The Informal Networks of Innovation

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ABSTRACT

Innovation continues to draw scholarly attention across a range of disciplines and intellectual communities. Scholars from multiple disciplines offer up a diverse range of theories regarding technological innovation. Through this theoretical essay we review these conceptualizations of innovation practices and posit that (1) innovation processes are likely to take place through network-like arrangements and (2) these networks are often informal and long-standing. We argue that innovation is done through networks because these can best facilitate the exchange of innovative ideas and competencies. We also argue that innovation network structures are often based on extending and formalizing informal relationships among individual actors. Relative to our second point, we further note that there is little research which investigates the nature and influence of these informal interactions and their network structures. In an effort to address this gap, we build on our review of relevant existing literature to develop theoretical constructs which illuminate the constitution and the salience of informal networks of innovations. These theoretical constructs draw from the literatures of social network theory, communities of practice, invisible colleges, and actor network theory. Based on this review, a model of informal interaction is constructed which is constituted of human actors and social institutions, specific technological artifacts, innovative concepts and the time dimension. We conclude by elaborating on the interactions of these network components.

INTRODUCTION

Through this theoretical essay we develop a conceptual model regarding the importance of informal ties in supporting innovation. In doing this we argue that there is a need for more scholarly attention and empirical research to raise our collective understanding of the extent to which innovation hinge upon informal relations among individuals and, how these ties underlie innovation (Gulati, 1995; Powell, 2000). In particular, we synthesize current frameworks to help us conceptualize the structure of informal networks and their contribution to the innovation process.

We theorize that technological innovation has a network structure made up of four distinct characteristics: individuals, relevant and resource-providing firms, core concepts or ideas, and particular technological artifacts that illustrate core concepts or make visible core ideas. The basis of these innovation networks is that they extend and partially formalize pre-existing informal relationships among individual actors. In theorizing the centrality of informal relations among actors as the basis for innovation networks, we further argue that formal institutions, such as organizations where these people may work, play important -- but secondary roles -- as temporary homes and providers of resources. To develop our argument regarding the constitution and the salience of informal networks of innovations we draw from the literatures of social network theory, communities of practice, invisible colleges, and actor network theory. Based on this review, we develop and discuss a model of informal interactions which is constituted of human actors and social institutions, specific technological artifacts, and innovative concepts. We conclude this theoretical essay by elaborating on the interactions of these network components.

INNOVATION VS. INNOVATING

Naïve conceptualizations of innovation frame it as an achievement of a single individual. This makes for good stories but is not empirically supported and cannot be considered a viable model of innovating. A more conceptually supportable view, and one underlying much of the writing in economics and organizational theory, is that the firm is the locus of innovation. Within the boundaries of the firm, some small group provides the innovating impetus which the firm then harnesses for economic value. This view implies that by controlling the innovation, it becomes a competitive advantage and the firm will be able to accrue the benefit of the innovation. Such thinking suggests that firms can develop, manufacture, market, distribute, and provide ancillary services related to the innovation. In this traditional view of innovation, an internal research and development (R&D) unit is an indispensable strategic asset and perhaps even a formidable barrier to competitors (Maclaurin, 1949). As such, each firm needs to control and guard its innovation processes so that competitors are not able to profit from them.

Firm-centric models of innovation typically frame the process as a series of stages or phases of development. The activities within each stage also exhibit an orderly or cyclical equilibrium. These models impose a logic of process stability as a means of reducing the inherent instability of innovation into a more manageable activity. Gordon and Greenspan (1988 , p. 2) note, "we assume stability because only stable behavior persists; an unstable system in dis-equilibrium soon explodes and therefore, is only of transient interest". This is why innovation is generally attributed to be the result of rational efforts of a small number of actors within an organization. These actors exert considerable control over the innovation process.

This firm-centric, linear process that is based on guidance from a small number of key actors stands in sharp contrast – in at least two places – to the detailed empirical findings of

innovation processes (e.g., Hughes, 1983b). The first contradiction made clear in the empirical work is that innovation efforts are complex, non-linear and characterized by high degree of uncertainty (Van de Ven, Polley, Garud, & Venkataraman, 1999). Second, the empirical work on innovation makes clear that the outcome is a product of multiple players' participation (Brown & Duguid, 2001a). The knowledge needed to innovate is typically located with players who are part of different institutions – making innovation multi-institutional. Further, this suggests that innovation is not controlled by one firm or set of actors as much as it is emergent across many firms and multiple actors.

The empirical findings summarized above suggest the linear model of firm-level innovation masks the actual nature of innovation, perhaps confusing desire to take value from an innovation with the nature of innovation work. The firm-centered and linear model of innovation does not account for those features of innovation processes that do not seem to lend themselves to an equilibrium or set of stages. Thus, any efforts to cast the innovation journey into a set of quasi-stable stages fall short of accommodating the intricacies of innovation work (Van de Ven, 2005). The volatile and indeterminate nature of the innovation process has prompted a group of researchers to search for alternative perspectives (i.e. Hannan & Freeman, 1989).

The linear model of innovation also seems ill-equipped to account for the multi-institutional nature of innovation. New technologies and businesses are seldom developed by a single firm (Chandler, 1990; Nelson, 1982). Necessary skills and know-how needed for such developments often lie across multiple firms (Powell, 2000). Teece and Pisano (1987) note that large corporations are increasingly aware that innovation knowledge is situated outside their boundaries. And, contemporary organizations are becoming less self-sufficient in their ability to generate knowledge to fuel innovation processes (Fusfeld & Haklisch, 1985). This translates

into an increasing reliance on inter-firm alliances, and external sources for R&D. In this context, innovative ideas are increasingly likely to originate outside the firm. And, boundaries of firms are becoming more porous than traditional thinking based on organizations as hierarchies, such that innovations and knowledge often crosses organizational boundaries (Chesbrough, 2003).

