scalability. Started at the Santa Fe' institute, its focus relies on the study of "surface complexity arising out of deep simplicity" (Andriani and Mckelvey, 2009). In other words, it is nowadays possible to map complex structure and observe their dynamics overtime, and therefore reconstruct such structures from simple mechanisms of interaction at the local level. Andriani and Mckelvey list 15 mechanisms that have been demonstrated empirically to reproduce complex structures from micro rules. The same results can be found in other review such as Gross and Blasius (2008).

However, recent empirical evidence, has demonstrated that complex structure can be the result of different mechanisms operating simultaneously at the micro and macro scale (Powell et al 2005, Contractor, 2006).

Overall, even if neglecting much of previous works in sociology and anthropology, these new wave of structural analysis has developed methods able to account for network dynamics and change. I have emphasised in the previous sections how much of the empirical work in social network research has been static

2.1.2.4 *Observations*

In this first section I have discussed different streams of literature that relate to a conceptualisation of structure.

In structural thinking, we have seen how, by separating the forms of relations from their meaning, formal models or structure of social configurations can be constructed through a mathematical apparatus. These formal models exemplify social behaviour relying on positional and relational aspects, external to the individual dimension. To this extent, roles and interpersonal structures provide the suitable architecture for the investigation of different social phenomena.

A parallel strand of structuralist thinking argues the need for underlying explanations of social fact. These rely substantially on cognitive and symbolic structures as well as on the situated activities of knowledge agents. Although such arguing offer ways to account for human agency and structural change, few empirical works have supported this cultural paradigm in network research

Complexity theory, through the deployment of methods developed in the natural science, while neglecting much of the arguments of previous sociological enquiry, has developed methods able to analyse network dynamics and change overtime.

2.2 Exploring knowledge networks

While there is broad empirical support in literature for the effects that "*networks"* arrangements play on *"knowledge"* outcomes, and a limited one the other way around, the nature of their mutual relationship is far from clear.

Moreover, their most popular coupling, "knowledge networks", lacks consistency and a satisfactory definition.

As a result, in the following sections I will draw some conceptual boundaries aiming to highlight the challenges that a conceptualisation of *knowledge networks* implies and identify what bodies of literature such conceptualisation underpins.

2.2.1 Seeking an overarching link between Knowledge and Networks

2.2.1.1 *An Epistemology for Knowledge*

The purpose of this section is not to provide a detailed review of the diverse conceptualisations of "knowledge", but rather to sketch the terrain toward its meaningful association with *"networks".*

Indeed, a rigorous definition of *"knowledge"* could serve the aforementioned scope. Notwithstanding, seeking to define "*knowledge*" would inevitably demand the assumption of an ontological stance concerning the knowability of reality as well as somehow dealing with the long-standing epistemological debates across positivist, relativist, empiricist and realist theorising about the nature of knowledge.

This entrenchment in contrasting epistemologies, which in turn rely on a particular ontology, makes a definition of "*knowledge"* or trivial or so all-encompassing that it loses its meaning.

For instance, one of the most cited definition of knowledge is the one provided by Davenport and Prusak (2000, pg.5):

> *"Knowledge is a flux mix of framed experiences, values, contextual information and expert insight that provides a framework for evaluating and incorporating new experiences and information. It originates and is applied in the minds of knowers. In organizations, it often becomes embedded not only in documents or repositories but also in organizational routines, processes, practices and norms".*

While this definition encodes, as it will be clearer in the following, essential aspects of the process of knowing and knowledge itself (e.g. its dynamical, contextual, individual and collective nature), the different concepts it encompasses are not clearly linked and explained: so broadly defined knowledge emerges as a "*little-revealing"* concept (Tsoukas, 2001).

Rather than stressing the lack of definitional clarity, the point at issue here is to actually identify a clear epistemology. This suits our aim. Here we consider knowledge through network lenses, and then clarify the consequence of this engagement.

One of the most widely acknowledged (Spender, 1996) viable way of framing an epistemology for knowledge has been in terms of Polanyi's (1962) distinction between tacit and explicit knowledge. Moreover, knowledge can refer to individuals as well as to collectivities. As it will be repeatedly emphasised in the following, these fundamental dimensions in interaction underlie the dynamic essence of knowledge.

2.2.2 Types of knowledge at the individual levels

Polanyi (1962) has provided deep insights on the nature of knowledge. Arguably his most acknowledged contribution has been in defining two diverse dimensions for *knowledge*, a tacit and an explicit one. Tacit knowledge is associated with experience; it is unspeakable and goes beyond conscious knowledge. The explicit one, instead, is articulated or codified knowledge which can be easily communicated.

This differentiation is similar to Ryle's (1949) argument on the contrast between "*know how*" and "*know that*", being *"know how"* ineffable in nature and thus in contraposition with "knowing that", which in turn is defined as *free flowing*.

However, despite providing consistent argument for such a distinction, both Polanyi and Ryle recognised the interdependent nature of these two dimensions of knowledge. In Polanyi's terms, explicit knowledge stems from the formerly interiorised tacit one. Ryle, similarly, argues the necessity of an appropriate "*know how"* in order to make *"know that"* useful. Moreover, both Polanyi and Ryle affirm that the acquisition of *know how* or tacit knowledge is not just an intellectual process, but it takes place through individual practice. In their seminal works, the two authors do not explicitly establish any social component of knowledge.

Thus, Polanyi's and Ryle's argument relates to the individual-based perspective of knowledge. Their view of knowledge demonstrates a cognitive and experiential emphasis. Even though their definition about the two distinct dimensions of knowledge can lead us to assume the tacit dimension as *"dark matter"* while the explicit one as *tradable*, a careful interpretation of their argument reveals an interdependence of the two dimensions, one requiring the other. Thus, knowledge is created by individuals through a dynamic process of experiencing and interiorising, while *practise* smoothes this two-way loop (Brown and Duguid, 2001).

However, insights coming from sociologist such as Durkheim (1938) or philosophers such as Wittgenstein (1958), as well as from many scholars (e.g. Teece et al, 1994) studying learning, knowledge flow, spillover effect, suggest that knowledge is fundamentally collective and it depends on the social context. Therefore, the questions to be addressed are: how can we extend this individual view of knowledge to the collective level? And what does this switch in level of analysis entail?

2.2.2.1 *Moving toward a non-individualistic concept of knowledge*

If we are to move towards a collective understanding of knowledge, we must consider two fundamental theories of organizational knowledge: Nonaka (1994) and Nelson and Winter (1982).

The reasons for this are two-fold. First, aiming to expand the understanding of knowledge from the individual to the collective level entails defining a context, indeed a social context. Second, a collective view of knowledge intuitively requires a shift in focus from defining a pluralist epistemology for knowledge, which we have seen to be tacit and explicit knowledge, to how these two dimensions interlink in a dynamic fashion.

Nonaka (1994), in his dynamic theory of organizational knowledge creation, adopts as his starting point Polanyi's epistemology for knowledge and the continuous interaction among tacit and explicit knowledge at the individual level. He further expands such philosophical view of tacit knowledge, formalising it more practically as both:

a) *cognitive elements*, recalling Johnson-Laird's (1983) *mental models,* which are representations of the external reality that human beings create by analogies in their mind and they use in perceiving and defining the world.

b) *technical elements*, such as concrete *know how* and skills to be applied in a specific context.

Most importantly Nonaka introduced an ontological dimension, which he names *the level of social interaction*. This is based upon the belief that interactions among *communities* play a fundamental role in creating knowledge. Even though such communities may span the organizational boundaries, what is crucial is that they add a further dimension to knowledge creation (Nonaka, 1994).

Thus, while knowledge is still produced by individuals and can be differentiated into tacit and explicit forms, Nonaka sees social interaction as a process through which knowledge can be amplified, while the organizational level as the context that supports such creation of knowledge. He, therefore, defines four conversion modes (fig.3) through which tacit and explicit interactions yield new and augmented knowledge:

- **Socialization** – conversion of tacit knowledge to tacit knowledge between individuals through observation, imitation and practice. The basic requirement this conversion requires is shared experience among people.
- **Combination** – combining sets of explicit knowledge held by individuals through social processes.
- **Externalization** – involving interaction between explicit and tacit knowledge through social dialogue to create shared concepts, normally within a team and often involving the use of metaphor (he saw this *codification* process as the least developed concept theoretically)
- **Internalization** – is seen as closest to traditional organizational learning, although action is seen as an important component

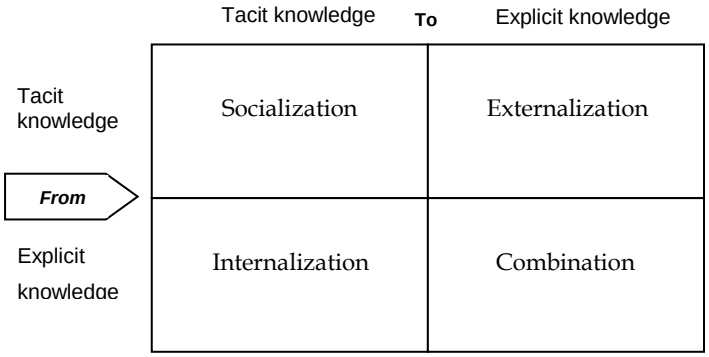

Figure 3: four modes of knowledge creation (source: Nonaka, 1994)

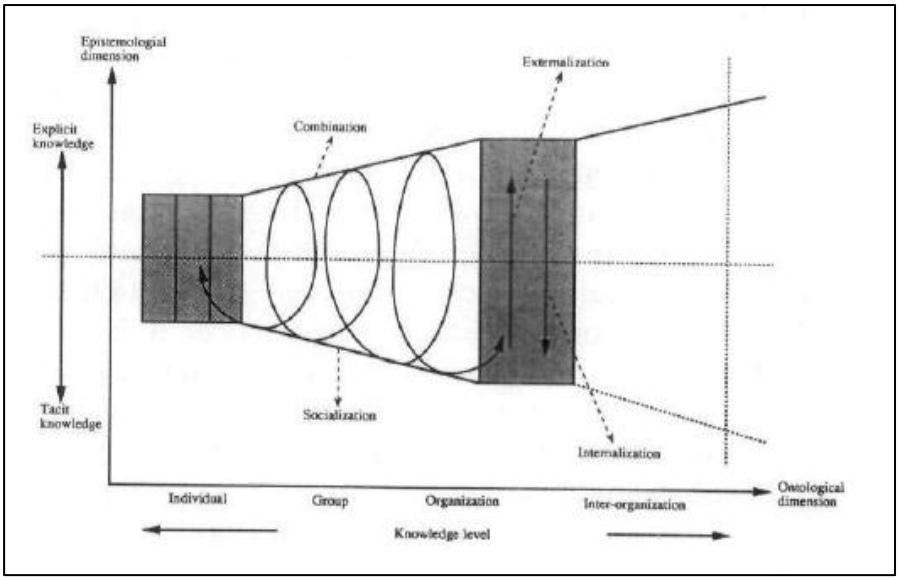

Figure 4: Spiral of knowledge creation (source: Nonaka, 1994)

How these independent modes of knowledge creation interact dynamically through the organizational dimension is illustrated in their spiral model of knowledge creation (fig.4).

On the other hand, Nelson and Winter (1982) proposed their evolutionary theory of economic change, grounded on a critique of the central tenets of standard production theory. Synthetically, this latter theory claims the existence of an optimal conversion of inputs into outputs, namely a production function. The classical inputs are capital and labour, and the technical knowledge required for this productive transformation is considered universally available, through information-processing lenses.

In other words, all the information produced during the productive transformation of inputs into outputs can be detectable and processed to obtain the technical knowledge required to achieve optimality. Information-processing approach, a core idea of cognitive psychology, considers human beings as information processor, acquiring through their sense inputs/information provided by the surrounding environment which can be stored, elaborated and retrieved.

In responses to this conception of technical knowledge as available since embodied in equipments and machinery, Nelson and Winter propose an

adapted production function which accounts also for tacit knowledge, skills, even rules of thumbs and knowledge socially embedded in organizational structures.

According to Spender (1996), Nelson and Winter have been the first authors to introduce tacit knowledge into the formulation of a theory of the firm.

What embodies and links such stocks of both explicit and tacit knowledge and is the basis of their theory of the firm are routines. Organizational routines are in fact the natural repository of knowledge since they bridge in quasi-formal way individual skills.

The underlying concept of the evolutionary theory assumes that firms adapt to the external economic environment through dynamically combining tacit and explicit knowledge, and that such knowledge is embedded in organizational routines.

Thus, routines are seen as the memory of organizational knowledge, which constrain individual choices of individuals, acting as a set of rules both implicit and explicit. According to the historical and economic reality a firm is experiencing, emerging choices of individuals can be selected and change brought about, which again is fed back into routines that will constrain further individual choices. In this sense the theory reveals its evolutionary character. Thus, routine seems to cover all the aspects required to apply an evolutionary framework:

- How variation takes place: routine have the capacity to mutate.
- How selection occurs: individuals embedded in routines take choices, which are selected according to the historical and economic reality.
- How selection in one period is transmitted into the next period: routines are considered as the memory of the organization as well as to represent stability.

Whereas routine seems to be a suitable unit of analysis, its understanding and definition remains still imprecise (Cohen et al., 1996).

Without extending further this discussion concerning routines, it has been noticed (Becker, 2004) that the concept of "*pattern"* has been essential for many scholars, including Nelson and Winter, in defining the concepts of routines as the unit of analysis for evolutionary studies. It is the meaning of *patterns* the locus of ambiguities, leading to a dualism among theorists: some emphasising the role of routines in organizational inertia and stability, others arguing their dynamic and generative nature (Pentland and Feldman, 2005).

As final point of this brief summary of the main tenets of Nelson and Winter's theory, it needs to be clarified that in evolutionary theorising in economic change, individuals operate in bounded rationality, which means that firms can know independently from their employees' conscious reasoning.

2.2.3 A critical appreciation of knowledge theories

We have seen in the previous section that collective knowledge can be represented as a dynamic relational approach linking different types of knowledge embedded in a social context. While knowledge can be created by individuals, there are stances to look at it in collective terms.

First of all, knowledge relies on the social context in which it is produced. Secondly, knowledge creation can be amplified by mechanisms of social interaction.

In Nonaka, knowledge creation is central and the four models of knowledge conversion in interaction amplify and augment this process. However, as Spender (1996) points out, there is no explanation how individuals generate tacit knowledge and there is no concern for the problem of agency. Furthermore, the externalization mode of knowledge conversion, which Nonaka claims as an under-researched area, is indeed a point of divergence among information-processing approach and the tacit knowledge tradition.

Nightingale (2003), through an interesting analogy with Darwinian theory and discussing recent advancements in neurological studies, highlights a set of intriguing conclusion, some of them are worthy of mentioning:

- our cognitive and linguistic capabilities are recent evolutionary developments and they stem and remain intertwined with non-conscious processes
- learning and problem solving is both tacit and explicit
- As learning occurs, knowledge becomes more tacit and nearly impossible to articulate

Therefore, the claim made by information-processing or codification theorists that tacit and explicit knowledge are substitutable inputs, meaning that codification of tacit knowledge is feasible through the advancement of Information technologies, is substantially false.

Nelson and Winter, therefore, have made a seminal contribution in providing a dualistic representation of different dimensions of knowledge, since more than substitutes these different dimensions are complements. Furthermore they address the problem of agency through the conception of routines as a set of rules that constrain individual choices.

