THE IMPACT OF GLOBAL AND LOCAL COHESION ON INNOVATION

IN THE PHARMACEUTICAL INDUSTRY

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Running head: The Impact of Local and Global Cohesion on Innovation

Keywords: cohesion, intra-organizational networks, innovation, pharmaceutical industry, global vs. local

Abstract

In this paper, we examine how the configuration of intra-organizational networks, and in particular, cohesion among members of an organization, influences organizations' innovative output. We argue that the cohesion among R&D scientists could be at a local level or a global level, and that local and global cohesion may have different impacts on firms' innovation performance. We test our hypotheses by examining the structure of the R&D collaboration networks within firms that operated in the pharmaceutical industry between 1981 and 1989, and their innovative outcomes – patents that led to new product launches. We find that local cohesion has a positive impact on the innovative performance of a firm, and global cohesion has a negative impact.

The importance of the informal structure in influencing organizational outcomes beyond the formal organization of tasks and resources has been an important tenet of work on strategy and organizations (e.g., Allen & Cohen, 1969; Burns & Stalker, 1961; Katz & Kahn, 1966; Tichy, Tushman & Fombrun, 1979). In particular, an early body of work in this stream has focused on the importance of the structure of communication among individuals in an organization for innovative outcomes (e.g., Allen & Cohen, 1969; Tushman, 1978; Tushman, 1979; Tushman & Katz, 1980). This literature has underlined the importance of understanding whether and how the design of the informal structure within an organization, along with task characteristics, may influence the organization's innovative outcomes. However, since these early attempts at understanding what constitutes effective informal structure, there has been limited research in this area. In 1988, Krackhart and Stern wrote, 'there is no current theory that points to an optimal structure of the informal relations in an organization' (1988: 123).

More recently, there has been a surge in studies adopting a network approach, allowing us to learn about the patterns and consequences of network ties at different levels of analysis. These studies have vastly enhanced our knowledge on how networks influence innovative output, for individual inventors, teams, or organizational units, both from a structural and relational perspective (e.g., Fleming, Mingo & Chen, 2007b; Hansen, 1999; Nerkar & Paruchuri, 2005; Reagans & McEvily, 2003; Rodan & Galunic, 2004; Singh, 2005; Tsai, 2001; Tsai & Ghoshal, 1998). While these studies have contributed significantly to our understanding of the role of informal network structures on innovation, two important gaps remain: (1) An overwhelming majority of studies examining communication networks focus on ego-networks, and examine the position of a focal actor (individual, unit or team) within the overall structure, rather than the design of the overall structure; (2) Most studies focus on how a particular network feature enhances the performance of the focal actor, rather than the performance of the overall organization. As a result, research examining the overall configuration of intra-organizational networks, and its impact on organizational innovation outcomes, has remained scarce. In 2007, Kleinbaum and Tushman noted, 'Relatively few scholars have directly studied the benefits that intra-organizational social networks bring to the organization itself' (2007: 108).

In this paper, we aim to address this gap by examining how the configuration of intra-organizational networks influences organizations' innovative output. In particular, we focus on a key dimension of the intra-organizational network configuration: the cohesion among members of an organization. Prior research has established that employees, teams or even firms that are embedded in cohesive networks enjoy a variety of advantages, such as trust, enhanced information sharing, and enforceability of norms and sanctions (Coleman, 1988; Nahapiet & Ghoshal, 1998; Uzzi, 1996), while others have pointed out the downsides of membership in cohesive networks (e.g., Burt, 1992). Many empirical studies have examined these claims, sometimes with contradictory findings (e.g., Fleming *et al.*, 2007b; Obstfeld, 2005; Rodan & Galunic, 2004; Rowley, Behrens & Krackhardt, 2000). We contribute to this literature in two related ways. First, as opposed to prior work that has focused on the consequences of cohesion *for the focal actor*, we examine the outcomes of a cohesive network configuration on the overall organization (Kleinbaum & Tushman, 2007). Second, we distinguish between local cohesion within the immediate neighborhood of each actor, and global cohesion within the overall intra-organizational network. We suggest that the two structural features of the intra-organizational network may have different consequences on innovation outcomes.

We test our hypotheses by examining the structure of the R&D collaboration network within firms that operated in the pharmaceutical industry between 1981 and 1989, and their innovative outcomes. This is an attractive context to examine our research question for several reasons. First, following prior literature, we infer the structure of the intra-organizational collaboration network by studying co-authorship patterns on patents issued by the members of each firm (e.g., Fleming, King & Juda, 2007a; Nerkar & Paruchuri, 2005; Singh, 2005). This allows us to circumvent the difficulties related with collecting and systematically comparing large amounts of data on the intra-organizational networks for a large sample of firms. Second, we are able to test the impact of the intra-organizational network configuration on innovation outcomes with data on new product launches resulting from the organization's patenting activity, the ultimate performance goal and innovative outcome for pharmaceutical firms (Thomke & Kuemmerle, 2002).

INTRA-ORGANIZATIONAL NETWORK CONFIGURATION AND INNOVATIVE OUTCOMES

In this study, we adopt a perspective of organizations as networks of communication and exchange between members (e.g., Katz & Kahn, 1966; Powell, 1990; Tichy *et al.*, 1979). Above and beyond the formal lines of structure, the informal network is frequently the means by which individuals and groups share information, recombine ideas, and generate innovative outcomes (e.g., Hargadon, 2003).