CHARACTERISTICS OF INNOVATION NETWORKS

If the innovation process does not take place within the boundaries of a firm, how might it ensue? Several competing theories attempt to address this question. For example *transaction cost economics* focuses attention to the roles of *markets*. The theory suggests that transactions that involve more uncertainty and recur more frequently are more likely to be conducted within hierarchically organized firms. Transactions that require no transaction-specific investments, and are more straightforward and less repetitive, will take place in a market. Firms organize transactions in a market when they seek to reduce production expenditures. The stereotypical competitive market is characterized by self-interested, non-cooperative, and unconstrained social interactions. In this theory of markets, price is recognized as the major organizing mechanism (Williamson, 1979).

However, Powell (1991) notes that the adherence to the twin pillars of hierarchy and market blind us to the emerging diversity of organizational forms and underlying social interactions. The current wealth of literature in the area of economic sociology considers price to be an over-simplifying mechanism; it is therefore incapable of explaining the intricacies of the idiosyncratic and dynamic exchanges that take place in innovation processes (e.g., Swedberg, 2003). The exclusive focus on transactions - rather than the underlying relationships - can be misleading as the primary unit of analysis may be poorly understood. Thus, the transactional

view tends to gloss over the social activities (and embedded social values) in the exchange process (Granovetter, 1985).

Within the innovation process a surprising proportion of inter-organizational exchanges are carried out in arrangements that may not reduce transactions cost. These sorts of exchanges are performed in order to provide concrete benefits or intangible assets that are far more valuable (Powell, 1991). For instance, Helper et al (2000) observe that trends for automobile subcontracting turn into interdependent and deep relationships, which are not sustained exclusively on cost reduction considerations.

In addition, many inter-organizational networks are particularly useful in the production and dissemination of knowledge (Hansen, 1999; Owen-Smith & Powell, 2004; Scott & Davis, 2007). Knowledge transfer is germane to exchanges that arise in innovation processes. This knowledge could include qualitative expertise, technological capability, and the like (Polanyi, 1967). Beyond the relationships among individuals and firms, we know that knowledge is critical to innovation (Rogers, 1995). Most flows of information in a hierarchy and most exchanges of information in a marketplace occur in order to produce information or acquire a commodity. Developing new meanings and novel interpretations is daunting; sharing this through hierarchies or across markets magnifies the difficulty. Innovation knowledge is situated and emergent. This makes it difficult to move within a hierarchy, possibly because it has no clear tangible value or easy-to-package message that can be shared up and down the hierarchy. Nor can innovation knowledge be easily traded in markets: the knowledge is too fluid, its value too amorphous[1]. This is where network arrangements come into play. We know that knowledge is exchanged more freely in network arrangements, in contrast to markets and hierarchies, and that this sharing

[1] This notion is being challenged by concepts of idea markets and "crowd sourcing." For more on this see: Miller, Resnick, et al. (2005). We note only that the applications of these ideas are primarily for feedback to the members of an organization.

also generates more connections (Powell, 1991). This suggests that a central value of network arrangement has to do with their capacity for generating, sharing and interpreting information. The inherent dynamics of knowledge sharing networks has the potential to enable complex channels of communications which may be uncommon in the other arrangements (Kaneko & Imai, 1987).

An innovation network is constructed on the grounds of two underlying assumptions. First, no single firm is likely to possess enough resources and knowledge for completing the innovation process, leading us to believe that the process requires going beyond a firm's boundaries. As a result, each firm may be dependent on intangible resources controlled by others, and these intangible resources may be widely distributed. Second, gains are expected to accrue from the pooling of resources: there must be something that draws players together.

Knowledge sharing networks serve as webs of communication that can afford participants with access to intangible assets, such as tacit knowledge and technological innovation, which cannot be as readily developed within the bounds of one firm or in one person's head. The enhanced flow of information brings together different logics and novel combinations of ideas, which in turn serve to produce more innovation. In this light, an innovation network serves as a virtuous cycle (Powell & Grodal, 2005). Ties among individuals that extend beyond organizational boundaries enhance innovation, and innovation outputs in turn encourage further collaborative linkages. These cyclic and generative effects of networks can enable self-sustaining, autopoietic mechanisms. Both Ahuja (2000) and Stuart (2000) note that firms with a better record of innovation are more likely to forge network alliances, underscoring the role that networks ties play in the recurring process of innovation and growth. Network arrangements also increase firms' flexibility to respond to the unpredictable changes in their

competitive environment. According to Zueker (1991, p. 164) firms often lack "expert" information and must therefore seek it externally. Hence, sourcing information from external sources, provided by informational networks, allows firms to both increase their learning capacity and extend their boundaries, because each external source of knowledge provides firms with "strategic sourcing option" that they can draw upon only when necessary (Volberda, 1996).

The advent of inter-organizational networks considerably raises the diversity of institutional actors and their interdependence in the innovation process. The synergy brought about by this diversity can provide access to new sets of information, resources, and technological capabilities (Gulati, Nohria, & Zaheer, 2000; Subramani & Venkatraman, 2003). More diverse and broad network relationships can lead to more diverse experiences, competencies, and added opportunities for the participants (Beckman & Haunschild, 2002). This is particularly evident in knowledge-intensive industries, in which the networks connecting R&D units are critical to knowledge proliferation. In this context, collaborative R&D efforts manifest themselves as a vehicle for developing strategic flexibility, and getting access to unprecedented assortments of innovation knowledge (Fritsch & Lukas, 2001; Pisano, 1990). Networks of innovations can also reduce the participating firm's R&D costs, as these networks often provide access to leading research institutions (DeBresson & Amesse, 1991; Liebeskind, Oliver, Zucker, & Brewer, 1996).

INFORMAL NETWORKS VS. FORMAL NETWORKS

Powell (1996, p. 120) maintains that "beneath most formal ties lies a sea of informal ties." The formal structure of networks is largely contingent upon the solidification of pre-existing informal relationships. Most commonly, informal relationships are reified in the forms of interest groups which span multiple organizations, and many of these groups may not

necessarily be recognized by the formal organizations that employ the members (Cross, Borgatti, & Parker, 2002a; Cross, Nohria, & Parker, 2002c; Cross & Parker, 2004; Krackhardt & Hanson, 1993). Moreover, these networks are not preplanned: they emerge (Krackhardt et al., 1993).