However, it is not clear where the boundaries of these routines end up or in other words where the boundaries of the firm lie. This is a limitation due to the current economic scenario, where inter-organizational collaborations are becoming the dominant trend, increasingly reducing the boundaries of organizations.

Overall, evolutionary theorists locate the boundaries of a firm where knowledge becomes not easy to codify. However, identifying these barriers in the current information era is far to be an easy task. It presumes in fact the ability to codify tacit knowledge and it neglects the importance that tacit knowledge lying outside the firm may have.

Moreover, even though the evolutionary theory of the economic change refuses the exogenous explanation of change as in standard production theory (where technical knowledge is universally available), Nelson and Winter do not explicitly address how change occurs and there is limited empirical evidence based on their work on how routines change when assumed as the unit of analysis.

The conclusion of this critique of these two important theories is that communities of social interaction that share common practices and routines are two crucial collective entities upon which to explore the dynamic nature of knowledge. Both these collective entities span the organizational boundaries and function as conduits along which knowledge is created, amplified and flows. Therefore, more than packing them into a theory of the firm, it appears reasonable to embed and study them into the social context: a social network perspective serves this idea.

2.2.4 Social Networks as the knock down of epistemic culture

Spender (1996), using an analogy with the developmental sociologist Vygotsky, argues for the social entailment of knowledge. Drawing on a branch of developmental psychology interested in how children learn about the world and achieve their sense of self, Vygotsky argues that such abilities are not genetically programmed, but rather internalised from the social context in which a child grew up.

Substantially, Nonaka's modes of knowledge conversion points to the same arguments, in particular identifying social interaction as the vehicle through which convert and amplify knowledge. Nonaka takes as example community of practices as an ideal interaction community along whom tacit knowledge of individuals flows due to their shared practices.

More recent arguments follow the same trajectory. Tsoukas (2009) puts emphasis on social interaction through a dialogical approach, which allows

people to step back from their unreflexive ways of acting and develop further articulation concerning their task, leading to increased knowledge creation. Ponomariov and Boardman (2012), in their recent review of knowledge transfer channels between public and private organizations, highlight the importance of the personal involvement in processes of knowledge transformation according to the complexity of the knowledge involved. Drawing on David and Foray's definition of knowledge transformation as a social and dynamic process, they identify the concept of relation intensity (Perkmann & Walsh, 2007) as a proxy to describe the extent to which personal involvement of the participants is required in a particular knowledge transfer channel.

So, if knowledge has as well a social and interactional component, what role the social dimensions may play in benefiting or impeding knowledge creation and transfer?

It is the contribution of Brown and Duguid (2001) that traces a step forward in this direction. The authors emphasise that, independently from the type of knowledge, knowledge is amplified and flows through social interaction in communities that share common *practices*. In addition, drawing on previous work in scientific communities, they bring to attention the problem of epistemic barriers that originates from belonging to different scientific practices, which avoid any communication between people that could potentially share a great deal of knowledge. They refer to such loose epistemic groups as "networks of practices".

Moreover, drawing on the insights provided by March (1991) and Demsetz (1988), respectively on "exploration and exploitation of knowledge" and "on specialisation and coordination", the authors highlight the importance to balance among the search for new knowledge and the refinement of the existing one.

This could be thought of as a balance between more stable and coordinated patterns of interaction such as in routines, and more improvisational, adaptive and knowledge producing activities as in communities of practice.

However, undertaking a similar social perspective does not account for the types of knowledge that a social process underlies. This carries the risk to get a partial view of the phenomenon of interest as it applies when considering only types of knowledge as explanatory variables for knowledge creation and transfer.

In other words, it remains to be seen whether some specific social structures may ease such barriers of interaction.

2.2.5 Knowledge Networks

In this review of knowledge at the individual and collective levels we have identified a set of pillars that can be resumed as follow:

- An overarching epistemology of knowledge is the one provided by Polanyi which consists of a tacit and an explicit dimension.
- Knowledge is fundamentally individual, but can be amplified through collective activities
- Shifting from an individual to a collective view of knowledge entails defining a social context and addressing a dynamic interplay among tacit and explicit knowledge
- Tacit and Explicit knowledge are not substitutes, but rather complement, one requiring the other to achieve knowledge creation and transfer
- Tacit knowledge can be transferred and augmented among communities that share common practices
- Routine are a useful unit of analysis in explaining differences among Organizations
- Research among scientific communities reveals the existence of epistemic barriers that avoid knowledge transfer among communities that could potentially share a lot.

Recently Phelps et al. (29th May 2012) have provided a systematic review of empirical literature concerning knowledge networks. There is in fact increasing

empirical evidence showing how social relationships and the network they constitute affect processes of knowledge creation, diffusion, absorption and use (Phelps et al., 2012). However, as the authors assert, no systematic review of the literature on knowledge networks has surprisingly been addressed before. Understanding knowledge production and diffusion is without a doubt key in order to explain and address economic growth. Furthermore, there is increasing multidisciplinary evidence concerning *structural and relational properties* at the individual, group and organizational level constituting both the triggers and drivers of knowledge production and transfer. This evidence lays the foundation for a joint consideration of the network of relationships and knowledge in explaining economic or innovation outcomes.

However, a review of the literature on knowledge networks is not an easy task. Phelps et al. (2012:1117), drawing on previous notable contributions concerning the construct (Monge and Contractor, 2003; Yayavaram and Ahuja, 2008), define a knowledge network as:

"*a set of nodes- individuals or higher level of collectivities that serve as heterogeneously distributed repositories of knowledge and agents that search for, transmit, and create knowledge- interconnected by social relationships that enable and constrain the acquisition, transfer and creation of knowledge*".

This definition raises a fundamental question: Should ties among nodes in a knowledge network be only based on the social relationships occurring among them or should they instead account for members' knowledge stocks (e.g. diversity or complementariness in terms of the knowledge nodes have) or both simultaneously?

These in turn would affect the structure of the network itself, so that the meaning or interpretation of commonly addressed structural measures such as centrality, closure can be questioned: would they have the same significance when referring to knowledge?

Furthermore if the nodes are considered to be both repositories of knowledge and agents searching for, transmitting and creating knowledge, then the links among them could be established in virtue of knowledge-related mechanisms (e.g. seeking or communication mechanisms, interactional mechanisms for knowledge transfer).

Moreover, different conceptualisations of knowledge may introduce a further variable affecting the conceptualisation of a knowledge network.

To sum up, there are different ways in which a knowledge network can be constructed and giving prominence to one aspect over other may affect the type of outcomes.

In my view, this variety of possible constructs and perspectives has hindered the development of systematic reviews of the knowledge network literature, even though studies around this topic have existed for a long time.

Phelps et al. (2012) have finally proposed a stratified review model according to the level of analysis (interpersonal, intra organisational, inter organisational) and linking knowledge outcome (creation, transfer, adoption) with knowledge network elements (structural properties, relational properties, nodal properties and knowledge properties). This is for sure a step forward for advancing empirical research in knowledge networks. However if we return to the argument made so far, this framework does not distinguish between the variety of constructs, the contexts of investigation, mechanist (longitudinal) or cross-sectional approaches and the conceptualisation of knowledge adopted.

In this supplementary paper I provide four different perspectives of knowledge networks that, to the best of my knowledge, represent the overarching constructs that have been devised in literature. I will argue that some of the shortcomings highlighted by Phelps et al. (2012) stem from the particular conceptualisation of knowledge and the construct adopted for investigation. I will then come up with a Review question that in my opinion may extend the review proposed by Phelps.

2.2.5.1 *A set of overarching constructs*

The first construct stems from those network studies that examine the structure of relationships occurring among social entities and its effect on knowledge outcomes. Generally such relationships are drawn building advice networks (e.g. who do you mostly rely upon when sourcing knowledge?), measuring the strength or frequency of such relationships and inferring knowledge outcomes. While the structural and relational measures underpinning such studies may point to knowledge, the construct remains mainly focussed on the structure of social relationships occurring among individuals, units or organisations. These studies are mostly cross-sectional and results revolve around the positive correlation between particular relational or structural configurations and outcomes such as ease of knowledge transfer or knowledge creation (e.g. Reagans and McEvily, 2003).

Underpinning theories or constructs: structural sociology, advice network

The second construct, proposed by Hansen (2002) is quite similar to the first but it includes knowledge considerations directly in the network of relationships. The knowledge network therefore consists of the existing relationships among units which share common knowledge, as illustrated in figure 5.

Underpinning theories or constructs: structural sociology and absorptive capacity

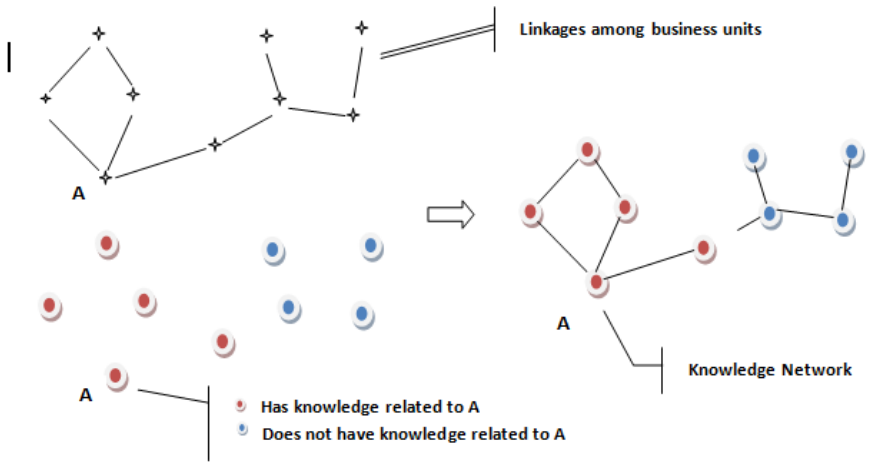

Figure 5: Knowledge Network (source: Hansen, 2002)

The third construct, such that developed by Saviotti (2003, 2005), considers knowledge as a correlational structure and a retrieval/interpretive structure. This means to provide knowledge with two properties:

1. knowledge establish co-relations, or connections, between variables and concepts
2. knowledge enables us to recover types of knowledge similar to those we already knew, therefore aligning with the absorptive capacity construct.

Ties in this conceptualisation of a knowledge network denote the co-occurrence overtime of the same knowledge attributes among nodes. Through the use of Social Network analysis measures (density, degree centrality, betweenness centrality, closeness centrality) the authors are able to exemplify the structure and evolution of the knowledge base of a firm or sector and relate it to changes in firm strategy and firm organization (Saviotti et al. 2003, 2005)

Underpinning theories: complexity theories (e.g. Prigogine)

It is worth pointing out that Phelps (2010) and Krafft et al. (2011) combining the **construct 1** with **construct 3** have been able to quantitatively ascertain processes of exploration and exploitation or distant and local search.

In the fourth construct, introduced by Contractor et al (1998, 2002), nodes (be they individual, collective entities or even knowledge repositories) have different *knowledge items* as attributes. A tie is likely to occur among nodes when they share some attributes. The more knowledge items are common among two nodes the more the tie which links them will be strong. A representation of knowledge networks so conceived is illustrated in figure 6.

Again, the metrics developed in social network analysis can be used for the analysis of such networks. However the focus here is, more than the analysis of the knowledge base, toward testing multiple theoretical mechanisms that drive the evolution of the network at different levels (see appendix A for a clarification of the various mechanism).

Underpinning theories or constructs: multiple theoretical mechanisms which operate simultaneously

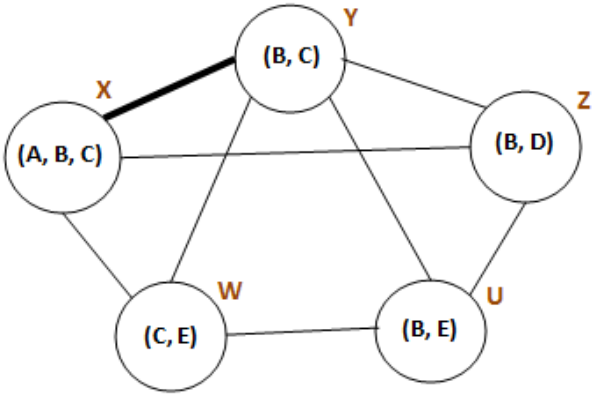

Figure 6: Knowledge Network (source: Contractor et al., 1998)

2.2.5.2 *Future research in Phelps et al. (2012)*

It is reasonable to assume that as a consequence of the particular construct and the conceptualisation of knowledge adopted we may find different outcomes, causal mechanisms and relevant properties of the network associated. It would be therefore interesting for the systematic review to categorise the articles revised by Phelps et al. (2012) along the conception of knowledge and the construct used, and relate these to importance of structural and relation properties and outcomes.

Overall, Phelps et al. (2012) raise some interesting avenues of research substantially based on the lack of current research in considering knowledge diversity, or in other words, the depth and diversity of network members' knowledge stocks and their effect on knowledge flow and creation. The argument is based on the need to disentangle the effect of particular structural and relational properties on knowledge outcome from the influence of members' knowledge stocks on such outcomes. Being the majority of knowledge networks study focussed on the consequence of structural and relational properties on knowledge outcomes and treating nodes as "passive vessels through which information and knowledge flow unimpeded and unchanged" (Phelps et al., 2012:1148), the authors argue that nodal agency and stocks of knowledge have suddenly been overlooked in current literature. Addressing these points may resolve some of the conflicting results found in knowledge network literature. However, when expanding on this argument, Phelps et al. (2012) call for the human cognitive nature of knowledge, and associate it with memory.

Shedding light on the various conceptualisations of knowledge and the constructs of knowledge network deployed confirm to be crucial in order to address future research.

2.3 A bit or reasoning: The review question

In my scoping study I attempted an articulation of the theoretical arguments around structure and knowledge network. This has highlighted, on the one hand, the importance of stable and changing patterns of structural configurations and, on the other, the dynamic nature of knowledge and its dependence on the social context. It is not difficult to realise that interactions occurring between an individual and his surrounding environment and between people (standing within and beyond collective entities) support the processes of knowledge creation, diffusion and use. Again, a network representation enables us to reason about such patterns of interaction: where do they come from? how might they enhance some outcomes? or how could they explain the occurrence of certain phenomena. What has been widely argued is that an epistemology for knowledge is required along the specification of a context in order to obtain knowledge-based explanation for particular outcomes and phenomena. Whatever dimensions for knowledge we chose to explain particular outcomes or phenomena, focussing on patterns of interaction and coupling overtime appear to be crucial.

I want to focus therefore on longitudinal studies and observe how the structure of knowledge network changes or remains stable overtime.

Focussing on change is the most suitable way to understand systemic variation and identify causes and mechanisms of change, be they related to the whole network, the local one or even nodal properties. This is to say that network change and evolution is not exclusively related to structure, but can rely on external stimuli or endogenous factors triggered by changes in the nodes. However, the *structural dimension* is without a doubt the most evident and assessable one when exemplifying network change, evolution or dynamics and may provide the most complete overview of knowledge network phenomena.

Similarly, stable network configurations are of particular interest, since they may inform us about knowledge factors responsible for holding wholes together.

My review question therefore is:

How and in what circumstances does change or stability occur in knowledge networks' structure?