Innovations typically come about through recombinations of existing knowledge (Fleming, 2001; Schumpeter, 1934). Inventors bring together components in novel, previously unthought-of ways (Hargadon, 2003). They search for successful recombinations by varying the composition of familiar components, and introducing new components, typically one or few at a time, or by utilizing scientific findings as guiding principles for new combinations (Fleming, 2001). While the number of successful innovations may be correlated with the number of systematic trials, the value of each innovation to the external world and to future innovative efforts is typically a function of its novelty in recombination. Since each individual scientist possesses a limited amount of knowledge, collaborations among scientists is the key to novelty. Sharing and transfer of knowledge are best accomplished through interpersonal interaction, since recombination requires a detailed level of understanding of each component that is usually tacit and hard to transfer (Hansen, 1999; Sorenson, Rivkin & Fleming, 2006).

Informal networks within organizations not only ensure knowledge flow between scientists that lead to novel recombinations, but also provide support, buy-in, and resources necessary for new ideas to flourish (Allen & Cohen, 1969; Tushman & Katz, 1980; Tushman & Scanlan, 1981a, 1981b). Prior work has underlined the importance of intra-organizational networks in generating and developing innovation. A series of studies on the structure of R&D labs has shown that, especially in projects involving complex and non-routine tasks, the extent and pattern of intra-organizational communication influences innovative outcomes (Tushman, 1978, 1979). The presence of gatekeepers and boundary spanners, or centralized individuals that transmit information among members of the organization as well as from external sources, enhances innovative outcomes (Allen & Cohen, 1969; Tushman & Katz, 1980; Tushman & Scanlan, 1981a, 1981b). Intra-organizational linkages increase the awareness of each researcher about the knowledge repositories available within the firm, and how they fit with the researcher's own work, especially when units within the firm are geographically dispersed (Lahiri, 2010). Others have pointed to importance of linkages among different organizational units in enhancing performance (e.g., Tsai, 2000; Tsai, 2001; Tsai & Ghoshal, 1998). In particular, the strength of the tie among subunits may influence project completion time, depending on the nature of the task at hand. For projects involving complex and interdependent knowledge, having strong ties between units is more beneficial (Hansen, 1999). Moreover, work on R&D teams has shown that teams share knowledge with more ease, and are more productive, and when they are internally cohesive, and have non-redundant ties to diverse knowledge areas and external sources of information (Reagans & McEvily, 2003; Reagans, Zuckerman & McEvily, 2004; Reagans & Zuckerman, 2001).

Informal networks are typically multi-faceted, and involve multiple types of ties, such as friendship or collaborations. They may also have a variety of influences on organizational outcomes. Many prior studies has used survey methodology to capture the influence of network ties and structure on innovation (e.g., Allen and Cohen, 1969, Tichy, Tushman and Fombrun, 1979; Tushman, 1978, 1979, Tushman and Katz, 1980; Rodan & Galunic, 2004; Reagans & McEvily, 2003; Tsai, 2001; Tsai & Ghoshal, 1998; Obstfeld, 2005). While this methodology may allow researchers to capture the content of ties with more accuracy, it also makes it difficult to collect and compare network data from multiple organizations. Studies that employ survey data often limit their scope to one (e.g., Reagans and McEvily, 2003; Hansen, 1999; Obstfeld, 2005) or few organizations (e.g., Tsai, 2001).

In this study, we focus specifically on patent collaboration ties between individual scientists in an organization. Prior work has found that patent collaboration networks provide a suitable proxy for informal channels of information and resource exchange necessary for innovation (e.g., Fleming *et al*, 2007a; Nerkar & Paruchuri, 2005; Singh, 2005). First, collaboration ties are distinct from the formal organization structure, as initiation of collaboration is voluntary and shaped by the individual scientists' research interests rather than formal organizational lines (e.g., Fleming *et al.*, 2007a; Liebeskind, Oliver, Zucker, & Brewer, 1996; Tushman & Romanelli, 1983). For instance, Singh (2005) finds that collaborative ties explain away a large fraction of knowledge flows due to collocation of scientists, typically associated with the formal organization structure (Argyres & Silverman, 2004). Second, significant levels of knowledge exchange occur through collaboration networks (Singh, 2005). For instance, Fleming et al (2007a) report interview findings that patent co-authors rely on collaborators for information exchange and infrastructural support. Third, interpersonal ties formed through patent collaborations last for many years, as patents are typically culminations of research programs, and persist beyond the duration of the patented project. Scientists rely on their collaboration network ties for information and support not only through but also after collaboration (Agrawal, Cockburn & McHale, 2006; Fleming *et al.*, 2007a; Singh, 2005). We therefore follow prior research in examining the patent collaboration network as a proxy for the informal structure of knowledge exchange. Although it does not cover all facets of the informal organizational network, it provides a suitable and well-established proxy of the networks of information exchange, and allows us to collect and compare network data from multiple organizations without the prohibitive effort of capturing complete and comparable informal network data through primary data collection. As a result, this study is among the first to focus on and empirically examine organization-level outcomes of collaboration networks.

In sum, the informal structure of collaboration within a firm's boundaries is likely to shape the recombinant activity and the innovative performance of the firm (Allen & Cohen, 1969; Nahapiet & Ghoshal, 1998; Tsai, 2001; Tsai & Ghoshal, 1998; Tushman, 1978, 1979; Tushman & Katz, 1980). Although network ties provide the necessary connections through which knowledge transfer may occur within and outside firms, firm boundaries are still likely to contour patterns of communication through physical proximity, shared identity, and frequency of interaction (Borgatti & Cross, 2003; Kogut & Zander, 1996; Reagans & McEvily, 2003). Therefore, the structure of the intra-firm collaboration network is likely to be an important determinant of a firm's combinative capability, or its ability to generate novel and valuable recombinations of knowledge (Nahapiet & Ghoshal, 1998).

In the next section, we turn our attention to a specific structural feature of networks, cohesion, summarize prior research findings on its impact on innovation, and develop our hypotheses.