As Macneil (1985) posits, the cornerstone of networks are defined by interdependence, friendship, and altruism: a sharp contrast to the formalisms of hierarchies or the discretized and transactional nature of markets. These links enhance knowledge exchange, and the generation of new, valuable information, since informal networks are "the most flexible, and adaptable forms of organization" (Castells, 2000). Likewise, practitioner accounts recognize the importance of such informal relationships with colleagues and friends -- particularly in the formation of innovative ideas (Sull, 2002).

Many inter-firm relationships are extensions from interpersonal ties, with a high degree of concurrent informality. For example, technology brokerage, which facilitates the transfer of innovative ideas across networks, is visible at the level of firms and industries. However, it is realized through interactions of individuals and teams (Hargadon & Sutton, 1997). These boundary-spanners go about identifying, translating, and relaying information across firms (Fleming & Waguespack, 2007); they transfer information from firms where it abounds to firms where it is dear. These types of informal relations include but are not limited to participation in ad-hoc industry committees, executive education program, conferences, trade and professional association activities. The mobility of personnel among firms, and the shared norms and experiences that accrue to those with common educational backgrounds is also a driver for developing informal linkages across firms.

Informal links are salient because they often become formal and contractual alliances. The consolidation of formal ties seems stronger when they "rest" upon the strength of informal

ties. Murray (2002) argues that in the life sciences, R&D partnerships emerge out of enduring co-authorship, mentor-mentee, and common training relationships which often display an informal sprit. These informal personal ties also hold a great potential to evolve into intellectual properties like patents, and thus to subsequently forge formalized contractual agreement among firms. The embedded nature of the informal ties can also enhance the distribution of complex information, mainly tacit and situated, making a substantial contribution to innovation practices (Granovetter, 1985; Uzzi, 1997).

Informal networks that co-evolve with or into formal arrangements can portray a different image than presented by formalized structure of networks, since they are often unconstrained by preordained formal structures (Contractor, Wasserman, & Faust, 2006). These informal links serve to support the exchange of ideas, experiences, and expertise among individual and groups. These links, and the networks that they form, greatly influence the ability of knowledge workers, workgroups and the whole firm to innovate as they determine how information can be exchanged across a network (Cross et al., 2004). As an example, a study of two successful new biotechnology firms, conducted by Liebeskind et al (1996), indicates that almost none of the substantial external exchanges of scientific knowledge that entered the firms were governed by formal contracts or other market mechanisms, but happened though an informal scientific social network.

These informal links do not exist only among members of cooperating firms. They often can be found in a highly competitive environment, which are characterized by opposing interests. Von Hippel's (1986) study of US steel mini-mill producers exemplifies such situations. Frominterviews with plant managers and engineers, he found that the exchange of proprietary information between competing manufacturers is not an uncommon practice. These "leaky"

pieces of information were mainly centered on production problems, matters of pollution control and safety, and industry-related concerns. The informal trade of information was reciprocal and based on the expectation that requests for helps would not remain unanswered. In addition, strong personal friendships (i.e. between former colleagues) that exist in an occupational community encourages individuals to share some information which is unlikely to be transferred through formal conduits (Rogers, 1982).

In stark contrast to their significance, very little attention has been directed to informal ties. Many organizations are largely unaware of the extent to which formal activities are hampered or enabled by informal relationships (Cross et al., 2002a). As for research, a small but well-established stream of organization theory examines how informal connections relate to the formal structures of firms (i.e. Blau, 1969; Dalton, 1959). A few organizational researchers have investigated the impact of informal networking in large, multinational corporations, (i.e. Bartlett & Ghoshal, 1990; Hansen, 1999). Beyond these sterling examples, most empirical studies of the innovation networks have focused on formal ties established among firms (Powell et al., 2005), and the role of informal linkages may be the most important under-explored element in the innovation process (Cockayne, 2004).

The studies of formalized networks of innovation tend to focus on the effects of networks on patenting or codification of knowledge, and use patents or published papers as proxies for innovation. In such studies, patents are a dependent variable and formal relations are one of the independent variables. Although patents can be identified as a measure of knowledge creation (Griliches, 1990), there are distinct limitations. For instance, patent analyses are incapable of identifying the actual mechanisms of knowledge transfer (Jaffe, Trajtenberg, & Henderson, 2002). Furthermore, some types of innovation are not patentable (i.e. innovations in financial

service products) (Jaffe, 2000). And, perhaps more importantly, many collaborations do not lead to any patents, but may lead to innovation.

The paucity of empirical investigations concerning informal networks is understandable. Informal interactions are often hard to trace, monitor and measure due to their plasticity and heterogeneity (Fischbach, Gloor, & Schoder, 2009). This means approaches that rely on post-hoc proxies of innovation will find it difficult to identify and analyze these personal interactions empirically, given their qualitative nature (Hienerth, 2006). To better understand the nature and value of informal networks relative to innovation, we draw on four strands of contemporary research as each helps to partially explicate how informal relationships unfold and subsequently affect innovation networks (see also the summary of this analysis in Table 1): social networks, communities of practice, invisible colleges, and actor network theory. In what follows we briefly outline to what extent each conceptual framework can contribute to our understanding of the informal networks of innovation. We then propose a general model in which we integrate these partial insights into a more coherent and still tentative arrangement.

THE SOCIAL NETWORK PERSPECTIVE

A strong tradition of theory and research has explored different elements of social networks (e.g. Burt, 1992; Granovetter, 1973; Merton, 1957). These and other contributors to our understanding of social networks elaborate on the informational, status-providing, and resource advantages of having a collection of ties with others. These networks of relations are enacted by sharing of information between nodes (people) via ties (the means of interacting with the nodes). The social network perspective provides a conceptual vehicle for integrating different levels of foci, as Nohria (1998, p. 4) asserts: ” the premise that organizations are networks of recurring relationships applies to organizations at any level of analysis— small and large groups, subunits

of organizations, entire organizations, regions, industries, national economies, and even the organization of the world system". This perspective is also illustrative for mapping informal networks while the featured concept of social network may or may not be contiguous with the boundaries of a legally defined organizational entity. In this view, a social network can include members of more than one formally-defined organizations, and can embrace the nature of informal, cross-organizational roles like "boundary spanners" (Liebeskind et al., 1996).