3 Methodology

The aim of this chapter is to provide a detailed view of the process I followed in developing this work by means of systematic review. To this end, I will first discuss briefly what a systematic literature review consists of and in what ways it substantially differs from traditional types of literature reviews. Following this, I will describe all the steps taken to address this work in conformity with the systematic approach proposed by Tranfield et al. (2003). These consist of: 1) forming an advisory panel, 2) search strategy, 3) statement of the inclusion/exclusion criteria, 4) quality appraisal and 5) process of synthesis and reporting.

3.1 A Systematic Literature Review

A systematic approach in conducting a review of the literature has its roots in a movement, developed in the early eighties across the UK, demanding more rigorous and evidence-based policy and practices (Tranfield et al., 2003). To this end, more reliable and transparent procedures of synthesizing research findings proved to be necessary.

Medical sciences have pioneered this renewed attention for the quality improvement of the review process. This was due to the particular need in medical sciences to make sense of the massive production of often-contradictory evidences. Furthermore, the positivist tradition of this field aided the establishment of more evidence-based approaches. In fact, it is often feasible in medical research to aggregate results from different studies so as to bring them in comparison or contrast through statistical lenses.

Literature reviews in the medical sciences have thus increasingly entailed the deployment of more systematic, transparent and replicable processes of synthesis aiming to minimize the bias and preferences of the researchers, often attributed to more traditional narrative approaches. Statistical procedures such

as meta-analysis, suitable for the characteristic findings of medical research, have been developed in order to increase the reliability of processes of synthesis of diverse results but that can be somehow aggregated.

While such evidence-based review practices have found application in other areas of scientific inquiry, this has not been the case for management research, due to its fragmented and divergent nature. However, Tranfield et al. (2003:219) suggest that even if an evidence-based approach is nearly impossible in the management field, this can benefit from 'evidence-aware' or 'evidence-informed' approaches aiming to bound available options that may better inform decision-making processes.

Thus, after having scoped the literature surrounding my field of enquiry, I will follow the steps suggested by Tranfield et al. (2003) so as to pursue a systematic approach suitable for management research. This, as already mentioned, entails:

- Selecting an advisory panel which may provide support during the various phases of the systematic review
- Identifying a search strategy and an effective search string
- Selecting papers according to well-defined criteria of inclusion/exclusion
- Appraisal of the selected papers according to explicit quality criteria
- Data Extraction
- Developing a synthesis of the findings which is 'evidence-informed' or 'evidence-aware'.

The first five steps are outlined in the following.

3.2 Advisory Panel

The purpose of assembling a review panel is to identify a set of technically balanced experts which may provide:

- guidance and feedbacks on both theoretical and practical issues underpinning my field of enquiry
- help in those methodological aspects more closely related to the systematic review process (inclusion and exclusion criteria, database search, quality appraisal).

The members of my panel are listed below (Table 1) and detailed for their specific involvement and frequency of interaction.

Table 1: Members of the Panel

Person	Organization	Involvement	Frequency
Colin Pilbeam	Cranfield School of Management	Supervisor: coaching, review of all my writings	Very frequently
Liz Varga	Cranfield School of Management	Reviewing my scoping study and advising me on relevant literature in network research	Occasionally
Mark Johnson	Cranfield School of Management	Reviewing my scoping study and advising me on relevant literature in network research	Occasionally
Marco Tortoriello	IESE Business School	Advising me on relevant literature in knowledge network research	Occasionally
JC Spender	Esade & Lunds Business School	Advising me on relevant literature and providing insights on epistemological issues about knowledge	More than occasionally
Dimitris Assimakopoulos	Grenoble School of Management	Advising me on relevant literature on tacit knowledge, logics of social structures and networks.	More than occasionally

Parimal Patel	SPRU, University of Sussex	Providing insights about the advantage and limitations of using patent data in conducting network research	Occasionally
Maria Weir & Ludo Pyis	AREOPA group	Providing insights about relevant issues in knowledge management from a practitioner standpoint	More than occasionally
Heather Woodfield	Cranfield University Library	Information Specialist: advising me on literature searches and database management	Occasionally

3.3 The search strategy

3.3.1 Key words and search string

The review question framed in my scoping study (*How and in which circumstances does change or stability occur in knowledge networks' structure?*) informs my search strategy by putting particular emphasis on *change* and *stability* in the structure of knowledge networks. Obviously both change and stability in a network structure can be appreciated through time, thus remarking the need to focus on longitudinal empirical evidences. The keywords used as synonymous of *change*, *stability* and *knowledge networks' structure* are illustrated in Table 2. These will be meaningfully linked so as to formulate a pertinent overall search string.

Table 2: keywords used in the overall search string

Topic	Keywords	Explanation
Change	chang*, dynamic*,evolution*, evolv* and volatility	While there are arguments in literature drawing clear distinctions among evolution, change and dynamics, they have been often confused and therefore interchangeably used.
Stability	stability and longitudinal	Longitudinal here has been chosen in order to emphasize the interest towards stability observed through time.
Knowledge Network's Structure	Network, structur*, configuration*, knowledge	I have pointed out in the scoping study that the terms network and structure had hardly been distinguished in literature. The keyword configuration* is a pertinent synonymous, while for knowledge it can be misleading (or equivalently it implies that I am embracing a particular perspective of it) to look for other words that hold the same meaning.

However, before I provide the overall search string whereby I ran queries to relevant databases, some premises are necessary. Indeed, terms such as *knowledge, network and structure* are overused in literature, thus requiring an effective articulation of the keywords which compose the string. To this end, I made use of an adjacency or proximity operator (w/n) which allowed me to choose how close (n) two terms need to be to each other in a record in order for this record showing up among the search results. The adoption of such constraints on the way words couple together may in fact ensure a degree of relevance of the articles being selected through querying different databases.

Based on meaningful combinations of the words '*network, structure and knowledge*' (e.g. 'the knowledge in the network', 'the structure of a knowledge network' and so on) as well as relying on my experience on how these terms have been combined in the literature, I came up with the following overall search string (Table 3).

Table 3: Overall search string

Focus of the review question	Overall Search String	Clarification
Change/Stability on knowledge networks' structure	knowledge *w4* (structur* or network*) OR network *w3* (structur* or configuration*) **AND** Chang* or dynamic* or evolution* or evolv* or longitudinal or volatility or stability **AND** Knowledge	This first line ensures that an article covering: 1) whatever combination of '*knowledge and structure'* or '*knowledge and network*' within 4 words and in any order **OR** 2) whatever combination of '*network and structure'* or '*network and configuration*' within 3 words and in any order, passes the first threshold. Articles which satisfied the requirements fixed though the first line of the string need to refer to one of the words detailed in the second line in order to be selected. While knowledge in this third line appears to be redundant (thus not compromising anything discussed so far), it indeed implies that articles which have passed the *first* threshold via condition 2) must explicitly refer to knowledge in order to be included among the results.

Posed this way, the overall search string encompasses a wide but relevant range of word combinations that will allow extracting the largest number of possibly significant papers. In fact, it does not only identify papers directly referring in the full text to ‘change or stability’ and ‘knowledge network’ (or compounds indicative of them), but it does include as well articles that talks more generally about ‘network structure’ or ‘network configuration’ and which explicitly refer to knowledge. From my experience, it may well be the case that such articles are relevant for the purpose of this review in knowledge network research.

3.3.2 Search results

I have used the string discussed above to search across three different databases: EBSCO, ABI and Scopus. EBSCO and ABI are the most comprehensive database sources for business and management studies. Moreover, these databases cover a wide range of scientific publications in the fields of knowledge management, organization theory and practice, strategic management and research policy. In particular ABI covers more than 3000 periodicals with coverage of all the aspects relating to business and economic systems. While there is a degree of overlap between the two, EBSCO is even wider than ABI, covering key additional journals on the above mentioned fields of enquiry. All these fields of research have been crucial in positioning my field of enquiry, making therefore ABI and EBSCO pertinent sources for the focus of this review. Moreover, their search interfaces provide very sophisticated mechanisms for searching, browsing and limiting, allowing the use of Boolean and proximity capabilities.

Nevertheless, while the focus of this review revolves around how knowledge network research may inform business and management practices, it was as well evident in the scoping study how my field of enquiry has its roots on long-standing sociological and psychological tradition of research. Furthermore, due to the increasing multidisciplinarity of network research, with recent contributions coming from physicists and information scientists, a search has been also performed in Scopus. Scopus is the largest abstract and citation

database of peer-reviewed literature and it is particularly useful in researching beyond the scope of management literature, including peer-reviewed studies in psychology, sociology as well as in information science, scientometric and physics. Again, as for EBSCO and ABI, the advanced search of Scopus is very functional and permits to limit the search across disciplines and areas of research.

The number of hits resulting from the search string (the search has been performed over the full text by ticking the box: *linked full text*) across the different databases is illustrated below in Table 4.

Table 4: Hits from different databases

EBSCO	ABI	SCOPUS
955	2511	3671

The number of hits was quite high, making the process of screening and identification of relevant studies a fairly time consuming task. Relevant hits spotted by EBSCO and ABI nearly overlapped, while Scopus provided a different bunch of papers, although often irrelevant. The criteria of inclusion/exclusion undertaken in this work allowed speeding up this laborious process, and are discussed in the following section.

3.3.3 Inclusion/Exclusion Criteria

The criteria of inclusion/exclusion embraced in this work stem from the review question framed in the scoping study. These have been applied in first instance to the title, abstract and, when required, to the methodology section, and secondly to the full paper.

3.3.3.1 *Inclusion/Exclusion criteria applied to the title and abstract*

The focus of this review, as discussed in the scoping study, is on longitudinal empirical evidences accumulated so far in knowledge network research. Therefore I followed previous literature reviews with similar objectives and narrowed this review around empirical studies (Phelps et al., 2012, Provan et al., 2007). As Phelps et al. (2012:1118) have pointed out, 'including untested theoretical arguments would make it difficult to compare and contrast studies since some would contain empirical findings regarding particular theoretical arguments while others would not'. Furthermore, I argue that a comparison between cross-sectional and longitudinal studies is as well problematic, leading to possibly incorrect and unsubstantiated results. In conformity with my review question the main criteria of inclusion/exclusion adopted in this preliminary screening impose that an article to be retained has to provide empirical evidence and to undertake a longitudinal approach (Figure 5). There were no restrictions regarding journals ranking, qualitative vs. quantitative approach, levels of analysis, date or language of publication: I tended to be as inclusive as possible given the limited number of publications expected.

This has resulted in the selection of **96** empirical articles of which **70** claimed to be longitudinal.

Table 5: inclusion/exclusion criteria applied to title, abstract and data analysis sections

Inclusion Criteria	Exclusion Criteria	Number of records relevant
Empirical	**Conceptual or theoretical**	96
Longitudinal study	**Cross-sectional study**	67

When the title and the abstract of an article did not provide sufficient information regarding its empirical and longitudinal lens, I verified this was or was not the case by screening both the methodology and data analysis sections.

A more detailed look at the foregoing sections revealed that some of the 70 longitudinal empirical studies (N=3) made use of longitudinal datasets but in reality they did not empirically observe variations overtime.

An example is the work of Ozel Bulent (2012), whose aim has been to investigate the relationships between collaboration patterns in academia and individual cognitive structure in a given scientific community. While using a longitudinal datasets of co-authorships and having identified a set of network measures related to individual cognitive structure, the author limited his empirical analysis to a cross-sectional statistical correlation, thus referring to a cumulative network of collaboration and overlooking patterns overtime.

For similar reason the three papers have been excluded.

3.3.3.2 *Inclusion/Exclusion criteria applied to the full paper*

Two criteria were applied sequentially to the full text so as to identify papers clearly referring to knowledge network research. The former consisted of ensuring that each paper conducted empirical analysis based on social network variables, explicated as:

- At least one variable is related to a characteristic of a social relationship or a collection of social relationships

The latter, instead, required that each paper referred closely to knowledge, though in one of several ways. I therefore selected papers that satisfied at least one of the following conditions (all revolving around knowledge):

- A dependent or independent variable was related to knowledge (e.g. proxy for knowledge creation, transfer or knowledge characteristics of actors)

- A particular construct built for conducting empirical analysis was indicative of knowledge. (e.g. assuming technological classes as knowledge-related artefacts, a network in which nodes represent such

classes with a relation defined over them is an example of a knowledge network construct)

- A clear conceptualization or theory of knowledge was underpinning the empirical analysis

Using these second set of inclusion/exclusion criteria I ended up with **17** articles.

Table 6 : Inclusion/exclusion Criteria applied to the full text

Inclusion Criteria	Exclusion Criteria	Number of records relevant
At least a variable refers to a characteristic of a social relationship or collection of social relationships	**Lack of social network variables**	41
If a paper satisfied just one of the three following criteria (inclusion criteria) this has been accepted		
A dependent or independent variable related to knowledge	**Lack of knowledge-related variables**	17
A construct used for analysis is indicative of knowledge	**The relational construct, built for network analysis, does not refer to knowledge**	
Theory or conception of knowledge underpinning the empirical analysis	**There is any theory or conceptual framework for knowledge guiding the empirical analysis**	

3.3.4 Other sources

I decided to search for further articles by cross checking the references of the papers selected so far. The most relevant papers have been validated through the criteria discussed in the previous section, resulting in two additional works. It

needs to be emphasized that by looking just at the title and abstract of these paper, they match the requirements in terms of keywords imposed through the search string. This questions the accuracy of database search through tailored strings of keywords. The two articles are referenced below:

- Orsenigo, L., Pammolli, F., Riccaboni, M. (2001). Technological change and network dynamics Lesson from the pharmaceutical industry. *Research Policy*. 30(3), 485-508

- Phelps, C.C. (2010). A longitudinal study of the influence of alliance network structure and composition on firm exploratory innovation. *Academy of Management*. 53(4), 890-913

3.3.5 Quality Appraisal

The 19th papers which passed the exclusion/inclusion requirements have been subjected to a quality appraisal. This consisted of a set of questions adapted from Huff (1999) and Kmet et al. (2004), which differ according to the methods deployed in the study under scrutiny. Questions in Table 5 have been used to assess quantitative studies by giving a score from 1(not at all) to 5(to a significant level), while those listed in Table 6 have been used for evaluating qualitative studies.

Table 7: Questions for assessing Quantitative Studies

Appraisal for Quantitative Studies	1	2	3	4	5	N/A
Theoretical foundations and hypothesis generation						
Are the propositions and hypothesis of the study clearly articulated?						
Are the basic arguments of the paper relevant to the review questions?						

Are relationships among variables clearly explained?						
Description and evaluation of methods						
Is the methodology of the paper clearly identified?						
Are data collection methods and sampling strategy adequately described?						
Is the operationalization of the variables and constructs plausible (content validity)?						
Are dependent, independent and control variables identified and described?						
Is there evidence of reliability or internal consistency in the study?						
Results						
Are results clearly related back to original propositions, hypotheses, research questions, and data analysis?						
Some estimate of variance is reported for the main results?						
Is implied causality justified?						
Has the author made us of verification procedure(s) to confirm validity and to establish credibility?						
Has the author adequately alternative explanations for the results found?						

Table 8: Questions for assessing Qualitative Studies

Appraisal for Qualitative Studies	Yes(2)	Partial(1)	No(0)

Question / objective sufficiently described?			
Are the basic arguments of the paper relevant to the review questions?			
Connection to a theoretical framework / wider body of knowledge?			
Sampling strategy described, relevant and justified?			
Data collection methods clearly described and systematic?			
Data analysis clearly described and systematic?			
Use of verification procedure(s) to establish credibility?			
Conclusions supported by the results?			