COHESION AND INNOVATION

The literature suggests three ways in which cohesion helps innovation: Enforceability of sanctions and norms, trust and reciprocity, and knowledge sharing. First, cohesion encourages cooperation between members of the network, as opportunistic behavior is more likely to have adverse reputational consequences in cohesive networks (Coleman, 1988). When a member of a cohesive network behaves in a way that harms another's interests, this information travels easily through a cohesive network, influencing the reputation of the focal member. Moreover, other members can more easily punish unwanted behavior when the network is closed. Therefore, cohesive networks discourage opportunistic behavior and make it easier for each member to share proprietary information and ideas, facilitating the recombination and exchange that lead to innovation.

Second, beyond the norms and sanctions, prior research shows that members of cohesive networks are more trusting toward each other, and are more open to cooperation (Uzzi, 1996). As opposed to sparse networks, where competition between members for information and access is the prevailing norm (Burt, 1992), cohesion leads to a culture of sharing and working in tandem. In such networks, members can more freely engage in idea and knowledge exchange without fear of adverse consequences. Trust generated by cohesion increases the motivation of network members to 'invest time, energy, and effort in sharing knowledge with others' (Reagans & McEvily, 2003: 240), as well as increase their willingness to experiment and share risk (Nahapiet & Ghoshal, 1998). Cohesive networks also provide more support for innovative ideas, and present less internal conflict (Obstfeld, 2005; Podolny & Baron, 1997).

Last, cohesive networks facilitate knowledge sharing among members, because the kind of tacit knowledge that is essential for exploratory tasks may be best transferred through the strong and embedded ties that are most often found in cohesive structures (Hansen, 1999; Obstfeld, 2005; Uzzi, 1997). While knowledge shared in sparse networks may be more diverse, knowledge exchange in cohesive networks is more likely to be 'meaningful' (Nahapiet & Ghoshal, 1998: 253), rich, and instilled with context (Obstfeld, 2005). Actors within cohesive networks share a common language and understanding (Nahapiet & Ghoshal, 1998; Obstfeld, 2005), akin to communities of practice (e.g., Brown & Duguid, 2001; Obstfeld, 2005) or invisible colleges (Merton, 1973; Uzzi & Spiro, 2005). As a result, cohesive ties offer advantages for innovative tasks that require intensity and richness in the shared knowledge.

Local cohesion and global cohesion

While the extant theory summarized above seems to suggest that most of the benefits of cohesive networks are structural (i.e., they arise from a particular structural configuration), most of the empirical work is at the ego-network level, examining cohesion within the immediate neighborhood of the focal actor rather than the overall network structure. Moreover, with few exceptions, these studies test the benefits that accrue to the actors that hold positions in cohesive networks, rather than to the overall organization. While the general assumption appears to be that the consequences of network cohesion for the overall structure will be equal to the aggregation of the benefits to the individuals comprising the network, this assumption remains largely untested (Kleinbaum & Tushman, 2007; Nahapiet & Ghoshal, 1998).

In aggregating the findings from ego-network studies to a study of the overall configuration of the informal organizational network, one of the difficulties to arise is to anticipate the overall structure that will ensue from the aggregation. In an organization where individual members are embedded in cohesive networks, two types of overall structural patterns may emerge. First, cohesion may be limited to neighborhoods, in which focal actors are densely connected to their neighbors, but sparsely connected to the rest of the organization (local cohesion). Second, cohesion may be a characteristic of the global network, in which all members are embedded through cohesive ties. It is important to understand whether both aggregate structures confer similar cohesion benefits (or limitations), since this has consequences for the design of the informal structure, as well as for organizational innovation outcomes.

While there is no systematic test of either the local or global cohesive structures for overall organizational innovation outcomes, the literature offers some guidance into the organizational consequences of each. Two streams of research exist with respect to the impact of local cohesion on innovation. On the one hand are studies which suggest that local cohesion, in which network members are densely tied to their immediate neighborhoods, makes it easier to mobilize members around new ideas, due in part to similarities in perspectives and interests (Obstfeld, 2005). Such networks provides members with the enforceability, trust and knowledge-sharing benefits summarized above, enhancing creativity and innovative outcomes (e.g., Fleming *et al.*, 2007a; Fleming *et al.*, 2007b; Uzzi & Spiro, 2005). It is important to note that many of these studies focus on small-world structures within overall industries, regions or fields, rather than on intra-organizational networks. For instance, Fleming, King and Juda (2007a) and Fleming, Mingo and Chen (2007b) examine ties among inventors, and Uzzi and Spiro (2005) examine the level of clustering among creative artists, but not necessarily within the same organization. Moreover, most of these studies, like the ones mentioned in the previous sections, only test the benefits that accrue to the holders of individual positions in the network, not to the overall network. Other studies show that team-level cohesion helps team performance, providing some evidence that network structure enhances overall performance at the team level (rather than at the individual member level) (e.g., Balkundi & Harrison, 2006; Oh *et al.*, 2004; Reagans & Zuckerman, 2001). These studies suggest that network members may benefit from cohesion in their immediate neighborhood. If indeed local cohesion is beneficial for all members of the network, we can expect it to also be beneficial for aggregate innovation outcomes.

Hypothesis 1a. **The higher the level of local cohesion in the intra-organizational network, the higher will be the organization's innovation performance.**

On the other hand, proponents of a structural holes argument suggest that actors benefit from sparse network structures around them. Accordingly, actors occupying bridging positions in sparse networks enjoy numerous advantages, mainly in terms of information access and power (Burt, 1992). They are likely to come up with better ideas (Burt, 2004); and have higher innovative performance (Hargadon & Sutton, 1997; Rodan & Galunic, 2004). In contrast, as Nahapiet and Ghoshal (1998: 245) point out, membership in cohesive networks may reduce 'openness to information and to alternative ways of doing things, producing forms of collective blindness that sometimes have disastrous consequences.' Scholars suggest that organizations may overcome such idea saturation by establishing ties to diverse sources, through central actors, boundary spanners, or gatekeepers (Allen & Cohen, 1969; Tushman, 1978, 1979; Tushman & Katz, 1980). Accordingly, local cohesion might lead to lower organizational innovation performance by inhibiting the generation of novel recombinations.