Beyond this basic conceptual premise, social network theorists offer a number of constructs that can be employed for the analysis of informal networks. For instance, *the small world phenomenon* has been employed to elucidate the fast dissemination of knowledge in certain informal arrangement (Uzzi & Spiro, 2005). A small world is defined as a network that is both highly locally clustered and has a short path length, two network characteristics that are normally divergent (Watts, 1999). Using the concept of small world, Newman (2001) studied coauthoring structures within seven different scientific communities and concludes that each relies on small world structures. He infers that the small world phenomenon might be the reason for swift transfer of ideas across disciplines. Along the same line, Uzzi and Spiro (2005) illustrate that small world arrangements inspire innovation, as they connect and mingle specialized knowledge and resources embedded within multiple clusters that would be isolated otherwise.

The early studies of social networks focused on informal interactions of individuals, but many later studies have shifted towards investigating more formalized structures (Kilduff & Tsai, 2003). This s turned much scholarly attention from conceptualizing how networks form towards discussions of measuring, representing and analyzing the links and nodes: shifting attention away from the complexity of social realities to measuring what can be traced. As an

example, Cross and Borgatti (2002b) explain how the social network perspective can be used to chart the informal structures of communication in within an organization. They assert; "…conducting a social network survey is a straightforward process of obtaining a list of all people in the defined network and simply asking all members of the group to characterize their relationship with each other. In this process it is important to ensure that the kinds of relationships measured are appropriate for the task at hand and not unnecessarily inflammatory."(Cross et al., 2002b, p. 33) While this quantitative approach can help the researcher develop some sort of data set amenable to computational analysis, it diminishes the complexity of informal relationships. This approach to focusing on what can be collected fails to capture the multi-dimensional characteristics of informal connections. In the context of our interests, informal interactions among graduate students from different labs at a conference would not be captured in such a data collection approach. Similarly, the discussions of panelists from different organizations who come together at a conference would never be represented as ties or nodes unless there was some mechanism to remind them to code these.

Another limitation of most current network approaches has to do with their primary emphasis on structure over action. Network models generally posit that the attributes of actors are less important than their relationships with other actors within the network (Scott et al., 2007). This approach leaves less room for individual agency. In addition, most social network efforts examine current social relations between actors (Hargadon et al., 1997). However, an individuals' knowledge represents ongoing relations as well as remains from ties that have been accumulated over time. As such, any informal network has presumably a temporal dimension, which embraces not only the ties at hand but also all relationships that an individual has developed over time, which tend to come and go over time. In short, there have been few studies

of network dynamics over time, and those that exist do not tend to theorize strongly on the nature of the dynamics or the influence of the context on the dynamics.

COMMUNITY OF PRACTICE

The c*ommunity of practice (CoP)* literature focuses attention to the *voluntary* nature of informal networks. By recognizing the entangled nature of meaning and action, this work has sought to explain how knowledge and learning are situated in work practices. A CoP is a group of individuals sharing a similar set of interest, skills and expertise: more a shared occupational engagement than shared organizational allegiance (Wenger, 1999). A defining feature of CoP is that they emerge spontaneously from individuals who share similar activities and interest and maintain some type of informal interactions (Lesser & Everest, 2001). These loose clusters of individuals are engaged in related work practices, but do not necessarily work in the same place or for the same firm. Such networks may embrace formal and informal ties both within and among firms. From this perspective, while organizations are perceived as containing multiple and heterogeneous communities of practice, these communities may enable members to traverse organizational boundaries (Brown & Duguid, 2001b).

One of the significant benefits to members of a community of practice is facilitated circulation of ideas. The information that is shared and transferred via a community of practice is boundless (Dalkir, 2005). Brown and Duguid (1991) note that communities of practice are crucial to the innovation process because they constantly improvise, adjusting their activities to transcend the bounds of formal structures and canonical practices. As a dense, informally constituted network of shared practice, a community of practice presents "less inherent conflict between those who must agree to support the innovation." (Obstfeld, 2005, p. 107). The CoP conceptual framework offers a conceptual vocabulary for explaining the relative "leakiness" of

knowledge in innovative practices. The CoP theories postulate that these communities stimulate innovative ideas, as "the process of innovating involves actively constructing a conceptual framework, imposing it on the environment, and reflecting on their interaction" (Brown et al., 1991, p. 53). Such communities exert influence on knowledge dissemination within innovation networks, while they simultaneously emerge from and shape network structures. They constitute and constrain the inter- and intra-firms networks through which knowledge is acquired and conveyed (Lesser et al., 2001).

For instance, Saxenian (1994) reports that sharing of proprietary information goes on among engineers in Silicon Valley. The professional knowledge is shared on the grounds of strong commitments to peers in the community of practice rather than based on formal channels. Saxenian (1994) assumes the institutionalized informal knowledge sharing practice to make a considerable contribution to the fertile climate of innovation in Silicon Valley. In fact, the CoP framework emphasizes that information exchange is not fully under managerial control, although reciprocal interactions can be channeled by managerial involvements (Powell et al., 2005).

INVISIBLE COLLEGES AND EPISTEMIC COMMUNITIES

An *invisible college* can be characterized as both a distinct intellectual space and as a particular form of community of practice. The general implications of both conceptual frameworks also exhibit a great overlap. However, because the literature on invisible colleges has developed in parallel to the research on communities of practice, we discuss it independently here. While communities of practice can encompass any work practices, the concept of an invisible college denotes a group of researchers (mainly in the academic sphere) that work together closely. Like a community of practice, an invisible college includes not only people actually working together in a single organization, but also researchers who are distant in

geographical space (Verspagen & Werker, 2003). These collaborations can go beyond a national scale, to incorporate "all other countries in which that specialty is strong" (Price, 1986, page 119). In principle, belonging to and participating in these informal networks of scholars develops power and prestige for their members. An invisible college is signified when scholars "meet in select conferences; they commute between one center and another; they circulate preprints and reprints to each other; and they collaborate in research" (Price, 1986, p. 119).