Each characteristic listed above was considered as having the same weight for judging the quality of the papers. Obviously the cut-off was different for quantitative and qualitative studies. I deemed a quantitative article accepted if showing an average score of at least **3** while not assuming the value of **1** in any items. For what concerns qualitative articles, these were included in the review when scoring in average **1** and nowhere **0**. In other words, I fixed the threshold around the mean value and I have taken into account for the skewness that such a choice might entail by fixing the minimum score an article has to meet across all the items to be accepted.

The 19 articles selected for this review scored consistently above the fixed thresholds, at the exception of just one article. The criterion according to which this quantitative article (Yu et al, 2011) did not match the fixed threshold is that demanding relevance of its underlying arguments for answering the review question. The foregoing consideration led to retain nearly all the papers, with just one rejected.

A schematic representation of all steps addressed for the methodology of this review is depicted in Figure 8.

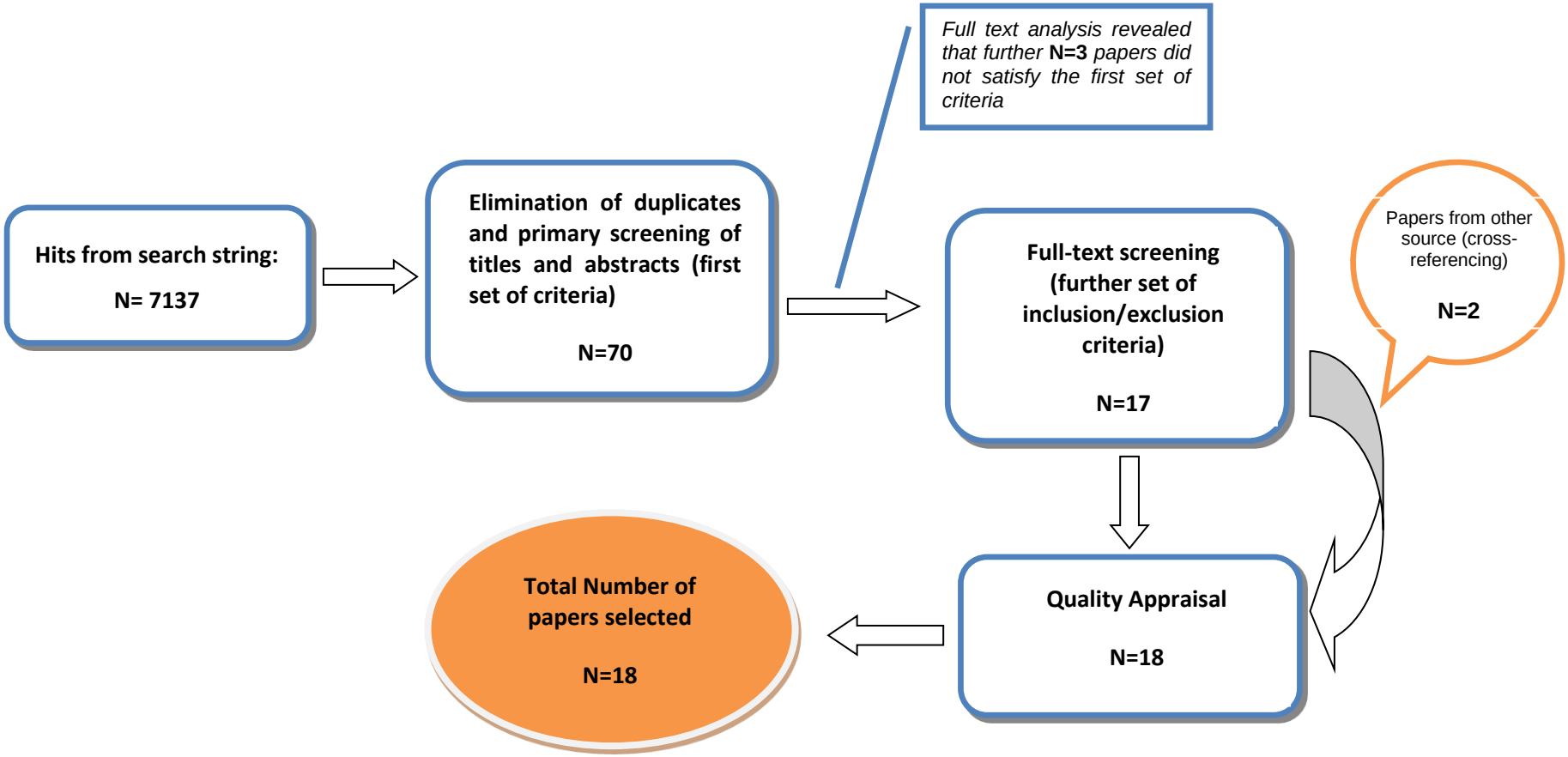

Figure 7: Overview of the Methodology

3.3.6 Data Extraction Form

The aim of designing a data extraction form is to ensure that consistent information is extracted from all the papers so as to ease the process of synthesis while enhancing the relevance of the outcomes of the review. To this extent, I decided to not include in the form more general information (title of the publication, journal, country of the first authors that will be depicted in the descriptive analysis) and give prominence to particular aspects that my accumulated knowledge of the literature and a preliminary overview of the papers suggested.

The form adopted is illustrated in table 7, where a description of the label used is provided when necessary.

Table 9: Data Extraction form

Authors	Context	time interval between observations and data sources	Underlying conceptualization of knowledge	Network Representation undertaken	Structural Parameters	Knowledge-related variables	Findings
			What the authors implicitly or explicitly assume knowledge is about	What nodes and links of the network built for analysis represent	Characteristics and measures concerning a web of social relationships		

4 Descriptive analysis of the literature

This chapter is intended to provide an overview of the main features of the body of literature selected for this review. The aim is to describe general trends but also to identify conceptual divides or alignments among the papers selected so as to inform the analysis of the findings, which is presented in the next chapter. In so doing, this descriptive analysis consists of two main sections. The first deals with more background information contained in the articles, such as the types of journals covered, the geography of the publications, methodology deployed, sources of data and distribution of the number of publications overtime. The second section instead starts addressing more content specific trends, such as the conceptualization of knowledge undertaken, the types of parameters adopted in the empirical corroboration.

Therefore the conceptual analysis presented in this chapter offer some overall insights concerning the area of enquiry as well as a preliminary understanding of its conceptual base.

4.1 Main Features of the selected papers

The trends discussed in this section are: 1) the range of journal covered by the body of literature selected, 2) growth in longitudinal studies on knowledge networks, 3) geography of the publications, 4) contexts of investigations, 5) sources of data and 6) methodologies deployed.

4.1.1 Journal Covered in the Review

Considering the number of papers relevant for the purpose of this review, the range of journal covered by these is quite wide. It consists of 12 journals, 8 of which are highly ranked (4*). These are represented in Figure 10. The only journal which dominates the scene is *Research Policy*, mainly focusing on the empirical analysis of the interaction between innovation, technology or

research, on the one hand, and economic, social, political and organizational processes on the other.

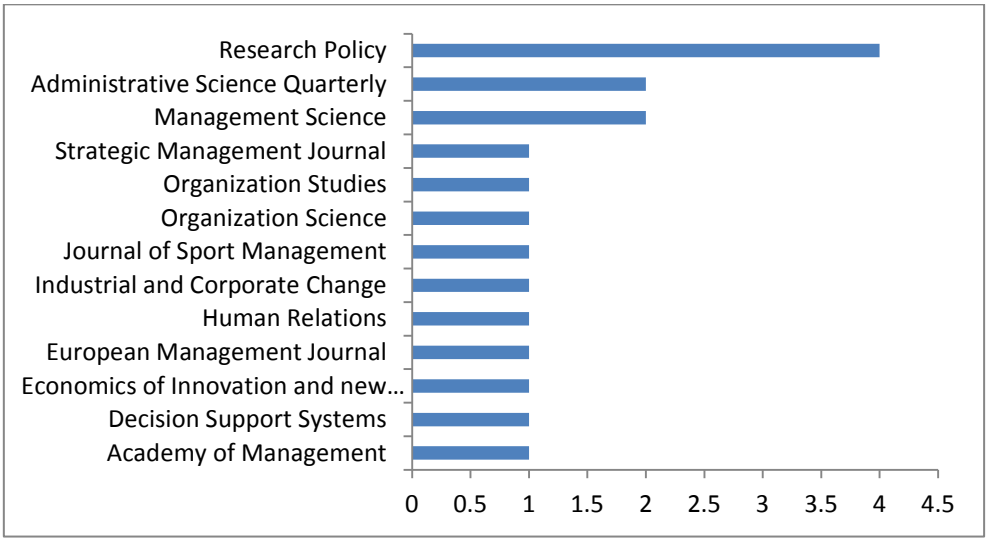

Figure 8: Number of Papers (*x*-axis) distributed across Journals (y-axis)

4.1.2 Growth in Knowledge Network Research

The distribution of publications across time (Figure 1) suggests that longitudinal knowledge network research is a fairly recent and fast-growing body of literature. This may be due to the increasing availability of longitudinal data sets or fundamentally a result of the acknowledged limitations that the more established cross-sectional perspective implies for the analysis of knowledge processes.

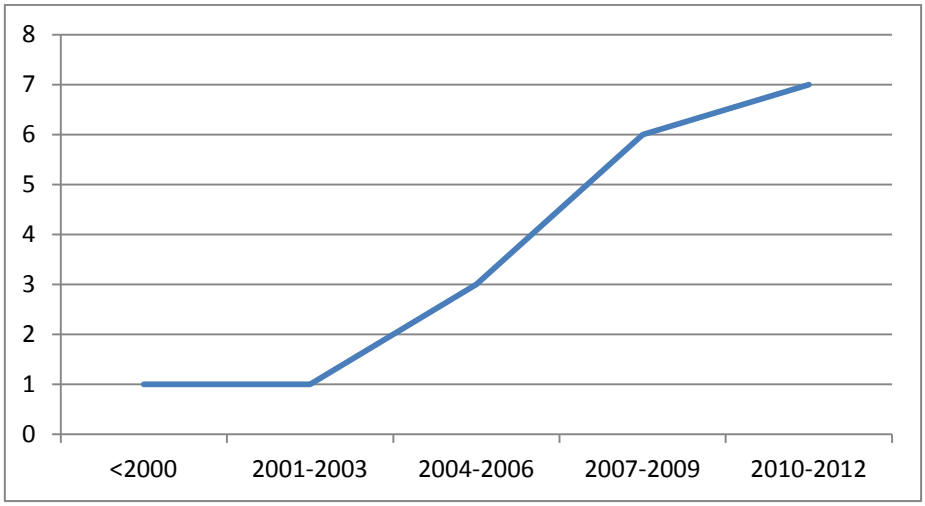

Figure 9: Number of longitudinal studies on knowledge networks over time

4.1.3 Geography of the publications

Figure 11 depicts the geographical trend among the selected literature. This has been obtained by retrieving the universities' location of the first author of each paper. Longitudinal Knowledge Network Research looks like a Western affair, even if few studies are emerging also in the East. USA leads the field, followed by Italy and France.

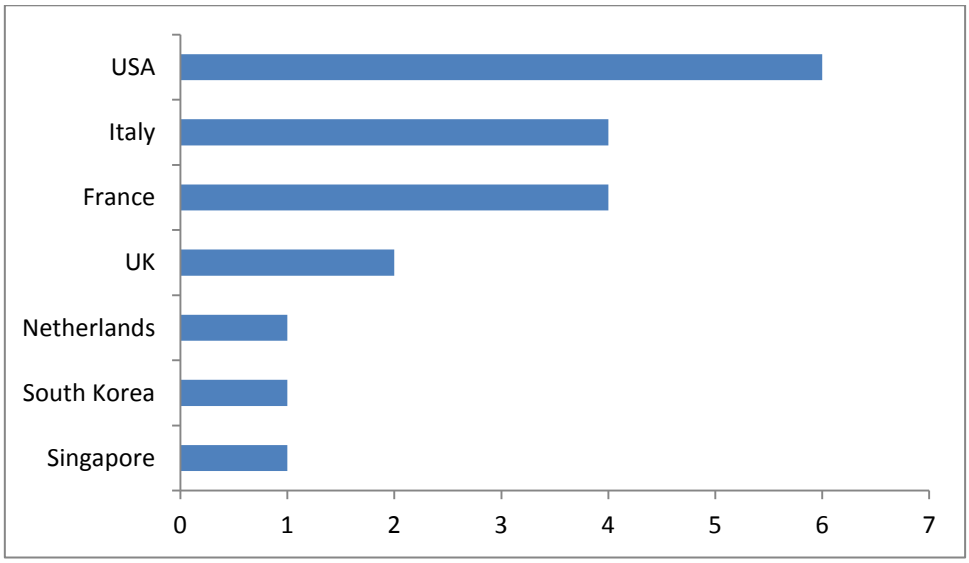

Figure 10: Location of the Institutions of the first authors

4.1.4 Contexts of Investigation

Figure 12 shows the range of contexts that have been chosen as settings for empirical investigations. The great majority of these are sectors with high research and development intensity, characterized by continuous technological change and rapidly expanding intellectual developments. This is not surprising given that the emphasis of the review question posed for this systematic review was centred on *change* and *knowledge*. Similarly, such rapidly developing fields rely on knowledge which is both sophisticated and widely dispersed among social actors, thus going beyond the capability of any single entity and calling for greater connectivity. This makes the social network paradigm a suitable one for examining knowledge processes.

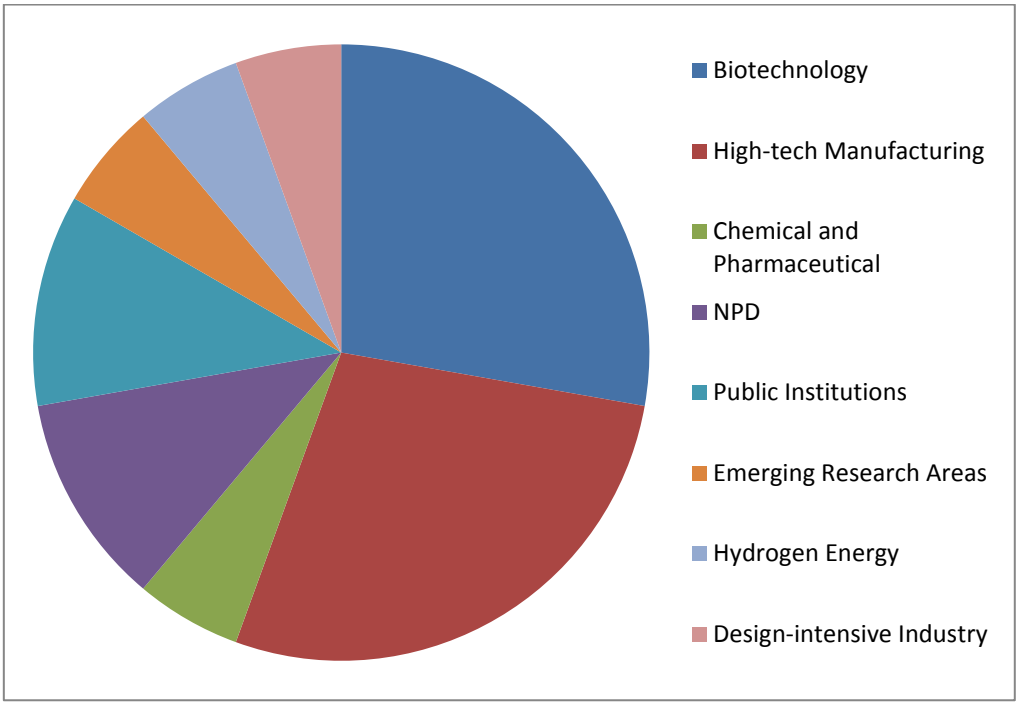

Figure 11: Range of sectors chosen as empirical settings

4.1.5 Sources of data

I have discussed in the previous section that fields characterized by rapid intellectual developments entail mechanisms of integration among widely dispersed social actors with different stocks of knowledge. This in turn may imply that the knowledge resulting from such joint activities is disclosed to a wide audience and objectified, and thus pretty much prone to leak across porous boundaries or to be exploited by few key players through opportunistic behaviour.