Hypothesis 1b. The higher the level of local cohesion in the intra-organizational network, the lower will be the organization's innovation performance.

There is less guidance in the literature about whether global intra-organizational cohesion also confers similar benefits to the organization. On the one hand, the assumption of aggregation of individual benefits suggests that organizations with more cohesive internal networks are likely to have higher average innovation performance. On the other hand, the benefits of cohesion may arguably be more valid for localized structures than global networks.

Even though the discussion and comparison of global and localized structures is scant, the literature offers some hints that the cohesion benefits are local in nature. For instance, Rowley et al. (2000) suggest that the benefits of cohesion are unlikely to apply to distant parts of the network. In other words, it is the cohesion of an actor's immediate neighborhood that influences its innovation outcomes, and global cohesion does not offer additional benefits beyond those available through localized structures. Examining interfirm alliances, Garcia-Pont and Nohria (2002) report a similar dynamic. Accordingly, firms are influenced by the local cohesion of alliances within their strategic groups rather than global cohesion at the industry level. Similarly, it is possible that members of an intra-organizational network do not benefit significantly from global cohesion in the informal structure, but only from local cohesion in their immediate neighborhoods.

Furthermore, it is also possible that the cost of establishing and maintaining cohesive ties at a global level may outweigh the benefits. Cohesive ties are often thought to be strong ties, characterized by extensive resource exchange and repeated interactions (Granovetter, 1973; Hansen, 1999; Obstfeld, 2005; Reagans & McEvily, 2003; Uzzi, 1997). As Burt (1992) has emphasized, each network tie imposes a nontrivial cost on the focal actor. Exchange theory suggests that each party in a relationship is expected to contribute resources when called upon (Emerson, 1967). Therefore, network members need to invest time and resources to build ties with other members, and help them as needed (Hansen, Podolny & Pfeffer, 2001). When actors do not periodically renew their investment in their ties, these ties become obsolete (Adler & Kwon, 2002). Assuming that a globally cohesive network requires each member of the organization to maintain ties not only to others in their local neighborhood, but also to distant others in the organization, the quantity of ties to be maintained, and the time and effort required to maintain them, may become burdensome for the organization, draining organizational resources that can be used in other ways. Even though individual members may still benefit from their cohesive ties, the cost of maintaining the overall network may surpass its value to the organization. Consequently, a globally cohesive network may impose more costs than it imparts benefits to the overall organization (Hansen *et al.*, 2001).

Combined with the aforementioned knowledge-access limitations of cohesive networks, the added costs and limitations of global cohesion might mean that organizations with sparse global networks may have better innovation performance. This idea is consistent with prior findings that team performance increases with cohesion within teams, and structural holes between teams (e.g., Reagans & Zuckerman, 2001), and exploratory task completion time is shorter for teams within sparse networks (Hansen *et al.*, 2001), although we reiterate that these studies focus on benefits for the teams rather than the overall organizational outcomes.

In sum, given the localized nature of cohesion benefits, and the costs of globally cohesive networks, we expect organizations to have lower innovation performance when the global cohesion of the intra-organizational structure is high.

Hypothesis 2. **The higher the level of global cohesion in the intra-organizational network, the lower will be the organization's innovation performance.**

METHODS

Data and variables

In order to test our hypotheses, we need a research setting that satisfies the following criteria. First, we need to be able to observe the intra-organizational networks of communication. Second, we need to be able to compare and contrast the intra-organizational networks of multiple firms in order to detect systematic differences in global and local cohesion. Third, we need to be able to measure innovation performance of the entire firm, as opposed to individual units or individuals within the firm. Pharmaceutical industry comprises an attractive context, since it satisfies all of these criteria. As discussed above, collecting data on entire intra-organizational network structures is costly and time-consuming, prohibiting the possibility of gathering such data for multiple organizations. Inferring the intra-organizational collaboration structure within pharmaceutical firms from the patterns of patent co-authorship among members of the same firm helps us circumvent this problem. We collected the patent co-authorship data for 33 of the largest firms that operated in the pharmaceutical industry between 1981 and 1990.

We measure the informal structure of the organizations for each of the years between 1981 and 1990 for the thirty organizations mentioned in Table 1. For each of these years we obtained data on whether any of the patents acquired in this period led to a product launch in the years subsequent to the filing. We do not measure patenting activity prior to 1981 as our measurement begins that year and we have captured all successful efforts from that year.

*****Insert Table 1 about here******

We restricted our timing to this period as the 1990s saw a lot of merger and acquisition activity in the pharmaceutical industry and may have made it difficult for us to disentangle our theory from other confounding effects. We constructed the structure of the network of collaborations on an annual basis by forming a matrix of collaborative ties between scientists employed in each firm, measured as co-authoring relationships on patents granted with application dates between 1981 and 1990. We used patent application dates instead of grant dates to form the yearly collaboration matrices, because application dates are likely to better represent the timing of collaborative relationships among scientists (e.g., Sorensen & Stuart, 2000). Since we were interested in comparing the structural rather than the relational features of the network, we dichotomized the network matrix before calculating cohesion measures, so that we capture the presence of a tie among actors rather than the strength of the tie.