By investigating invisible colleges, Crane (1972) sought to "understand how knowledge grows" and "how scientific communities affect the growth of knowledge," which was in "sharp contrast with the attention being paid to how knowledge is stored, distributed, and used." Typical invisible college studies investigate scientific networks in order to map the structure of co-authorship and citations (Newman, 2003). For this reason, we argue that the concept of an invisible college is useful to uncover the situated interactions of research communities in the innovation process. This type of insight has practical importance when significant portions of innovation processes engage basic research which is mostly practiced in the academic arena. The collective inventions, which lead to further development or problem solving activities within a new technological paradigms is typically built on an invisible colleges (Dosi, 1988; Hull, 1988).

Through a phenomenon-oriented lens, the research on invisible colleges reveals the nuances of the innovative practices of scientists. It posits that the research process is a largely social enterprise in that an informal network of scientists, organized around an important research agenda (a phenomenon), makes crucial decisions. Indeed, young scientists and graduate students are acculturated into the value of both participating and perpetuating these invisible colleges, what Karin Knorr-Cetina (1999a) has famously called epistemic communities. In epistemic communities members learn or are mentored to see any new technological

breakthrough as either arising from within the community or as a result of the invisible college responding collectively to external breakthroughs. The invisible college—as an informal network of researchers—crystallizes attention, discourse and effort around some commonly shared intellectual interests, evidence and approaches (a "paradigm") to study a common research idea. In this way, the invisible college endows researchers with a means to dispense with the uncertainty of the research process. The invisible college of researchers and the respective paradigm provides researchers who are affiliated with the paradigm with a basis for security and stability in the wobbly world of research (Crane, 1972).

Clearly, both *CoP* and *invisible college* literatures and concepts provide insight into the formation and value of informal networks. However, these approaches, as they are rooted in people's activities, suffer from a lack of explanation for the roles of artifacts in the network. That is, anything created through this process is of secondary importance: they disappear from view. Price (1986) recognizes the material contribution of invisible college members, noting that published documents are relevant – if note central – to an invisible college. In fact, much of the research traces invisible colleges by investigating the links among publications (e.g. by using bibliometric analyses). However, this limited view of materiality is not able to account for other forms of artifacts (i.e. information technologies). Similarly, CoP theories do not provide insights as to how the technological innovations, as the result of the network, themselves influence the network structures and performance. Neither CoP nor invisible college theories help us to explain how technologies embody knowledge and how they might affect the exchange of knowledge across these informal networks.

ACTOR NETWORK THEORY

Actor network theory (ANT) has emerged from the sociology of science as a means for representing networks as embracing not only the human actors but also the physical artifacts and the concepts to which those actors relate (e.g. Callon, 1986, 1999; Latour, 2005). This directly addresses the handicap of CoP and invisible college perspectives because ANT expands the notion of a network to reflect the technological capabilities and the knowledge that resides within (or is embedded into) artifacts. At the heart of ANT lies the concept of *generalized symmetry*. Generalized symmetry implies that all the heterogeneous elements of a network, both human and non-human, can be explained in the same terms. In this light, non-human (mainly technological) contributions are important, insofar as they are related to human components. The resulting network is a chain made up of intermediaries, actors, texts, knowledge and scientific facts, each contributing in its own way to push forward innovation among those whom the network wishes to mobilize (Callon, 1992). At its core ANT provides precedent for understanding the contribution of both humans and artifacts to the innovation processes. It explains how certain actors construct the identity of the other actors by making the latter act in accordance with the former's wishes. An actor-network is constructed through the enrolment of allies (both human and non-human actants) into a network by means of negotiations. The process through which actors interact with one another to build or to transform the network is called "translation."A group of actors plays a more significant role, as they try to advance innovative propositions, mobilize resources and translate the interests of others in hopes of engaging them. The heterogeneous network operates by virtue of multilateral agreements that derive from the translation of actors' disparate interests, which will eventually converge (Harrisson & Laberge, 2002). In a nutshell, through concepts like *symmetry* and *translation*, ANT posits that not only

can networks enhance innovation processes, but they also constrain it by circumscribing the kinds of innovations produced, their subsequent interpretations, and their final uses (Callon, 2002).

The concepts of ANT have limitations relative to innovation networks. Due to its high level of abstraction and epistemological approach, ANT is descriptive. An ANT analysis does not engage in explaining or evaluating particular social structures. In addition, ANT does not provide a means to clarify why a network takes the form that it does. Instead, ANT is more concerned with exploring how networks of actors are constructed, maintained, or destroyed. In addition, given its descriptive disposition, ANT has questionable utility for discerning which actors are instrumental within a network and which are not. Because of the heterogeneity of the network and the principle of general symmetry, ANT does not suggest any criteria to define the nature and score of the actors in advance. Latour notes that the concept of network "is also a way of getting rid of system and structure" (Crawford, 1993 ,page20). Another issue with ANT is the desire to provide a complete description of the network. The number of potential elements to be identified is virtually infinite; while Callon (1991) argues, "the description (of the networks) has to cover all details, since every detail counts". Since ANT's holistic approach is not meant to leave out any details, the absence of a criterion for judging the relevance of the networks' elements can be theoretically unmanageable.