In order to avoid this, organizations make efficient use of institutional mechanisms, such as patenting and formal agreements. The consequences of this are twofold: on one hand patenting and formal agreements play a crucial role in knowledge-intensive sectors, while on the other hand the availability of electronic data concerning such activities over time are increasingly exploited to investigate knowledge network phenomena. Figure 13 illustrates how patent data and alliances databases are the most used sources of secondary data in longitudinal studies in knowledge network research. Other secondary sources are R&D program data, publication databases and archival records. Primary data are less popular in the field, probably due to the obvious difficulties in generating longitudinal network data.

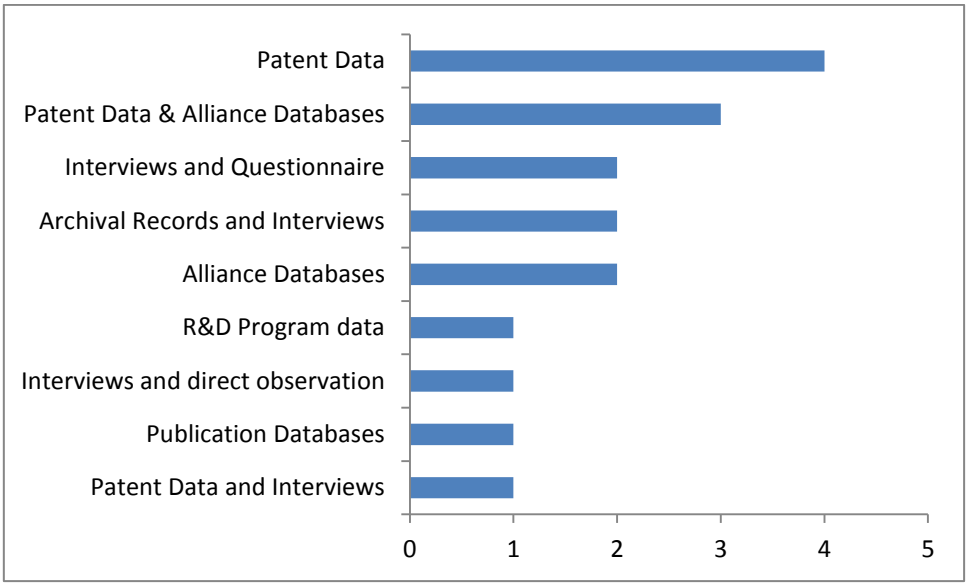

Figure 12: Sources of data

4.1.6 Methodologies deployed

The field so far is quite homogeneous in terms of epistemological stances and methodologies deployed. In fact, almost the entire body of literature examined assumes a positivist stance and make use of quantitative methods. Few papers make use of mixed methods, while just one study adopts an interpretivist epistemology, making use of ethnographic methods. This is illustrated in figure 14.

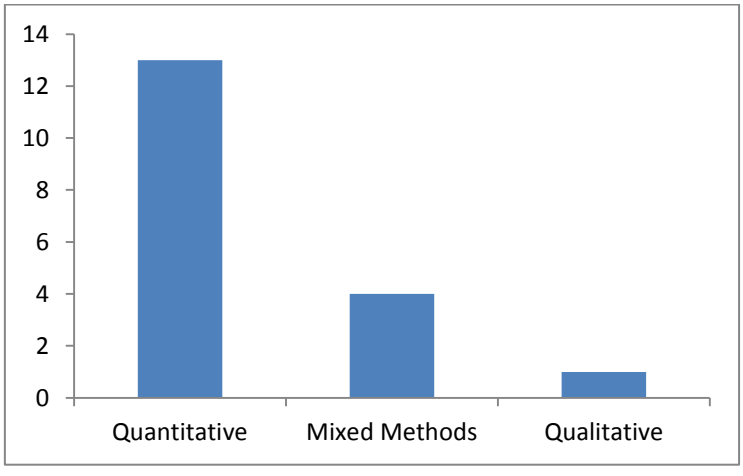

Figure 13: Methodologies deployed

4.2 Descriptive Content Analysis

The aim of this section is to start synthesizing some conceptual information contained within the 19 articles of this review so as to set the scene for the more thorough content analysis offered in the next chapter. In conformity with the issues raised in the scoping study, which led to the review question grounding this systematic review, it will be useful to scrutinise 1) the underlying conceptualization of knowledge undertaken across the various papers, 2) the structural and relational parameters addressed.

4.2.1 Underlying conceptualizations of knowledge

During the scoping study I have stressed the importance that a particular conceptualization of knowledge might exert on building a knowledge network and thus on the types of results that the empirical analysis of such a network might yield. It is therefore relevant to outline the various conceptualizations of knowledge that have been explicitly or implicitly addressed in the empirical investigations selected for this review. These are represented in Figure 15.

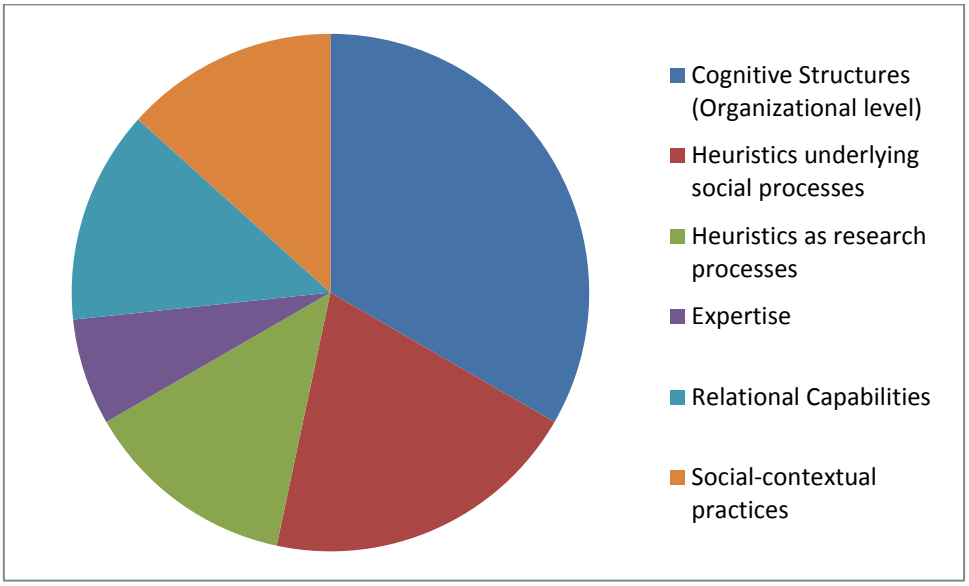

Figure 14: Conceptualization of knowledge

Almost 30% of the papers (N=5), among those that both implicitly and explicitly refer to a particular conceptualization of knowledge (N=15), understand knowledge as underpinning search-related processes at the organizational level. In so doing, they rely on artefacts (technological classes) and describe knowledge in relation to the decision-making processes which organizations undergo in coupling different artefacts. These coupling decisions depend on their belief or 'best guesses' about the interdependences that occur among different pieces of knowledge and the effect that coupling decisions might generate. However the underlying interdependences that exist among different elements belong to the realm of the natural world and are not known a priori. Therefore organizations rely on their cognitive maps of the world when attempting to understand the nature of the interdependences among different elements so as to inform their coupling decisions. Such form of organizational cognition is often argued to reside in routines, patterns of communications, organizational structure, beliefs and so on, but these pathways of information are hardly explored. What is at issue in these empirical investigations is the study of how coupling in network built around artefacts (patent data) occurs overtime. Once general patterns are identified, the next step consists of 1) relating these to other variables or 2) identifying a set of measures (see next section) that may provide explanations or predictions for such patterns. I put the label **'cognitive structures'** to categorize such conceptualization of knowledge operated by this bunch of articles.

Next to the aforementioned papers there are few articles (N=2) which investigated how change in heuristics (meant as research strategies or similarly cognitive features of the research activities) affect patterns of change or stability in different networks. When such networks coincide with those discussed above (technology classes networks) the aim is to unfold the links occurring among the artefact and knowledge level, the latter obviously referring to heuristics followed in research activities. On the other hand, when the network under analysis is simply that representing alliances overtime, the objective is to demonstrate that particular shift or characteristics of the heuristics are preserved in the structural evolution of the network of collaborative agreements, thus underpinning either

its change or stability. I identified such conceptualization of knowledge as **'heuristics as research strategy'.**

Different heuristics are examined by another limited bunch of papers (N=3) as grounding knowledge processes. Such heuristics refer more closely to rules underlying social processes that are followed in order to achieve specific goals or maintain certain positions. These vary from choices made in condition of bounded rationality or incomplete information to 'modus operandi' that stem from motives or belief that a characteristic way of 'acting' will yield certain results. It is obvious that the studies undertaking such conceptualization of knowledge base their investigation upon network of interpersonal relations. The aim is to observe change/stability of patterns of interaction overtime that enjoy positive outcomes and identify the social mechanisms underlying such patterns. In this reviews such conceptualizations have been grouped under the label **'heuristics underlying social processes'**.

Other few articles (N=2) similarly refer to knowledge as residing in social practices but without focusing on rules of thumbs followed by agents in interaction. The aim here is to understand how recursive practices bounding social groups underlie some phenomena (e.g. prevent knowledge sharing, maintain a particular state of affair) and what are the key factors responsible for this.

In two further papers knowledge is purported as **'relational capabilities'**, built through experiences and a history of cooperation, thus falling within the more general framework of *path dependence*. Such conceptualization of knowledge is associated with cumulative processes, in which past and the continuity of relational practices matter in shaping future network arrangements.

To complete this frame on the different conceptualizations of knowledge there is just a paper assuming it as expertise or **task-related** knowledge. The aim of this study is to show that under particular conditions, task-related knowledge is correlated to occupying central position in advice networks.

4.2.2 Structural and Relational properties

It is useful to conclude this descriptive content analysis by giving an overview of the recurrent variables that have been used in order to observe structural change or stability in knowledge network. Figure 16 depicts the extent to which a set of structural measures have been deployed across the empirical investigations selected, while figure 17 do the same for relational measures. Density and various measure of centrality (degree centrality, closeness centrality and betweenness centrality) are the most popular. As it will be clear in the following, change in the structure of knowledge network often involves rapid fluctuation in density, with new nodes entering the network and links occurring among them at a high rate of speed. Centrality measures instead are less subject to change and fit more with stability. Other important measures that exemplify change/stability are those I labelled as *clustering:* these make up for the inability of density to capture the sectional patterns occurring at a given point of time.

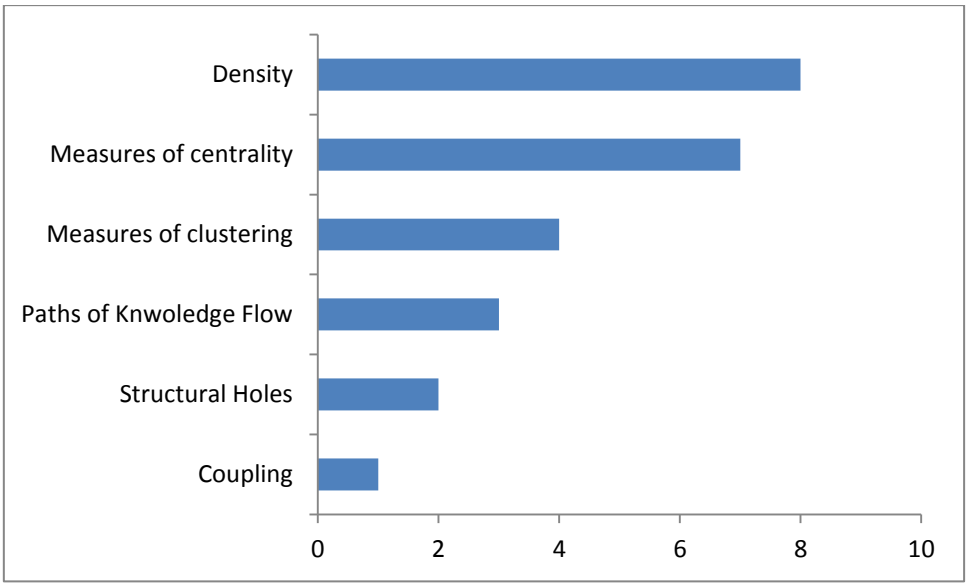

Figure 15: Structural measures

Relational measures are simply related to the strength of a tie, a measure introduced by Granovetter (1973) and that keeps triggering interests among

social network scholars being the object of continuous new conceptualizations. The number of different types of ties is as well addressed as of importance in understanding factors related to variation overtime of knowledge networks.

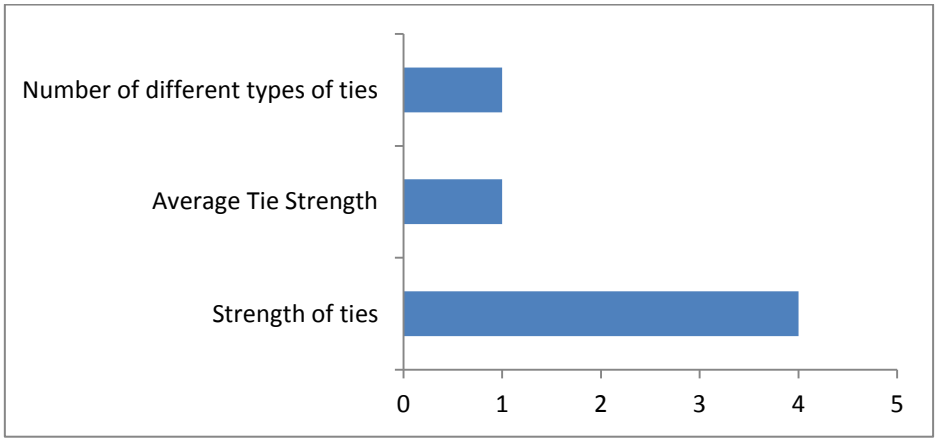

Figure 16: Relational measures strength

4.2.3 Knowledge-related variables

The knowledge-related variables adopted in the literature examined for this review are illustrated in figure 18. Most of them (N=6) rely on patents as a proxy to account for diversity, knowledge creation, breadth of the knowledge base and the interdependences among different knowledge elements. This suggests that current knowledge network research make use of collective representation of knowledge.