Dependent variable. We measured the innovative performance of each pharmaceutical firm as the number of patents that led to new drugs. A drug launch is one of the most important things that a pharmaceutical company can do. Taking into account failures and the cost of capital, the average cost of bringing a new drug to market was found to be over $800 million in 2000 dollars in the pharmaceutical industry(DiMasi, Hansen & Grabowski, 2003), or around $1.3 billion in 2005 dollars in the biopharmaceutical industry (DiMasi & Grabowski, 2007: 477).

We therefore measured innovative performance as the number of patents in each year of the observation period that led to a drug launch between 1984 and 2007. For instance, consider Merck – we know which of the patents that it filed in 1983 have led to the successful launch of a drug. Our observation period for the successful launch ends in 2007 when all the patents filed in the time period 1981 to 1990 would typically have expired. We are confident there is no right censoring in our data as the period of 23 years captures most of the launch activity in the pharmaceutical industry.

Independent variables

Local cohesion. The empirical body of work on cohesion from an ego-network perspective measures cohesion as the presence of ties between actors that the focal actor is connected to (e.g., Fleming *et al.*, 2007b; Hansen *et al.*, 2001; Obstfeld, 2005; Podolny & Baron, 1997; Rodan & Galunic, 2004; Rowley *et al.*, 2000). This measure typically captures the density of the actor's immediate network, i.e., the presence of connections between the actor's direct ties. The cohesion benefits of enforceability, trust and knowledge-sharing are likely to be higher if the immediate contacts of the actor are themselves connected, along with the disadvantages of knowledge redundancy and saturation. To capture a similar idea at the overall network level, we calculated the clustering coefficient of each intra-organizational network in each year. Clustering coefficient is a measure of the level of clustering in the network (Newman, 2000). The clustering coefficient of an individual actor is equal to the density of its neighborhood. The overall clustering coefficient for a network is the 'average of the densities of the neighborhoods of all of the actors' (Hanneman & Riddle, 2005). When this measure is high, all actors in the network are embedded in cohesive local neighborhoods (Hanneman & Riddle, 2005).

Global cohesion: We measured the global cohesion in the intra-organizational network with the density of the overall network. The density measure for the network is calculated as the proportion of all actual ties to the total number of all possible ties within the network (Wasserman & Faust, 1994). This measure captures the global degree of cohesion among all members of the network. Increasing values of this measure capture higher global density. All network measures were calculated using UCINET.

While local and global cohesion may seem conceptually and empirically related, they capture distinct aspects of the network structure. While our local cohesion measure captures the average density of the immediate network around each scientist, the global cohesion measure captures the overall network density. As Schilling and Phelps (2007: 1118) observed, 'While network density captures the density of the entire network, the clustering coefficient captures the degree to which the overall network contains localized pockets of dense connectivity. A network can be globally sparse and still have a high clustering coefficient.' It is possible to observe how these two measures capture different aspects of informal network structure through some examples in our dataset.

*********Insert Figure 1(a) (b) and (c) about here*********

Figure 1a shows the configuration of the informal networks in Abbott Labs in 1987. Accordingly, the collaboration network in Abbott Labs is characterized by small clusters of cohesive connections, with almost no connections between clusters. This is observable in the high clustering coefficient (0.94) and the low density (0.027) figures. In contrast, the collaboration network in Fujisawa in 1984 (Figure 1b), which is characterized by clusters of collaboration that are themselves connected, has a lower clustering coefficient (0.86), and higher density (0.06). Finally, the collaboration network in Alza in 1989 (Figure 1c) is characterized by larger agglomerations of collaborative ties, with fewer holes among clusters. As a result, the Alza collaboration network has a lower clustering coefficient (0.84), and higher density (0.19), in comparison to the two prior examples.

Control variables

We included a whole host of control variables that we believe represent R&D strategy of the firms and other aspects of organization, and can be potential confounds. We controlled for *isolates,* or the number of scientists in the organization who are not connected to any other scientist in that organization, since prior work suggests that lone inventors may have unique characteristics (Singh & Fleming, 2010). We controlled for the *number of claims per patent,* which represent unique contributions made in the patent and are the reason why the patent is granted (Tong & Frame, 1994). The *technological breadth* variable is measured as the average number of subclasses that the organization is patenting within the pharmaceutical area (class 514), and has generally been found to be positively associated with innovative performance (Rosenkopf & Nerkar, 2001). We also controlled for the *size of the network,* measured as the number of inventors per patent in a particular year for a focal firm, as well as the *size of the firm*, measured as the number of patents filed by a focal firm in any particular year.

Methods

We use a negative binomial model, as our dependent variable is the number of products introduced by the firm in the years subsequent to the year in which we have measured its R&D structure, and can only take discrete nonnegative integer values. The negative binomial model was preferred to the Poisson model given the over dispersion in the data. The regression takes the form

$$E(y_i / x_i) = e^{xit - 1\beta} \qquad (1)$$

where 'y_i' are the number of successful product patents (that lead to a product launch) by a firm by the end of 2004, and X_i is a vector of independent and control variables such as global cohesion, local cohesion, claims per patent, technological breadth, size of network and size of firm. The independent variables are all measured between 1981 and 1990. Since we had multiple observations per firm, we corrected the standard errors by clustering on firms in our regression models.

RESULTS

Table 2 shows the summary statistics and the correlation matrix of the variables used in the analysis. The average number of filed patents in a year that consequently led to successful drug launches across the firms in our data was 0.73 while the maximum was 10. None of the correlation coefficients were above 0.4 (except for $r_{\text{Size of firm x global cohesion}}$=0.45), reducing the possibility of multi-collinearity impacting our results. We excluded the size of firm from our models and found the results not to change, and therefore kept it as a control variable.