TABLE1:

Insightful perspectives for explaining the informal network of innovation

Perspective	Relevant Concepts	Focus	Insights	limitations
Social Network Perspective	• Exchange of information between nodes, • Small world, • network dynamics	The networks of individuals and their quantifiable ties	Elaborate on various dimensions of social networks	• Emphasis on structure over action. • Focus on current social relations (lack of temporal dimension)

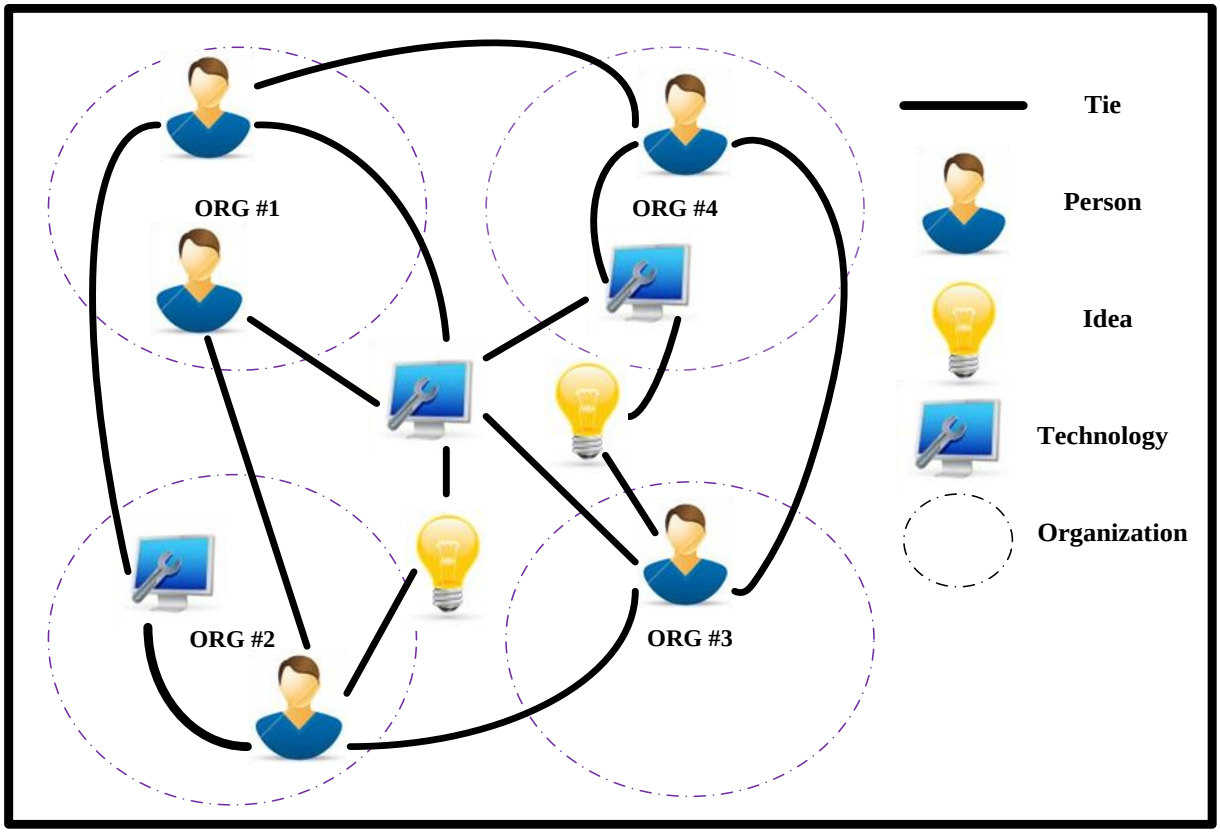
Community of Practice	• Voluntary nature of relations • Shared interest, and expertise • Learning as a social activity	CoP as a permeable and informal structures	Explain the rapid flow of information and propagation of innovation in the network	• Limited view on materiality and the contribution of technologies
Invisible College	• Power and pedigree • Basic research • Scientific paradigms	Distinct academic and intellectual spaces	Demonstrates how the real structure of scientific communities influence knowledge dissemination	• Limited view on materiality and the contribution of technologies
Actor Network Theory	• Heterogeneity of networks • General symmetry between humans and non-humans • Translation of interests	Heterogeneous network of human and technological actors	Explain both the contribution and the relations of technologies and humans, and integrate the temporal dimension	• High level of abstraction • Little explanation of the score of the actors

FRAMEWORK FOR STUDYING INFORMAL NETWORKS

This review of relevant research reveals that existing conceptual frameworks each can bring to light only some aspects of what we see as the informal network of innovation. We find ourself agreeing with the argument put forth by Hargadon and Sutton (1997): networks of innovation are organized around different sets of *physical artifacts*, *human actors*, and *concepts*. Our insight is that these are related through the *social structures of networks* and that these networks have a temporal dimension (See Figure 1). In the remainder of this theoretical essay, we advance our conceptualization of informal networks of innovation.

FIGURE 1

The Informal Network of Innovation



The Social Structures of the Network

While social structures, as sets of rules and resources, are not external to actors, they can both enable and constrain subsequent interactions of network elements (Giddens, 1986). Networks actors become engaged in the emerging network structure, also known as technological path (Garud & Karnre, 2003), that is shaped by previous and ongoing interactions. The network elements are in fact embedded in the very inputs that they have produced through

their current interactions and engagements with existing network structures. The networks' power is grounded in these social structures. The accumulation of inputs from different actors can then yield a momentum (Hughes, 1983a) which harnesses the inputs of distributed actors. Once the momentum is created as a set of institionalized social structures, it begins enabling and constraining the practices of involved actors (Dosi, 1982; Garud & Jain, 1996).

Nor can these social structures be attributed to any one individual actor, as they inherently involve the interplay of a multiplicity of actors (Bijker & Law, 1992; Latour, 2005). Furthermore, these structures are not stable: they do not reach any closure as they are constantly enacted and reenacted by involved actors. As noted, even the constitution of actors might undergo changes, since some may choose to leave at the same time that newcomers join the networks (Latour, 2005). And, the involved actors may also reflect varying levels of engagement (Bijker, 1987). In short, social structures emerge from the ongoing accumulation of artifacts, tools, practices, rules and knowledge (Latour, 2005) that in turn shape the relation of involved actors. Both the *CoP* and *invisible college* frameworks can be illustrative for identifying the role of these informal structures. Both focus on the relationships among the informal network structures and actor's collective practices (such as knowledge sharing). While a community of practice can facilitate the flow of knowledge and innovation within communities, it may also hinder knowledge flow across different communities (Brown et al., 1991). For instance, while scientists can collaborate or communicate globally with their colleagues from the same discipline, the community bounds may discourage them to reach out to other disciplines, and collaborate with other scientists, even at a local level (Knorr-Cetina, 1999b).