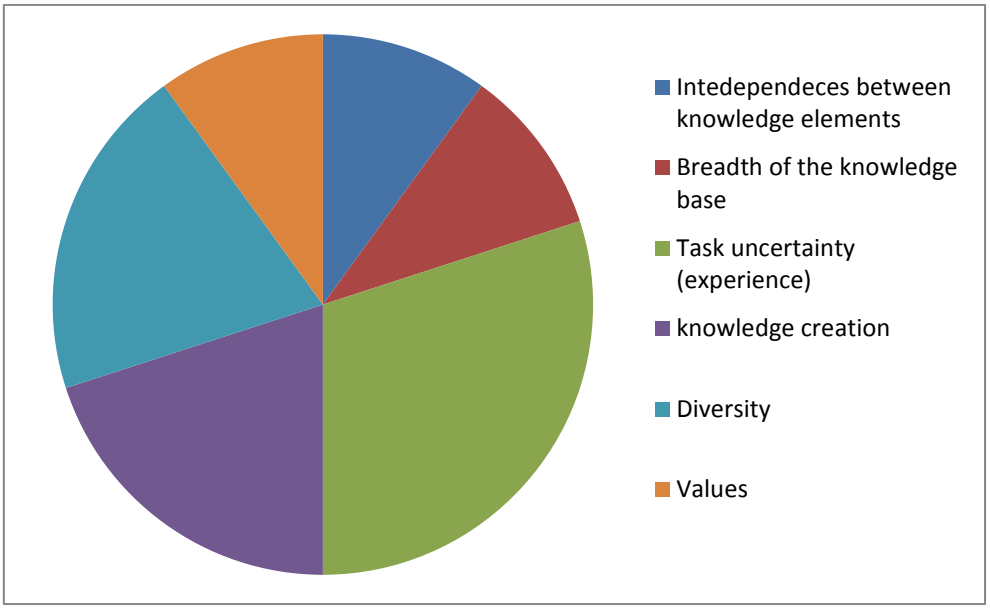

Figure 17: knowledge-related variables

5 Conceptual Analysis of the Literature

In this chapter I discuss the conceptual findings so as to inform the review question and identify gaps and possible avenue for future research. Generally, there are different dimensions along which data contained in a body of literature can be aggregated. The first step of this conceptual analysis is therefore to consider a set of dimensions that may ease the identification and organization of the most relevant information for answering the review question. In so doing, I induced a framework for organizing longitudinal research in knowledge network as a means whereby to compare, contrast and interpret meaningful patterns among the selected papers. Phelps et al. (2012) in their first review of knowledge network research have organized the findings around three distinct but related knowledge outcomes (knowledge creation, transfer and adoption) and discussed it across different levels of analysis (Interpersonal, intra and inter-organizational level). This has been in part a consequence of their inclusion/exclusion criteria, which consisted of selecting papers with at least one dependent variable related to the knowledge outcomes mentioned above.

This review had different objectives, namely to understand how change or stability occur in the structure of knowledge networks. This entailed a set of more flexible inclusion/exclusion criteria concerning the knowledge and the network variables and thus resulting in widely spread findings hard to compare in these terms. The framework adopted for this literature is shown in figure 10. This organizes longitudinal knowledge network research primarily based on the nature of the network constructs used for empirical corroborations and secondarily according to the level of analysis. The underlying idea is that meaningful patterns can be found along similar networks, where nodes and the relationships defined over them are comparable, at least to some extent. In fact, while the primary concern of Phelps et al. (2012) has been to spot coherency or conflicts of the findings both across and within level of analysis, I wonder if it makes sense to compare or distinguish straightaway patterns related to an intra-firm advice network (agent-based network) with those of an intra-firm patent network (artefact-based network). Moreover, organizing the findings

along network constructs it is believed to provide insights concerning the types of outcomes that their analysis might yield: this can be of great relevance for advancing current knowledge network research. I identified three types of network constructs: 1) the first refer to network built around artefacts, where nodes are patent or technology classes and a link occurs among two nodes through citations or co-occurrences of two technology classes within the same patent; 2) the second construct denotes network of social relationships, where the nodes are social agent (individuals, organizations or other collectives) and a tie refer to social interaction occurring among two nodes (e.g. a formal agreement or more generally an informal exchange); 3) the third construct refer to those network studies which have relied upon both artefact-based and agent-based networks (e.g. patent network and it correspondent network of inventors).

I also organized longitudinal network research based on the networks elements a study examined and accounting as well for the mechanisms that a longitudinal approach explicitly suggested or underlay. I have discussed in the descriptive analysis the most recurrent structural, relational and knowledge properties that the body of literature of this review addressed. Here attention will be paid to the directional effects of network elements. To assess such directional effects means highlighting the effect that a particular element or a collection of elements in interaction have either on other networks elements or on knowledge outcomes. This is purported to enhance our understanding of structural change or stability. For what concerns the structural properties, I follow Phelps et al. (2012) distinguishing among different network features: network position, ego network structure and whole network structure.

When possible, also an exploration of the main theoretical stances adopted will be provided.

Finally, I discuss outcomes along network constructs and network elements focusing on the implication that these may have on change or stability in the structure of knowledge networks.

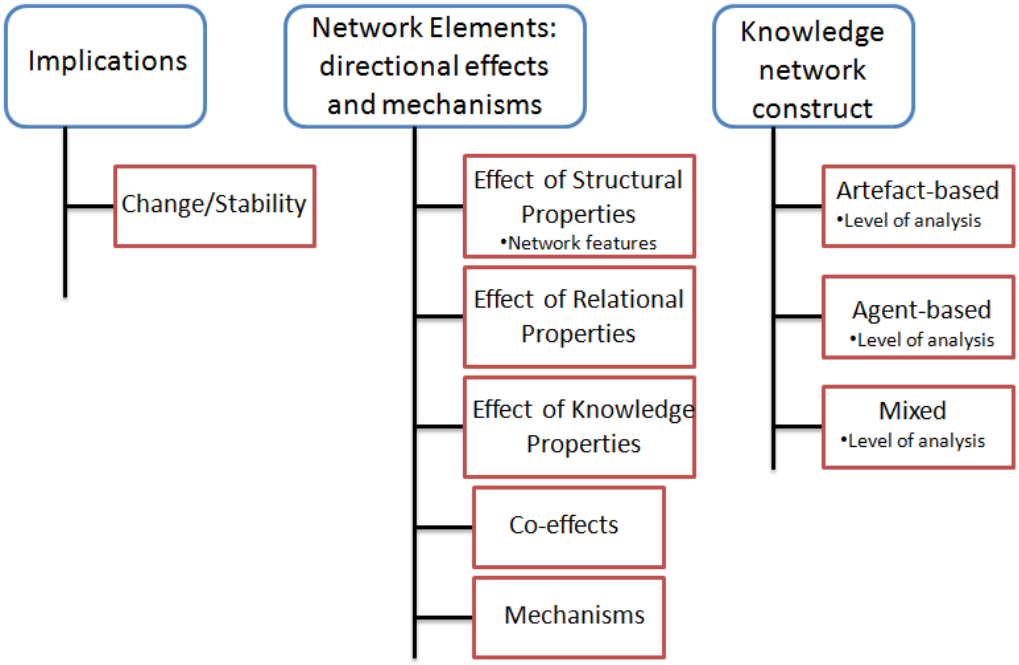

Figure 18: Organizing framework for Knowledge Network Research

5.1 Artefact-based network constructs

In this review, empirical investigations that make exclusively use of artefact-based networks were limited (N=3). This can be interpreted as a decrease in interest towards patent data as a sufficient source able to explain structural change or stability in knowledge networks. Moreover all these studies focus on *sector-level* analysis.

5.1.1 Theoretical and methodological stances

The dominant theoretical stance of these papers falls within theories of knowledge that stress its recombinant aspect (e.g. Schumpeter, 1939; Fleming and Sorenson, 2001). In short, all these papers assume that new knowledge comes fundamentally from the recombination of existing pieces of knowledge, even though some of them (Krafft et al., 2011) leave open the possibility that novelty can be generated also by the emergence of completely new pieces.

Thus, if knowledge comes from the recombination of existing or even new widespread pieces of knowledge, the problem of understanding change/stability in the structure of knowledge network can be recast as a problem of search in the knowledge space. It is by looking at interactions among units of knowledge (or similarly the way they couple) that we can shed light on the emergent properties of knowledge networks (structure) and get a grasp of how they vary overtime.

Attention has been paid recently to model developed in biology, such as the NK model, which enables a landscape view of the possible search path in a technology space. Social network analysis and its toolbox of measures constitute also a valid alternative in representing and get sense of the dynamics of the knowledge base.

Apart from modelling concerns, constructs such as absorptive capacity, theories of learning and organizational cognition underpin overall any attempt to make sense of patterns in knowledge networks overtime.

The operationalization of these ideas has been addressed in different ways, for example considering patent network and look at citations as a means to represent the knowledge flow. Another way is to build networks of technology classes and observe how they couple overtime by looking at patent portfolio. Networks built in this way generate a representation of the so-called ‘knowledge base’.

5.1.2 Effect of Structural Properties

The structural configuration of the knowledge base is the fulcrum of the analysis addressed in this bunch of articles. Yayavaram and Ahuja (2008) focus on its modularity asserting that the overall structure of the knowledge base is the most important aspect for distinguishing organizations, more than the knowledge elements that compose them. They showed that structures of knowledge networks that tend towards nearly-decomposable configurations (dense clusters

linked through few but strong ties) affect the usefulness of inventions. Krafft et al. (2011) instead look at the overall features of the knowledge base, identifying density and various measures of centrality as the fundamental structural properties through which change in the structure of the knowledge base can be observed and interpreted. The same applies in part for the work of Martinelli (2012), which examined the main paths of knowledge flow in a directed network of patents' citations. Their contribution is rather methodological.

5.1.3 Relational Effects

Relational effects are considered just in the study of Yayavaram and Ahuja (2008), with the deployment of a clustering coefficient able to account for both the modularity of the structure of the knowledge base and the strength of a tie.

5.1.4 Effects of the knowledge properties

Properties of knowledge are intrinsic in these studies, since the network construct is itself an expression of the knowledge base of a firm or sector. While these study focus on a collective representation of knowledge at the artefact level, they convey on the usefulness to explore knowledge connections at a lower level of aggregation. This would entail to analyse organizational routines and structure, information patterns and all the pathways that are responsible for the production of artefacts and the development of organizational cognition. However such analysis it is argued as an expensive task. Nonetheless, Martinelli (2012) goes a bit further into this, considering the effect that change in engineering heuristics exert on the paths of knowledge flow at the artefact-level. Such findings were possible by looking at the information contained within patents, augmented by interviews. The historical analysis of engineering heuristics has provided means to explain change in the structure of knowledge networks (in detail to distinguish change in trajectories from paradigmatic change) by looking at cognitive features related to the activities of research.

5.1.5 Mechanisms

The mechanisms considered in these studies are diversified and need to be spelled out. Yayavaram and Ahuja (2008) focus on the change of coupling overtime, which depends on organizational cognition or similarly on the belief that an organization has about the interdependences existing among knowledge elements.

Krafft et al.(2012) refer to a lifecycle in which new discoveries introduce discontinuities, breaking previous equilibrium. Emerging fields are characterized by the entering of new nodes and a decrease in density. Following this, a mature phase takes place, entailing an increase in density and a decrease on the importance (betweenness centrality) that some technologies play in connecting different technology classes in the network.

Finally, Martinelli (2012) argues that by interpreting paths of knowledge flow (built upon patent citations analysis) through an historical account of changes in engineering heuristics in the field, it is possible to distinguish change in trajectory from paradigmatic change.

5.1.6 Implication for change/stability

These studies suggest that change is both endogenous and exogenous. New scientific discoveries and change in engineering heuristics introduce discontinuities driving new network arrangements. Density, Centrality and Paths of knowledge flow measures can be good descriptors on how change occurs. However change occurs as well through the discovery of new interdependences among knowledge elements residing within the firm and resulting from the communication pathways pursued. By addressing a modular, nearly decomposable structure of the knowledge base firms succeed in bringing about change to greater extent in respect of highly or low modular knowledge bases.

5.2 Agent-based network constructs

5.2.1 Interpersonal level of analysis

5.2.1.1 *Position*

The positioning of individuals in a network of social relationships has been extensively investigated in social network research, yielding different results (Phelps et al., 2012). Overall, most of such results pertain to the informational advantages that occupying particular positions in a web of social connections (e.g. centrality, structural holes) entail (e.g. Burt, 2004). The only study in this literature review belonging to this category examines instead the effect that knowledge-related characteristics of individuals have on their chances of reaching central positions.

These works rely on social exchange theory, which posits that individuals form relationships based on mutual resources that can benefit both parties. Here resources are knowledge, this in turn referring to task-related knowledge.

Effect of structural properties

The group structure moderates the effect that having task-related knowledge play in reaching central positions. In particular, a functional group structure enhances the relationships between knowledge and centrality, while a divisional group structure exerts the opposite effect (Keith et al., 2010).

Effect of knowledge properties

Task uncertainty moderate the effect that being expert in a particular technology exert on reaching a central position in the network.

Mechanisms

In situation of high uncertainty, advice relationships revolve around actors which have knowledge related to the task, with these moving towards central positions.

Implication for change/stability

Task environment and uncertainty are key factors driving change in the position of actors embedded in a network. Furthermore change can occur in relation to the attribute that actors have, rather than being the result of exogenous or structural factors.

5.2.1.2 *Ego-network*

Ego-networks consist of a focal node and the ties it has with surrounding nodes (alters) encompassing as well the ties among alters. In this case just one study undertakes a longitudinal analysis at the interpersonal level considering the ego-network.

Structural properties

Density has been demonstrated to affect the rate of knowledge creation (McFadyen et al., 2009). In particular, an ego-network which shows increasing density ease communication and cooperation among network members, thus overall resulting in greater knowledge creation.

Effect of Relational properties

Strong ties increase the production of knowledge.

Co-effects

Strong ties increase their positive effect on knowledge creation when the ego-network is sparse.

Mechanisms

Networks of researcher in biotechnology tend to increase in density overtime. This occurs through means of ‘tertius iungens’: actors are willing to bridge relationships among partners.

Implications for change/stability

The network of a knowledge worker with strong ties and a sparse ego-network it is likely to become dense overtime, increasing the amount of knowledge production but reducing the novelty of the knowledge created. Thus it is very much likely that actors will change their network overtime, when new knowledge resources are needed and thus starting again to build strong ties in sparse networks and entering a new cycle.

5.2.1.3 *Whole network structure*

Studies of the whole network structures at the inter-personal level of analysis (N=3) all deal with the often argues sparseness/closure duality.

Effect of Structural properties

From a longitudinal perspective, there is a shared consensus on the sparseness of early stage networks, characterized by isolated groups of individuals which increasingly grow in connectivity overtime. (Quatman and Chelladurai, 2008; Simon and Tellier, 2011; Kijkuit and van den Ende, 2010). While density it is often assumed as a good proxy of the connectivity of a system, this measure has been proved to give little information about change in patterns within the network (Quatman and Chelladurai, 2008). Thus, it can happen that why dramatic change in patterns of connectivity occurs within a network at a certain point of time, density may remain stable overtime. Measures of clustering or centrality are more precise in this sense.

Another important factor affecting knowledge outcomes is group diversity, often referred in network research as range (Reagans and McEvily, 2003). This structural measure accounts for the extent to which a network includes members from different background or similarly coming from different functional areas (Kijkuit and van den Ende, 2010). The effect of this network composition, as it will be remarked in a while, depends on specific situations.