**********Insert Table 2 about here*********

Table 3 shows the results of the negative binomial regression model of the number of successful patents on the various independent variables. Model I includes only the control variables while model II and III have the main effects of local and global cohesion added to model I respectively. Some of the control variables are significant and in the expected direction. The number of isolates, claims per patent, and size of firm are significant while technological breadth and size of network are insignificant. Model IV is the full model that includes both local and global cohesion simultaneously. As we can see from model IV, Hypothesis 1a, predicting a positive association between local cohesion and innovation performance, is supported ($\beta_{\text{local cohesion}} = 0.5737$; $p < 0.05$), while Hypothesis 1b is not. Moreover, results provide support for Hypothesis 2 ($\beta_{\text{global cohesion}} =$; $p < 0.001$) , that an organization's innovative performance declines with higher global cohesion. Keeping all other variables at their means, an increase of one standard deviation in local cohesion leads to a 6.12 percent improvement in innovative performance while an increase in global cohesion leads to a 33.4 percent drop in innovative performance.

************Insert Table 3 about here**********

While we have hypothesized the direct effects of local and global cohesion on innovative performance, we also examined the interaction effects of these cohesion effects on each other and with technological breadth, a variable that has been considered typically key in explaining innovative performance (March, 1991). In Models V-VII we explore these interaction effects. Model V includes the interaction effect Local Cohesion x Global Cohesion to the full model in Table 3 while Model VI adds the interaction effect of Global Cohesion x Technological Breadth. Finally, Model VII shows the interaction effect = Local Cohesion x Technological Breadth. The only interaction effect that is significant is that of global cohesion with technological breadth ($\beta_{\text{global cohesion x technological breadth}} = 2.0889$; $p < 0.001$), whereby the negative effect of global cohesion on innovative performance is converted into a positive effect beyond a certain level of technological breath (8.38). This is within the range of the data in the paper, suggesting that globally cohesive networks are useful for innovative performance at extremely high levels of technological breadth.

CONCLUSIONS AND DISCUSSION

A key contribution of our study is the examination of how the informal structure influences innovation performance at the organization level. As opposed to prior studies focusing on individual or team-level outcomes, we are able to compare innovative outcomes across organizations, and show that the structure of the collaboration network has a significant influence on organizations' innovative performance. In doing so, we take advantage of two novel empirical approaches. First, building on prior research that infers information flows through patent collaboration networks (Fleming *et al.*, 2007a; Nerkar & Paruchuri, 2005; Singh, 2005), we use the structure of the intra-organizational patent collaboration network as a proxy for the informal structure of each organization. Second, by tracking which patents led to successful drug launches, we are able to measure the impact of the collaborative network structure on innovative performance at the organization level.

Our results show that global cohesion and local cohesion act in opposing ways on organizational innovation. We believe this result is interesting and adds to the literature in many ways. First, most work using co-authorship ties and network analysis has shown the benefits of being connected and bridging ties for individual scientists (e.g., Fleming *et al.*, 2007b; Nerkar & Paruchuri, 2005). Our results show that a globally cohesive network where all scientists collaborate with each other can lead to a drop in innovation. The drop in innovative performance is a result of the costs of maintaining ties and the lack of knowledge diversity that emerges through such ties. However, local cohesion helps as scientists benefit from the close interaction that provides members with the enforceability, trust and knowledge-sharing benefits, enhancing creativity and innovative outcomes. Our primary contribution to the literature is the finding that organizational density of ties has a subtle and nuanced effect on innovative performance whereby local cohesion helps while global cohesion hinders innovation.

Our results are consistent with prior work that suggests the importance of collaborative work in fostering innovation. Our results where local cohesion leads to an increase in the likelihood of successful product patents echo a pattern similar to that found by Jones (2010), whereby teams are associated with a 65 percent increase in the probability of a ‘home run’ patent. Similarly, Singh and Fleming (2010) find that collaborative patents are more likely to result in breakthroughs. Our results confirm the importance of collaboration, and extend these findings by demonstrating the differentiating role of various structural patterns in the collaboration network on innovative outcomes.

Our results help suggest a reconciliation for the tension between cohesion and structural holes in organizational networks, what Obstfeld (2005) called the action and information problems. While cohesive networks provide the trust and support that facilitate knowledge flows, and make action leading to innovation possible, they cannot provide the diversity of information that sparse networks with structural holes can provide. Our findings suggest that organizations may benefit most when local cohesion is higher, but global cohesion is lower. It appears that the cost of global cohesion outweigh its benefits, and therefore the organization is better off when actors engaged in innovation build locally cohesive networks and selectively bridge worlds, instead of indiscriminately increasing global cohesion. In other words, structures where scientists form clusters of cohesive ties, without necessarily engaging in organization-wide knowledge sharing, may be most conducive to innovative outcomes. These results complement prior findings that cohesive teams with bridging ties to other teams perform better (Reagans &

Zuckerman, 2001), by demonstrating that organizations also benefit from structures where cohesive clusters are tied though sparse connections.

The practical implications of this research are significant. Pharmaceutical companies spend billions of dollars on getting drugs out to market with meager success. While informal network structures are to a large extent emergent, pharmaceutical firms may provide the incentives and infrastructures that encourage locally cohesive collaboration networks. Our research shows that pharmaceutical companies might benefit from creating centers of local cohesion whereby scientists connect with each other, but should be wary of globally cohesive structures as they may drive out innovative performance. That said, projects that are technologically broad, and to a large extent radical, may require globally cohesive structures.