Current theorizations of social networks also illuminate how specific networks arrangements and structures determine the innovation processes. For example, Burt (1992;

2004), through the concept of a structural hole, explicates how individuals situated in the confluence of different social domains can harness the opportunities for the novel combination and recombination of innovate ideas.

Innovative Concepts

Innovative ideas and knowledge, crystallized into concepts, help to shape innovation and facilitate innovation processes. In an innovation network, concepts are often a means of connecting people. That is, two scholars may have read the same material on the nature of gesture recognition in computing displays. This concept, and the evolution of people's understanding of this, evolves as part of the network of relations (Weick, 1979b). Elements of the shared concept are drawn on by scholars to shape other ideas and designs. As a part of the network, concepts can be connected and such connections can proliferate into new sets of innovative ideas. These novel combinations are objectively new concepts on their own right, because they are built upon existing but previously unconnected ideas. Therefore, innovation processes involve the discovery of pre-existing concepts (Harper, 1996; Knight, 1971), and embrace the creation of new concepts through the combination and transformation of existing concepts and resources (Garud, Kumaraswamy, & Nayyar, 1998; Usher, 1954; Venkataraman, 1997). These concepts may never lead to an innovative outcome, but their combinations may.

Network structures contribute to this process by providing the means to connect concepts. For example, the detailed study of work done byThomas Edison's Lab is an exemplar whose products mainly reflected blends of existing but previously separate ideas (Hughes, 1983a). To this end, inventions from Edison's lab were not considered entirely original, but rather extensions and blends of existing products and concepts. Those in Edison's lab achieved these innovations through interactions with disparate industries. For instance, *the phonograph*

combined old and existing concepts rooted in telegraph, telephone, and electric motor industries as well as constructs developed by other entities with which the lab's engineers had previously worked (Hargadon et al., 1997).

In this regard, our review illustrates that the social network perspective provides insight and guidance relative to people's involvement in innovation activities. This body of literature provides guidance on how strategically posited individuals can facilitate the dissemination of information (Tushman & Scanlan, 1981). In a different fashion, ANT can accommodate the roles that are played. In ANT something that is "material-semiotic", underscores the capability of explaining the connections that are simultaneously "material" (happens between artifacts), and "semiotic" (between concepts) (Law, 1999). The invisible college framework also lends emphasis to particular "concepts" and "phenomena of interest" through which different researchers can be attracted to a network, and scaffold their collaboration structure.

Physical Artifacts

Like *concepts*, physical artifacts are directly crafted by human actors, but they can stand apart from their makers. A physical artifact can exert limited agency through providing or lacking certain material properties, inscribed be designer, which in turn influence peoples interactions (Orlikowski, 2000). For instance, "tailorable tools", which can lend themselves to various local needs, enable various users to construct or customize a specific version (Malone, Lai, & Fry, 1992).

As we have noted, while cursory observations may suggest a linear trajectory, more thoughtful examinations reveal a complex web of interactions among human actors and the physical artifacts they create (Garud & Rappa, 1994). In this respect, Weick (1979a) proposes that technologies lies in two intersecting arenas: the mental, and the physical. The interplay of

these two arenas is captured by the notion of *enactment* through which actors "actively put things out there" (Weick, 1979a, p. 165), and construct the physical artifact. In turn, while human actors interact with their products, these artifacts can shape their behaviors toward particular ends. However, through the concept of symmetry, ANT makes this distinction between the technical and the social more tenuous (Callon, 1986). Based on the concept of symmetry, both social and technical entities, including technologies, are explained as "actants" (Akrich, 1992), enabling researchers to contemplate the "impacts" of socio-technical networks in a non-deterministic fashion. By non-deterministic fashion, we mean a middle-ground between social and technological determinism.

We have a broad conceptualization of physical artifact, one that encompasses both written documents and technologies (and in particular for us "information and communication technologies"). Documentary practices, such as academic papers, technical reports, or even emails, serve to generate and preserve innovative ideas and are critical to the success of any multi-institutional collaborations (Chompalov & Shrum, 1999). These documents also constitute the "social memory" of collaboration in science. Other types of artifact, too, can play out proactively in the network, as they serve as an embodiment of knowledge. Thus, the relationships of actors are mediated by artifacts, into which the historical developments of the previous interactions are accumulated. The physical artifacts can be both enabling and constraining; they affect actors interactions with the historically collected experience and knowledge crystallized to them (Kuutti, 1995).

Institutions

Social institutions play two differing roles with regards to the informal networks of innovations. First organizations offer resources for individual members and for the exchange

processes that are central to social networks (Scott et al., 2007). These resources can be monetary. Of course, the structure and norms of organizations also constrain and enable individuals' behaviors: encouraging some activities and directing attention away from other choices (Orlikowski, 2000). More broadly, people within a willing organization will have the freedom to interact with other individuals situated in other organizations and will be able to exchange information through network mechanisms. Second, organizations can take advantage of networks of innovation. Those members of the organization who are also participants in innovation networks can use these ties to bring in information and resources to the host organization. For instance, those in the Edison laboratory could more easily innovate because the lab, through its members, occupied a "structural hole" in the larger informal network of professional networks. (Hargadon et al., 1997). The concept of structural hole denotes a gap in the flow of information between subgroups in a larger networks (Burt, 1992).

By definition, innovation networks are considered loosely coupled and self-organizing coalitions in the absence of any hierarchical control (Freeman, 1991). These arrangements therefore are orchestrated through a "subtle leadership" (Orton & Weick, 1990, p. 211) where hubs are instrumental in the initiation and growth of networks. While the hub firms wield their leadership by virtue of a combination of individual attributes and their central position in the network structure, the other institutions are by no means inert: they respond actively to the hubs' initiatives (Dhanaraj & Parkhe, 2006).