Effect of Relational properties

Tie strength, assumed here as related to the intensity of current and past communication among actors, has overall positive effect on knowledge outcomes along different instances (Kijkuit and van den Ende, 2010)

Mechanisms

Mechanisms whereby networks evolve as described above are very different. On one side, by undertaking a social constructionism perspective on knowledge, practices in community are shaped by influential actors occupying central positions and thus acting as gatekeepers.

On the other, needs and motives of individuals change along the various phases of a project in an idea network, this driving change in its structure. For example, during the idea generation phase actors are more willing to span across sparse actors that may provide different insights. During the validation phase they are more willing to exploit or create redundancy through introducing otherwise disconnected actors and so increasing network density.

Implications for change/stability

Actors entering in the early phase of an emerging network enjoy benefit gained through first-mover advantage, enabling them to shape the practices of future actors entering the field. On the other hand change in the structure of network may be led by motives and heuristics that actors deploy depending on their need in particular circumstances.

5.2.2 Intra-organizational

The only study at the inter-organizational level is a whole network study.

Effect of Structural properties

Operational proximity, meant as the intensity of face-to face interaction or similarly working side by side is essential for knowledge-sharing among individuals belonging to different network of practices (Tagliaventi and Mattarelli, 2006). Brokers play a crucial roles enhancing knowledge-sharing among members of different communities of practices. Generally they stand in peripheral position in their respective network of practices.

Effect of knowledge properties

Organizational values are important in order to knock down the barriers existing among different networks of practices in sharing knowledge.

Mechanisms

Peripheral actors within a network of practice which share spaces and time are crucial in order to acquire practice-related knowledge from members of other community and bring it in their own network of practices.

Implications for change/stability

Change in practices in social settings occurs at the interface of different professional groups or network of practices. Organizational values and operational proximity enhance knowledge sharing among them. Moreover a degree of interdependence among the different practices pursued in different networks of practices is a necessary condition.

5.2.3 Inter-organizational

5.2.3.1 *Network Position*

Firms with inter-organizational ties spanning diverse types of partners develop relational capabilities which lead them to assume central position and get access to key resources and information (Powell et al., 1996).

Mechanisms

Path-dependence is the key mechanism guiding the dynamics of the network. Firms which have accumulated experience in managing relationships with differentiated partners tend towards central positions and grow faster than firm with few ties. The connectivity of the system increases overtime so that to engage in partnership is essential to survive.

Implications for change/stability

Change in the structure of knowledge level occurs as a cumulative process of learning, where prior experiences and capabilities to manage relationships with diversified actors play a crucial role.

5.2.3.2 *Ego-network*

At the inter-organizational level, three studies undertake a longitudinal analysis of ego-networks.

Effect of Structural properties

Centrality of R&D organization structure affects the likelihood of a firm to form new alliances (Zhang, 2007).

Effect of Relation properties

Tie strength is a key driver of organizational performance. In particular by maintaining a network core of strong ties with external partners is crucial for innovation. However it is by integrating to such network core a large periphery

of weak ties that firms are able to sustain innovative performance (Capaldo, 2007)

Effect of knowledge properties

Breadth of the knowledge base is a key factor for explaining the formation of new alliances: it in fact increases the absorptive capacity of a firm and its propensity to undertake collaborations (Zhang, 2007).

Co-effects

The centrality of R&D organization structure can substitute for the power of the knowledge base in raising the chances to form new alliances.

Mechanisms

The mechanisms underlying such studies points to the need for organizations to maintain a level of breadth and depth of their knowledge base. This can be achieved through maintaining a stable network of strong ties' partners and sourcing new information alternating a periphery of weak ties' partners. The same can be obtained by pursue breadth in the knowledge base while ensuring mechanisms of integration through centralized R&D structure.

Implications for change/stability

Repeated interactions through times are the means whereby successful results are achieved. However they can lead to decreasing production of novel knowledge. It is by venturing in exploration activities that new ideas emerge. In order to do so a firm must increase its absorptive capacity that in turn affects the formation of new alliances leading to change in the structure of alliances networks.

5.2.3.3 *Whole network*

Effect of structural properties

Clustering and reach are two key structural properties in large-scale network in terms of diffusion and search. Their combination is synonymous of innovation (Schilling and Phelps, 2007).

Again, density and centrality may exemplify change in the structure of networks (Choi et al., 2011). However hub-and spoke structure presents high density while all the links are concentrated in few actors: this implies that density may not be synonymous, as often argued, of shared scheme and goal and coordination among actors. Furthermore the goals of specific network and thus the roles that actors entering the network play are important to understand the network structuration.

Effect of knowledge properties

Evolution of heuristics as research strategy enters onto the structuring of the network. Such change in the heuristics entail the emergences of a new form of knowledge base which in turn is reflected in new network arrangements overtime (Orsenigo et al., 2001)

Mechanisms

According to Schilling and Phelps (2007) networks evolve overtime by maintaining a balance between clustering and reach never exceeding in density since this would vanish the benefit that these configuration offer. In Choi et al. (2011) instead networks increase in the number of heterogeneous actors in the early phase of an emergent sector. Overtime density and centralization of the network tend to increase, even though external intervention may invert such trends. Finally, changes in the cognitive features of the dynamics of research strategy are preserved in the evolutionary paths of knowledge networks. First-mover advantages entail an initial structural inertia, until more fundamental major shifts in the underlying scientific and technological bases occur.

Implications for change/stability

Goals and network composition are crucial to understand change in the network structure of knowledge networks. First-mover advantages again confirm to be recurrent phenomena which underpin structural stability. Unobserved network variable such as change in the research strategies enter onto the structuring of the network, guiding new network arrangements.

5.3 Agent-based and Artefact-based constructs

The only two studies making use of both constructs undertake empirical investigation at the interpersonal and inter-organizational level.

5.3.1 Interpersonal

5.3.1.1 *position*

The two articles falling in this category analyse respectively the positive effects that proximity and position in a network yield.

Effect of Structural properties

Actors socially proximate to the source of knowledge have preferential access to the template, which refer to the original recipe combining different pieces of knowledge (Sorenson et al., 2006).

On the other hand, knowledge held by central actors is most likely to be selected since the position of actors offers guarantee of quality. This is even accentuated when central actors span structural holes (Nerkar and Paruchuri, 2005). In other words, this stems from an evaluation, in conditions of uncertainty and bounded rationality, of their positions as an indicator of the quality of their ideas.

Effect of knowledge properties

Interdependences existing among knowledge elements, measured through an historical view of how elements combined, can be assumed as an indicator of

the complexity of knowledge (Sorenson et al., 2006). The extent to which knowledge is complex in nature affects the ways it diffuses across network of social relationships.

Co-effect

When knowledge is of moderate complexity social proximity plays a crucial in order to understand its combination of different elements.

Implication for change/stability

The tendency of a network to form dense agglomerate of actors can be the result of the complexity of knowledge underpinning particular sectors. In fact when knowledge is of moderate complexity, social proximity to the source of knowledge constitutes an advantage in order to grasp its recipe and exploit it in other applications. Moreover, change may exhibit path dependence, meaning that a particular state of affair persists, influencing the selection of technological paths.

5.3.2 Inter-organizational

5.3.2.1 *Ego-network*

Co-effect

Diversity in the knowledge base in an ego-network is positively correlated with a firm exploratory innovation, with density exerting a strengthening effect (Phelps, 2010).

Implications for stability/change

Innovative network arrangement tends towards dense network in which actors have different knowledge base.

5.4 Discussion

Longitudinal literature in knowledge network research that focus on change or stability is still in its infancy. Furthermore the few empirical results consistent with the purpose of this review are sparse across levels of analysis, network features and constructs adopted, making very poor a comparison and contrast of their conceptual findings.

There are however common and distinct features worthy to be emphasised. These will be discussed in the proceeding sections, while a diagrammatic synthesis is provided in Table 8. This provides a synthesis of the foregoing discussions about the conceptual findings. It in fact re-organizes the implications for change and stability across the different constructs, levels of analysis and structural and relations features undertaken in the body of literature examined. Table 8 is therefore purported to provide an easy-to-consult overview of the different findings organized across meaningful dimensions of knowledge network research.

Table 10: Synthesis of the Findings

Network Construct	Level of analysis	Network features	Structural properties	Relational properties	Knowledge properties	Implications for change	Implications for stability
Artefact-based	*Field*	**Whole network**	• Near Decomposable structures result in more useful inventions • density and different measures of centrality offer means to assess change in knowledge networks' structure	Strong ties among clusters are beneficial for knowledge creation	Engineering heuristics in problem solving may explain change in knowledge networks' structure	New scientific discoveries and change in engineering heuristics introduce discontinuities driving new network arrangements. However change occurs as well through the discovery of new interdependences among knowledge elements residing within the firm and resulting from the communication pathways pursued.	
Agent-based	*Inter-personal*	**Position**	Group Structure (e.g. functional or divisional) moderates the extent to which knowledge about a technology affects the positioning of actors within advice networks (Centrality)		Individual's Technology knowledge leads them to reach central positions	Task environment and uncertainty are key factors driving change in the position of actors embedded in a network	

Agent-based		**Ego-network**	High network density results in enhanced knowledge creation	Strong ties exert a positive effect on the rate of knowledge creation		The network of a knowledge worker with strong ties and a sparse ego-network it is likely to become dense overtime, increasing the amount of knowledge production but reducing the novelty of the knowledge created .	
		Whole network	• Sparse and large network with enhanced range have a positive effect on initiation networks • In later stages, increasing density exert positive effects on knowledge outcomes	Strong ties exert a positive effect on the rate of knowledge creation	Individual motives and goals in particular situations result in heuristics that underlie network arrangements	Change is path-dependent. On the other hand, change is driven by heuristics that actors deploy depending on their need in particular circumstances.	First-mover advantages entails that actors maintain privileged positions so as to shape future practices.
	Intra-organizational	**Whole network**	Brokerage positions in the overall network structure (generally peripheral positions) are crucial for the transfer of practices among different community of practice.	Relational intensity has a positive effect on knowledge sharing activities	Organizational values and a degree of task interdependencies are key drivers of knowledge sharing practices across different units	Change in a network of practice occurs through boundary relations with different heterogeneous professional groups.	

Agent-based	*Inter-organizational*	**Position**	Numbers of ties spanning diverse actors affects the likelihood of reaching central position and getting access to resources		Relation capability, developed over-time, is key for growth	Structural Change is path-dependent, driven by cumulative process of learning, where actors' prior experiences and capabilities to manage relationships with other diversified actors play a crucial role.	
		Ego-network	Being central in a network increase the probability to develop new ties	Strong and stable ties are crucial for innovation. However weak ties with multiple actors ensure performance.	Breadth of the knowledge base explain the formation of new alliances	Change in knowledge networks' structure rests on actors' need to alternate explorative or distant search with repeated and exploitative relationships	
		Whole network	• Dense clusters and reach (average path distance) are crucial for innovation • Density not always explain shared goal and cooperation (e.g. hub and spoke structure) • Heterogeneity in the early phase of a network development reduces uncertainty		Heuristics as research strategy explain the structuring of the network as well as goals and roles of the actors.	Change to happen requires more fundamental shifts in the underlying research strategies of a knowledge-intensive field	First-mover advantages, again, entail structural inertia.

Agent and artefact based	*Inter-personal*	**Position**	• Proximity to source of knowledge enable the understanding of the interdependences among different knowledge elements • Centrality of actors is understood as an indicator of ideas' quality in conditions of uncertainty and bounded rationality	Knowledge complexity affects the way it diffuses.	Change in knowledge networks' structure may entail the formation of dense agglomerate of actors due to the complexity of the knowledge underpinning particular sectors	In condition of uncertainty or bounded rationality, actors occupying central position exert influences on shaping future practices, resulting in stability
	Inter-organizational	**Ego-network**	Density and diversity of network arrangements increase the innovative performance of the firm		Innovative change entails increasing density among heterogeneous actors	

5.4.1 Within and across constructs

Networks built exclusively around artefacts offer a partial view of knowledge processes. Among the papers making use of artefact-networks, knowledge is understood as a search and recombination process in the technological space. Organizational cognition, scientific discoveries and engineering heuristics are what underpin change in the structure of the knowledge base, albeit to different extents. While scientific discoveries and engineering heuristics refer to paradigmatic or path-breaking change, organizational cognition is often associated with recombinant processes that yield cumulative change. This entails that the former do not offer any predictive means whereby structural change can be examined. What they provide is rather a meaningful quantitative description (through network measures) of the overall changing patterns of the knowledge base. Explanations for such patterns rely on shifts in the scientific base or in the engineering heuristics underlying the technological trajectories. To some extent they provide overall insights on how networks evolve after a discontinuity and what kind of structural measures hold explanatory capacity.

The latter approach, instead, provides a more thorough account of why variation in coupling different technologies occurs, this stemming from cognitive features operating at the organizational level. The results indicate that it is the overall structure of the knowledge base more than differences among knowledge elements that allow for change. However, when clarifying how similar configurations can be achieved, or equivalently what underpins organizational cognition, the authors refer to communication pathways, across-cluster integration and routines. Nevertheless, these links between decision of coupling artefact and agent-based mechanisms of interaction are not explored and should be addressed in future research. A potential research question could be: *How patterns of social interaction within an organization and its technological trajectory co-evolve*?

When networks are built around *social relationships* the range of results is more interesting. This encompasses environmental factors, contingencies and path-dependency, overall suggesting a principle of network lifecycle.

By undertaking a longitudinal perspective on network research, this review revealed how knowledge networks change according to a variety of contextual factors and stages. We saw, for example, that in conditions of uncertainty (e.g. in the task environment or related to emerging sectors) individuals' peculiar knowledge play a crucial role in structuring the network (leading them to reach central position) or that a variety of different knowledge holders with diverse roles are needed both to reduce uncertainty and to ensure a degree of novelty. In sectors characterised by different phases and formal stages, such as in NPD, motives and goals of the actors change accordingly, entailing a shift in the structure of the social network. More research is needed towards deepening the understanding on the *social cognitive processes by which interacting individuals (in groups for example) achieve shared solutions in condition of task uncertainty or equivalently in situations of ambiguity (e.g. problem solving)*.

Another important factor in longitudinal agent-based networks is path-dependency. Actors entering the network in its early developmental stage enjoy first-move advantage. This consists of either occupying privileged positions so as to shape forthcoming practices or develop capabilities essential for future growth. In this last instance, knowledge networks are thought of as driven by a history of previous cooperation and experiences. Again, for such structural stability to be broken more fundamental shifts in the underlying research strategy of a particular field are needed. Apart from fundamental shifts, *a power perspective and its relationship with social structure may provide further insights on how particular positions or relational capabilities ensure stability overtime.*

Thus, contextual factors as well as positions and roles of actors are crucial to understand change and stability in the structure of agent-based knowledge network. Overall, it can be argued that a recurrent theme in these studies is the sparse/dense, or similarly exploration/exploitation, distant and local search, argument. Networks of emerging fields or ideas development show initial sparse configurations, marked by the presence of diverse actors or cohesive clusters, and see an increase in connectivity overtime with the development of strong linkages. This can be regarded as a kind of principle of network lifecycle,

starting with a heterogeneous network composition and ending up in dense and cohesive arrangements. Nevertheless, there are arguments among the papers supporting only partially the foregoing trend. Some authors argue for the innovation benefits that maintaining sparse and highly differentiated network configurations brings about. Others, even if acknowledging the positive effects of dense interaction, highlight the importance to preserve a degree of diversity in terms of network composition.