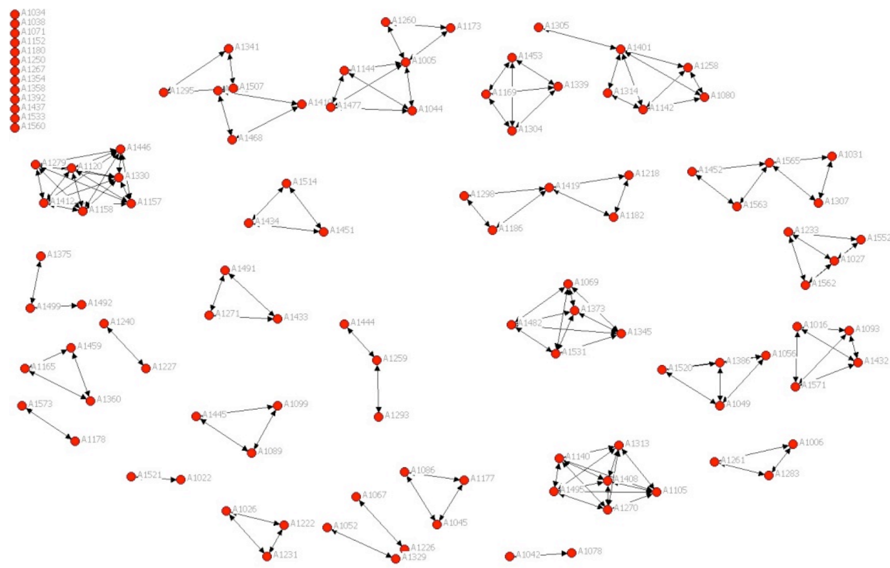
This research does suffer from some of the usual problems encountered in innovation research that uses social networks. We follow prior literature in using collaborative ties as proxies for informal structures. Scientists in our network could be connected to each other through ties such as friendship ties. We do not control for these ties because of paucity of information. Future research could examine if such ties have similar effects on innovative performance. Given that co-authored projects comprise a major way of knowledge exchange between scientists, we believe our measure to be a reasonable one. A second limitation of this research is the time frame of 1981 to 1990. Subsequent to this time frame the pharmaceutical industry went through an intense period of mergers and acquisitions. While these mergers and acquisitions do not impact our findings, they do limit the temporal validity of our findings. Interestingly, recent research suggests that firms with lower innovation productivity may have engaged in merger activity (Kapoor & Lim, 2007; Paruchuri, Nerkar & Hambrick, 2006). A topic that could be examined in the future is the relationship between mergers and acquisitions, the informal network structures of R&D organizations and innovative performance. For instance, do acquisition activities disrupt locally cohesive structures leading to a drop in organizational performance? Or do mergers lead to a reconfiguration of the informal structure in firms that engage in mergers and acquisitions as a remedy for poor innovative performance?

An important limitation to our research is the direction of causality in our theory. While we suggest that the informal R&D organization drives innovation, it is possible that the decision to collaborate itself may be a function of prior successful innovative efforts. That said, we believe this is less of an issue for our findings. We use collaboration patterns at an individual level to measure informal structure at an organization level. Further, the impact of this structure is not contemporaneous but at a later time. If our theorizing were at the 'ego level' this would be an issue to consider and control for empirically. However this does lead to an interesting research question for the future – why do inventors co-author with each other, do prior successes and failures at the inventor level influence such choices, and consequently, how do informal structures emerge?

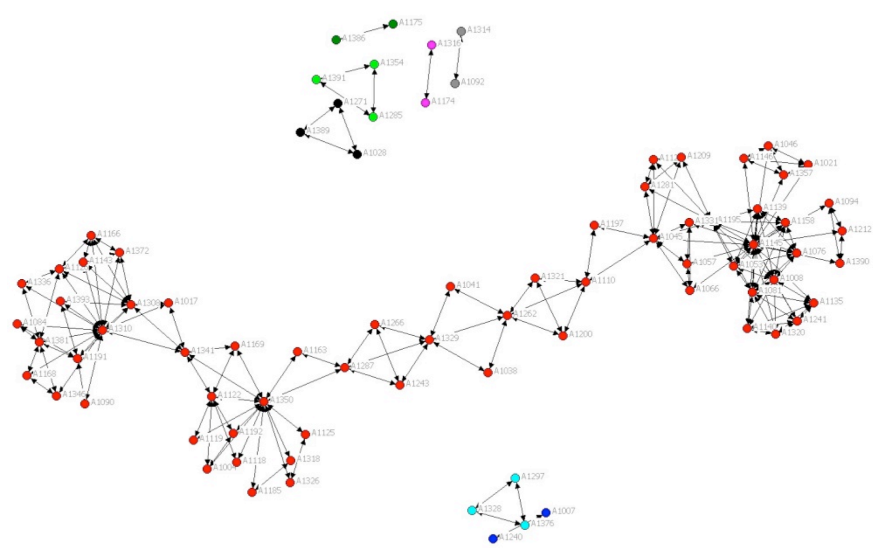
Finally, we have focused on whether drug launches have taken place, not the value of the drugs launched. While a small number of launched drugs become blockbusters, such as Zantac or Claritin with a large number of prescriptions and sales, others may provide lower returns. Due to data limitations, we were not able to connect each product launch and its sales to a particular R&D structure. Future research could explore whether certain R&D configurations lead to blockbuster launches while some lead to not-so-good launches, and could extend the findings of Nerkar and Roberts (2004), which show the joint effects of marketing and R&D experience on sales of new drugs.

In conclusion, the findings of this paper suggest that research on innovative performance that uses social network analysis at the organizational level can lead to findings that are complementary and in some cases counter to research that is done at the ego or individual level.