However, as the network paradigm demonstrates, individual firms are not the loci of innovation. In fact, a social network of individuals, which is not totally contingent upon the organizations with whom they are affiliated, sustain the innovative exchange between individuals, such as the exchange of knowledge (Wasko, Faraj, & Teigland, 2004). As noted

before, to transfer knowledge for innovation practices, the network organization is preferred over market mechanisms mainly because all learning activities involve collaboration between individuals (Grant, 1996). This argument is consistent with the premises of CoP and invisible colleague. According to both frameworks, the knowledge sharing traverses the limitation of formal organizations and canonical practices.

Human Actors

Arguably, the most fundamental elements of the informal network are human actors. Knowledge creation and its use are both human and social processes (Brown et al., 2001b; Davenport & Prusak, 1998). Innovation processes involve knowledge-intensive activities, such as cultural production, scientific research, design work, and professional services. These practices substantively involve forms of tacit knowledge, embedded in particular people, which is difficult to codify (Powell, 1991). These people represent "repositories" of innovative ideas that are also highly intangible and only partly mobile. Furthermore, any one individuals' body of knowledge represents both past and present linkages to other people, concepts and artifacts they have connected with over time. These individuals are not just impartial role actors, but "they become embroiled in diverse, partisan, and increasingly embedded ways" (Van de Ven, 2005, p. 369).

As a result, organizations should not be regarded as the primary locus of innovation, since these critical assets, human actors, may choose to walk away. Larsen and Rogers (1984) note that the departure of a key worker could be catastrophic for any organization, as they take their knowledge and skills with them. Movement of actors from one context of knowledge use to another would circulate knowledge and experience within a network. This sort of transfer is not conducted through formalized channels.

The social network perspective recognizes the centrality of specific individuals in innovation networks. For example, Allen (1977) introduces "gatekeepers" as critical individuals who import novel information, and link their organizations to the environment through their extensive informal ties. In this way, gatekeepers serve as the primary links to the external sources of information and technology (Katz & Tushman, 1981). Therefore, the innovative ideas are not created within formal structures but they emerge at the boundaries between mindsets. This is why firms can accrue networks externalities, by developing more multiplex ties with individual partners (Powell et al., 2005). As mentioned earlier, the concepts of invisible college and community of practice are illustrative for portraying these informal connections, and the way they coexist and interact with formal and contractual structures.

The Temporal Dimension

Any study of innovation can be evaluated based on its logical structure. Logical structure here denotes how each organizational study theorizes the occurrence of an innovation (Markus & Robey, 1988). To explain differing logical structures, Mohr (1982) distinguishes between variance and process models. Barnett and Carroll (1995) attempt to make almost the same distinction through the dichotomy of content and process of change. Content refers to what actually brings about organizational outcomes, and is of interest in variance models. In contrast, process models examine process, embracing the sequence of events over time as change unfolds in an organization. Rather than focusing on the deterministic causation, process models explain change through the narratives of the sequence of events (Crowston, 2000). In this way, it is integrative of critical events, turning points, and contextual influences (Van de Ven & Poole, 2005).

Historically, innovation scholarship has suffered from a lack of a process-oriented understanding of how innovations unfolded. Thus, most contemporary models of innovation fail to integrate the temporal dimension of the innovation processes. Van de Ven (2002) notes that innovation scholarship should break way from its current focus "only on individual or firm" and formulate "process theories that explain how and why technical and institutional innovations co-evolve." Most network studies tend to represent cross-sectional snapshots rather than to attend the evolutionary nature of innovation processes (Parkhe, Wasserman, & Ralston, 2006). In fact, very few studies have adopted a process view to capture temporal changes in networks (i.e. Burkhardt & Brass, 1990; Doreian & Stokman, 1997; Hite & Hesterly, 2001)[2]. Nonetheless, these are superb exceptions. Monge and Contractor (2003) have called for more process theory to explain the creation, maintenance, and dissolution of networks of actors. In contrast to the network perspective, ANT offers up a conceptual means for explaining the evolutionary nature of the innovation networks. ANT captures the innovation process and the sequence of events through the "sociology of translation" which aims to describe, rather than explain, many transitions and negations that take place when the network is configured (Callon, 1986).

In short, the informal network of innovation centers on relations among individuals, shared ideas, common technological artifacts, and supporting organizations. Individuals are connected through invisible colleges or communities of practice and can evolve over time. Innovative ideas and technologies also tie individuals. These non-human actors can travel across time and space and enable individuals to draw from the work of others. Within the network, organizations offer resources and take advantage of the flow of innovation knowledge, but are

[2] We note that the growth of networks is a central issue for much of the research in complexity theory, though their research findings are difficult to assimilate into the existing literature on innovation and social networks. For more on this see (Amaral & Uzzi, 2007)

not the locus of innovation. The social structures of the network chart the boundaries of the network, while are enacted by the dynamics of actors' interactions.

CONCLUSION

We have argued that innovation is not a property of institutions or even formalized structures. We have focused in particular on technological innovation and argued that it goes beyond the efforts of individual innovators and the boundaries of a particular firm. We have further argued that the skills and resources needed to take an idea from its inception to commercial use draws upon actors that may include non-human forms such as focal concepts and particular (and often technological) artifacts.

We have developed a nascent model of innovation networks founded on the logic that most of the inter-organizational relationships among people, concepts and artifacts are based upon the informal ties among individuals. Moreover, we have argued that informal ties play a critical but under-theorized (and thus under-studied) role in the innovation process. These informal networks facilitate the exchange of innovative ideas and experiences among different groups of actors. In our model we argue that the innovation process can be presented as a group of *people* creating *facts* and *artifacts* which are influenced by *structures* that have evolved over time. This model appeals to human actors, as the main fabrics of the network, and attend to the body of knowledge and experience they accumulate. Building on the ANT argument, the model also highlights the concepts and artifacts that interact at the theoretical level with human actors. The social structures define the boundaries and scope of a network. As the result of previous interactions, they would in turn shape the current interactions of actors within the network.

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