Moreover, while density and strength of ties are the commonly addressed network measures for investigating network dynamics, these are also argued to provide little information about sectional change. Measures of centrality and clustering are able to cope with this. A common assumption made in these studies is that actors or groups which show low interaction and communications among them or that simply belong to different community are diverse. In other words, diversity and how this indeed leads to innovative outcomes have not been deeply enquired.

Finally, when networks rely on both artefact-based and agent-based constructs it is possible to see that mutual influence of knowledge and social characteristics can be explored. However very few studies made use of both constructs, mostly highlighting path-dependency and the interplay between knowledge complexity and physical proximity. Again, to integrate social processes within an organization and technology trajectories confirms to be a fertile and hardly explored topic of research.

5.4.2 Across Levels of analysis

A common path across levels of analysis worth to be mentioned pertains to the conceptualization of knowledge undertaken in the 19 papers examined. All those at the firm level make use of patent as an indicator of knowledge. Just one study assumes as a collective proxy for knowledge organizational values. At the lower level of analysis knowledge is most commonly addressed as

relying on practices or heuristics followed by agents in interactions. Since most of the studies at the firm level assume that technology trajectories are linked to agents' practices, communication pathways and routines, it seems reasonable to argue that this missing link requires

Yet, network diversity as a condition for novelty and density as enhancing knowledge production are recurrent arguments across levels of analysis. Most of such studies focus on the effects that particular configurations and their evolving over time exert on outcomes such as innovation or performance. Some of them take into consideration onset stage, goals or contextual factors of the knowledge network to explain its particular arrangements. However, what in my view offers explanatory capacity for understanding stable or evolving patterns of knowledge networks are unobservable, cognitive characteristics of the actors in interaction. Few studies have attempted to shed more light on this linkage, mostly relying on historical analysis of the field or heuristics followed by agent in particular circumstances.

5.5 Conclusion

From the foregoing discussion, it can be noted how longitudinal knowledge network research is a novel field of enquiry, with a high degree of fragmentation in its empirical achievements. The aim of this review has been to find underlying and mechanist explanation of why particular network arrangements yield certain outcomes as compared to those offered by traditional cross-sectional analysis. However, while the conceptual analysis of the findings has provided valuable insights in this respect, more accumulated evidence is needed to identify specific gaps.

Nonetheless, some general conclusions can be drawn, this leading to the identification of a fruitful avenue for future research.

The literature has so far drawn extensively on artefacts for shedding light on variation or stability in the structure of knowledge network overtime. While the

great majority of studies recognize technology trajectories (or organizational cognitive features driving this) as relying on social practices or routines within the organization, there is an evident gap in explaining how these relate to each other. In this review just one study has focused on an Intra-organizational level of analysis, furthermore disregarding artefacts and assuming values as a collective proxy for knowledge. I consider the intra-organizational level of analysis, or similarly groups within an organization, as a particularly suitable one for understanding how recursive social practices affect stability or change in the structure of knowledge networks (be they built upon artefacts or other social relationships). This is because groups can be thought of as a sort of meso-level, where characteristics of the individual and macro-level structures can be brought both into view affecting group-level social mechanisms. To this extent, organizations active in NPD provide an appropriate context for empirical work. They offer not only a context in which artefact and social process can be both taken into account, but being characterised by formal stages and procedures they might as well reduce the indeterminacy of situations that may arise in organizational settings.

Another key point that this review suggested is that unobservable characteristics of the actors embedded in a social network are crucial in order to achieve meaningful explanation for variation or stability of patterns overtime (concerning either the network to which they belong or other related networks). In this regard, little work has been done. A good starting point for addressing such gap may entail identifying: 1) psychological, cognitive or social mechanisms relevant in a particular context, 2) types of relationships upon which networks can be built so as to unfold key interdependencies and reach explanatory capacity.

To this end, I believe that diversity, so prominent for explaining change and innovation as suggested by this review, has something to offer. There have been recent attempts to explain variation of network patterns overtime or innovation by means of cognitive distance (Phelps, 2010; Nooteboom, 2010), again relying on artefacts. These works could be extended on group level

analysis, assuming diversity as cognitive distance among individuals and looking at interactions (routines or social practices) among them as holding deeper insights on change and stability in the structure of group or higher level knowledge networks.

6 Reflection

I overall enjoyed this systematic review. As usual, with the wisdom of hindsight, you realize how some mistakes in the early stage of any endeavours propagate exponentially, affecting irreversibly the results. In this particular case I think that I should have narrowed my review question. It is a very broad question, which holds very little practical scope. On the other hand, my topic of interest is so wide-ranging that I did not want to run the risk of losing any important contribution. Again, more insights about relevant issues from a practitioner point of view could be of help in this regard.

Nevertheless, I think I have now a good appreciation on how to conduct a systematic enquire of the literature and the challenges it entails. It is for sure a powerful tool in order to achieve evidences of the current state of the literature in the field of interest and address therefore relevant themes and directions for future research.

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8 Appendix

Below the data extracted from the papers according to the form discussed in chapter are illustrated

No	Authors	Context	time interval between observations and data sources	Underlying conceptualization of knowledge	Network Representation undertaken	Structural Parameters	Knowledge-related variables	Findings
1	Yayavaram, S., Auja, G.	world-wide semi-conductor industry	1984 to 1994. Patent data	Awareness of the interdependencies existing among knowledge elements. It resides in organizational routines and structure, communication patterns and belief	Nodes represent technology classes, ties between nodes represent coupling among them and the strength of ties represents the level of coupling	Decomposability of the knowledge base (clustering coefficient accounting for the strength of ties). Change in coupling overtime		Reasons for change vary from external source to the discovery of new interdependences among knowledge elements. Here change refers to variation on the way technology classes combine (or couple) together over time. Structures of the firm's knowledge base that tend to nearly-decomposable configurations enjoy greater success in bringing about change.
2	Krafft,.J., Quatraro, F., Saviotti, P.	biotechnology sectors	1980-1990. Patent data	Knowledge is a co-relational and a retrieval or interpretative structure	Nodes are technology classes, and links represent their actual co-occurrence within patent documents. Strength of links is proportional to the frequency by which the classes that they link co-occur together	Density, degree centrality, closeness centrality and betweenness centrality		Change occurs by means of technological discontinuities in research-intensive sectors. When this happens new nodes enter the network while old ones become extinct. Network density decreases sharply until the field enters in a more mature phase with a high rate of creation of links. Centrality measures instead experience limited fluctuation, with only betweenness decaying over a long period of time.

3	Sorenson, O., Rivkin, J.W., Fleming, L.	Not specified	1980-1990. Patent data	Knowledge as a recipe, encompassing physical components and processes	Nodes represent patent and ties represent citations among patents. A correspondent network of inventors is operationalized.	Path length among actors in the inventor networks	Interdependences among knowledge elements as a measure of the complexity of knowledge: the extent to which a subclass within a patent has been previously combined with other subclasses indicates its sensitivity to interact with other chunks of knowledge	The underlying knowledge used by a firm influences industry structures, in particular it may trigger the formation of dense geographical clusters. This stems from the advantage that social proximity to the source of an invention offers particularly when the knowledge encoded in such invention is of moderate complexity
4	Nerkar, A., Parachuri, S.	Chemical and pharmaceutical firm	1972-1998. Patent Data	Heuristics followed in processes of decision making in condition of bounded rationality, uncertainty and incomplete information	Technological classes and intra-firm citations among them. A correspondent network of inventors is operationalized.	Centrality and richness of structural holes at the ego-level in the corresponding social network of inventors		Persistent patterns of technological classes among the firm patenting activity are due to network-mechanisms of knowledge choice: the knowledge of actors with high centrality and spanning structural holes is in fact most likely to be selected for recombination by other inventors.

5	Martinelli, A.	Telecommunications switching Industry	1924-2003. Patent Data	Heuristics as research strategy, guiding problem solving activities	Directed networks of patents, where the links represent citations	Main paths of knowledge flow measured through weighted indicators. Indegree, outdegree and betweenness centrality.		Patterns of technical change may refer to new trajectories or paradigmatic shifts. In both cases these are respectively the result of stable or changing engineering heuristics. This paper offers a methodology to detect discontinuities and unfold the link between the artefact and knowledge level.
6	Zhang, J.,	Biopharmaceutical Industry	1993-2002 Patent Data and Alliance Database	Architectural view of knowledge: how components of the system interact		Centrality of R&D organization structure	Breadth of the knowledge-base	Change may occur by mobilizing embedded knowledge as a form of dynamic capability. In this study the breadth of the knowledge base and the centrality of R&D organization structure positively impact the extent to which a firm engage with new alliances, thus contributing to network change.
7	Simon, F., Tellier, A.,	New Product Development in a Semi-conductor Company	1980-1999. Interview and Questionnaire	Actors' motives and strategic actions	Social Networks of key actors involved in various phases of the projects	Network Size, Cohesion and Redundancy of ties (distinguishing among strong and weak ties) overtime		Change in the structure of idea development networks is due to the motives that lead actors to exchange information or extend, reinforce or bridge ties along the different phases of new idea development projects.

8	Keith, M., Demirkan, H., Goul, M.	Group learning activities in a Business School	Snapshots across two different but consecutive projects	Expertise, task-related knowledge	Advice networks: a node represents an actor while a tie occurs among two of them when they seek advices from each other.	Network Centrality, Group Structure	Task uncertainty	Change in the structure of advice networks depends on the task environment and its level of uncertainty. As uncertainty decreases knowledge-sharing relationships decay, more remarkably for ties between different groups. The same happens for centrality of actors. When high uncertainty prevails, technology-related knowledge held by actors is a good predictor of their moving towards central positions in the network.
9	Capaldo, A.	Design-intensive Furnishing Manufacturers Industry	1966-1999. Archival Records, Interviews and Direct Observation	Relational Capabilities	Alliance Networks: nodes are actors belonging to firms and links indicates the interactions among them.	Strength of dyadic ties		Repeated interactions through time or similarly a history of cooperation is the means whereby quality of results and success are attained. Firms that innovate are characterized by a stable network core of strong ties with external partners. However it is by integrating a large periphery of heterogeneous weak ties that a lead firm is able to sustain innovative performance
10	Kijkuit, B., Van den Ende, J.	New Product Development in R&D labs of Consumer Goods Industry	14 Months. Archival Records and Interview	The ability to recognize, evaluate and assimilate diverse knowledge, closely related to prior experiences	Idea Networks: nodes are actors and links occur among them when they engage in discussion (social interaction among people mapped along the various phases of NPD projects)	Size, Density, Strength of Ties	Presence of senior people and decision-makers which reduce uncertainty and increase novelty of ideas	Network Structure of Successful Ideas change along the various phases of the front end of the NPD process. The network is large and peripheral during idea development, after decreases in size, increases in density and presents strong ties. Hypothesis about network content (knowledge-related) found limited evidence.

11	McFadyen, M.A., Semadeni, M., Cannella, A.A.	Biomedical Research	1989-1999.	Stemming from dynamic processes of social interaction	Co-authorship: Nodes are authors and a tie occurs among them when they co-author a paper	Ego-network density, average tie strength	Knowledge Creation	Change in the structure of networks of researcher in biotechnology occurs through an increase in density overtime. The authors hypothesize as the underlying mechanism of such change the tendency of actors to bridge relationships among partners. Density and average tie strength of the network resulted positively correlated to knowledge creation.
12	Phelps, C.	Global Telecommunication equipment Industry	1987-1997. Patent Data and Alliance Database	Experience gained from past search and problem-solving activities. It is tacit (cognitive structures, belief about cause-effect relationships) socially embedded and becomes embodied in organizational routine while guiding current research efforts	Alliance Networks: nodes are firms and links refer to the existence of a formal agreement among them.	Ego-network Density	Network Technological Diversity	Diversity is positively correlated with a firm explorative innovation, with density exerting a strengthening effect.
13	Powell, W., Koput, K., Smith-Doerr, L.	Biotech firms in human therapeutics and diagnostic	1990-1994. Patent Data and Alliance Databases	What allows to recognize and structure synergies (routines) along fluid and evolving social processes	Alliance Networks: nodes are firms and links refer to the existence of a formal agreement among them.	*Dependent*: Number of R&D ties, Number of ties of each type, Density, Degree Centrality, Closeness Centrality overtime	*Dependent*: Network portfolio diversity overtime. *Independent:* R&D experience	Change in the structure of learning network occurs by means of increasing connectivity (density). This relies upon the competences, diversity of knowledge base and relational capabilities developed by organizations overtime. In this sense change occurs as a cumulative process. Firms with previous experience in R&D network activities develop easily ties with other type of organizations, increasing their diversity in terms of knowledge base. This in turn enhances their centrality.

14	Tagliaventi, M.R., Mattarelli, E.	Radiation oncology unit of an Hospital	21 weeks. Field Study: Interviews and Ethnographic observation	How actors act and interact in order to perform their daily activities in a social setting	Knowledge-related interactions among different professional groups	Operational proximity	Organizational Values	Change in practices in social settings occurs through conflicts located at the interface of different professional groups or network of practices. However knowledge tends to flow within network of practices rather than among them. Operational proximity and Organizational Values are fundamental to knowledge transfer across different network of practices, with brokers playing a crucial role.
15	Orsenigo. L., Pammolli, F., Riccaboni, M.	Biotechnology	1978-1997. Alliance databases	Heuristics (structural cognitive features of the research activities) and research strategy in pharmaceutical R&D	Network of collaborative agreements overtime (Directed graph)	Density, asymmetry, intransitivity and Hierarchic structure		Networks in field of rapidly intellectual development increase steadily in size while decreasing in density. However some structural properties persist over-time, suggesting that a conservative growth takes place. This might be due to phenomena such as first mover advantage. Change in the network structure occurs along major shifts in the underlying scientific and technological bases. The authors demonstrated that the evolution of heuristics and research strategies are preserved in the structural evolution of the network.

16	Choi, H., Park, S., Lee, J.	Hydrogen Energy research in Korea	1989-2005. Government R&D program data		Network of participant (different type of organizations) in R&D projects	Density, Degree centrality, structural holes	The knowledge network related to an emerging technological field presents an increasing numbers of heterogeneous actors and ties. Centrality of Organization rises not uniformly but in relation to the role such Organizations serve. Density and centralization tend to increase after the initial phase although external factors may trigger the flow of new actors entering the network (Government Intervention). Depending on the goal and composition of a knowledge network, this can pursue different patterns of structuration (how integration of different set of competencies and knowledge occurs).
17	Quatman, C., Chelladurai, P.	Sport Management Research	1985-2007. Databases of publications	Social-contextual practices associated with scientific discovery.	Co-authorship network	Density, clustering	Co-authorship networks related to an emerging discipline are characterized by relatively sparse groups. Overtime the level of connectivity among this group increase. While density is a good proxy to assess the overall interconnectivity in this case its value does not change over time. The deployment of cluster techniques reveals the presence of cohesive sub-groups within the network as well as 'star' configurations. This indicates that few actors have great control over the information flow and in shaping research directions.

18	Schilling, M., Phelps, C.C.	High technology manufacturing Industries	1990-2000. Alliances Database		Alliance Networks: nodes are firms and links refer to the existence of a formal agreement among them.	Clustering and Reach	Knowledge Creation	Change in the structure of innovative inter-firm network implies both cross-sectional and temporal variation in network size and path lengths among dense clusters (reach). However the network never reaches high value of density since this would means homogeneity of information/knowledge and thus a decline in creative performance. A good balance between clustering and reach is found to positively affect the creation rate of novel knowledge