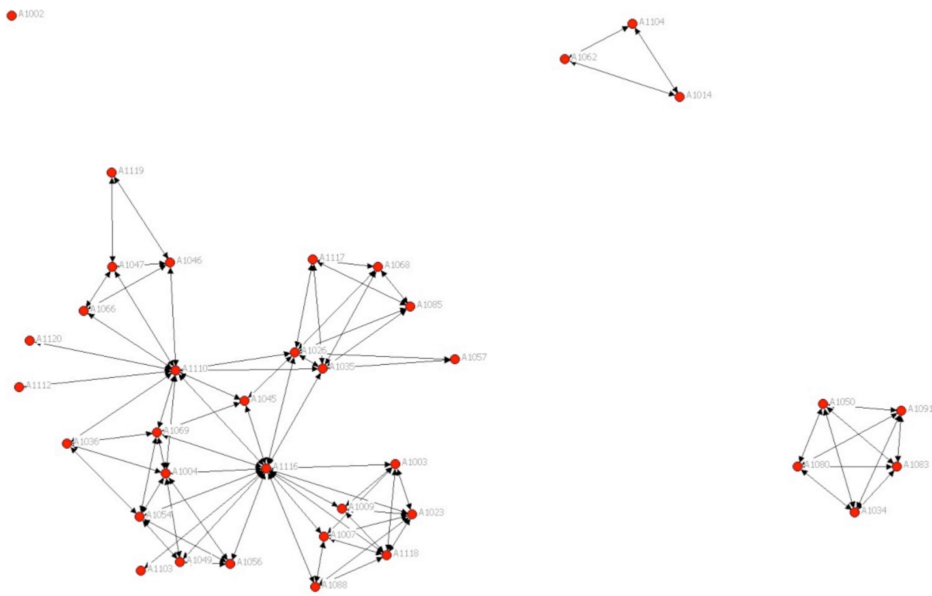
FIGURES



1a. Abbott Labs collaboration network, 1987



1b. Fujisawa collaboration network, 1984



1c. Alza collaboration network, 1989

Figure 1. Illustrations of different intra-organizational network configurations

ACKNOWLEDGEMENTS

We thank Will Mitchell and two anonymous reviewers for insightful comments and suggestions. We are also grateful to the participants of the 2009 Strategy Research Forum. Errors and omissions remain our own.

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Table 1. Pharmaceutical firms in the sample

Name	Successful product patents
Abbott Laboratories	2
Allergan	2
American Home Products	2
Alza	10
Bristol Myers Squibb	4
Boehringer	4
Bausch & Lomb	0
Chiron	1
Ciba-Geigy	4
Roussel	6
Sanofi	18
Fujisawa	8
Bayer	10
Glaxo	49
Hoechst	6
Johnson and Johnson	0
Janssen	3
Eli Lilly	24
Merck	9
Pfizer	11
Procter & Gamble	1
Pharmacia	2
Upjohn	0
Rohm and Haas	0
Rhone Poulenc Rorer	2
Smith Kline Beecham	26
Sandoz	5
Searle	0
Schering Plough	9
Syntex	9
Warner Lambert	7
Wyeth	0
Yamanouchi	7

Table 2. Summary statistics and correlation table

	Variable	Mean	Std Dev	Min	Max	(1)	(2)	(3)	(4)	(5)	(6)	(7)
(1)	Number of successful product patents	0.730	1.400	0.000	10.000	1.000						
(2)	Local cohesion	0.878	0.104	0.000	1.030	-0.028	1.000					
(3)	Global cohesion	0.057	0.065	0.004	0.556	-0.038	0.054	1.000				
(4)	Claims per patent	12.389	3.708	0.137	27.879	0.040	0.050	-0.029	1.000			
(5)	Technological breadth	4.967	4.494	0.055	62.400	-0.062	0.179	0.167	-0.022	1.000		
(6)	Size of network	1.666	0.586	0.018	4.200	0.023	0.279	0.221	-0.064	0.203	1.000	
(7)	Size of firm	90.614	104.222	2.000	546.000	0.027	-0.153	-0.451	-0.059	-0.145	-0.169	1.000

N=330, All coefficients greater than 0.05 significant at $p < 0.05$

Table 3. Negative binomial models of innovative performance

Variable description	I	II	III	IV	V	VI	VII
Local cohesion		0.604 **		0.574 **	1.942	0.596 **	-0.199
		-0.313		-0.300	-1.554	-0.334	-1.997
Global cohesion			-6.198 ***	-6.258 ***	13.041	-17.526 ***	-6.29 ***
			-2.156	-2.173	-15.521	-5.112	-2.227
Global cohesion x local cohesion					-21.969		
					-18.373		
Global cohesion x technological breadth						2.089 ***	
						-0.54	
Local cohesion x technological breadth							0.159
							-0.486
Isolates	-0.028 **	-0.029 **	-0.042 ***	-0.043 ***	-0.043 ***	-0.049 ***	-0.043 ***
	-0.015	-0.015	-0.016	-0.015	-0.015	-0.015	-0.016
Claims per patent	0.055 **	0.054 **	0.055 **	0.054 **	0.056 **	0.054 **	0.055 **
	-0.031	-0.031	-0.032	-0.032	-0.033	-0.032	-0.032
Technological breadth	-0.003	-0.005	0.006	0.004	0.009	-0.289 ***	-0.155
	-0.028	-0.029	-0.025	-0.025	-0.025	-0.076	-0.507
Size of network	-0.378	-0.408	-0.399	-0.43	-0.39	-0.353	-0.415
	-0.286	-0.281	-0.321	-0.313	-0.318	-0.286	-0.317
Size of firm	0.003 **	0.003 **	0.002 **	0.003 **	0.003 **	0.001	0.002 **
	-0.001	-0.001	-0.001	-0.002	-0.002	-0.002	-0.002
Constant	-0.608	-1.064	-0.142	-0.568	-1.911	0.815	0.157
	-1.186	-1.218	-1.259	-1.342	-2.427	-1.076	-2.298
Wald chi 2	144.56 ***	208.61 ***	319.51 ***	391.42	385.51 ***	347.24 ***	372.75 ***

N = 330, All tests single tailed, *** p< 0.01; ** p < 0.05. Application year dummies included in all models.