KNOWLEDGE FLOW AND VALUE CREATION:

INTEGRATING STRUCTURAL EMBEDDEDNESS AND KNOWLEDGE EMBEDDEDNESS IN ALLIANCE NETWORKS

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Scholars in a variety of disciplines, including organizational theory, strategic management, and economics, have devoted substantial attention to the question: why are some firms more innovative than others? It has been largely accepted that when the knowledge base of an industry is both complex and expanding and the sources of expertise are widely dispersed, the locus of innovation will be found in networks of inter-organizational collaborations than individual firms. Strategy researchers have recently begun to explore how inter-firm networking affects organizational innovation performance, and reported intriguing yet conflicting findings. Drawing perspectives from strategic alliance, social networks, and technology innovation, I proposed an integrative framework to investigate the combined effects of a firm's network centrality and structural hole on organizational innovation performance. Furthermore, I examine the innovation performance both in terms of innovation rate and innovation value.

I conducted a longitudinal study on a population of firms from 1990 to 1999 in pharmaceutical industry (SIC 2834). The results of the study indicate that: 1) Network centrality helps a firm to increase its rate of innovation, and structural hole helps to improve its value of innovation, while both effects are non-linear. 2) Network centrality positively moderates the relationship between structural hole and innovation value. 3) Structural hole negatively

moderates the effect of network centrality on innovation rate. The joint effects suggest that firms with advantageous network positions are more capable of making wise technology selections and focusing their efforts on innovations of greater value.

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This dissertation represents the culmination of my doctoral education at the University of Pittsburgh. Every thousand miles' journey starts with a small step forward. I am fortunate in that many people I have learned from and interacted with have made my doctoral study an extremely rewarding experience. Foremost among them are my dissertation committee members who have guided me through every stage of my progress.

Working with Sue McEvily as the dissertation chair has been among the most beneficial aspects of my doctoral study. I greatly benefited from her expertise on my dissertation topic, enlightening spirit, and great willingness to devote time to guiding me throughout my doctoral study. While my dissertation project investigates how organizations could improve the value of their innovation output, interacting with Sue over the years has deeply shaped my understanding on how to improve the quality of research output from every aspect. Without Sue's timeless input and thorough feedback over the past years, this dissertation project would have been ended up toward different directions. To me, she is not simply a dissertation advisor to seek advice from, but more importantly a close friend from whom to learn a positive attitude toward research and life.

John Prescott is among the primary reasons that made Katz’s program particularly attractive to me when I applied for my doctoral studies. I greatly appreciate his consistent guidance and support throughout my stay at Katz. I am deeply impressed by John's openness in expressing his opinions and willingness to listen to my ideas regardless how preliminary they might have been. He always encourages me to explore areas of new knowledge and develop strength in related topics. At every stage of my doctoral study, John's insight and suggestions

have guided my decisions. From working with John, I have learned a lot on how to develop and manage the progress of projects from the very beginning. John's personality always makes each interaction an enjoyable experience.

I first met Wenpin Tsai during the Academy of Management Meeting in Washing D.C. in 2001, and we have kept close contact ever since. Wenpin attracts my attention not only because of his expertise on alliance and networks, but also because of his unique way of interacting with people. Wenpin never put himself in a senior scholar's position, but as an intimate friend. Over the years he has provided much needed guidance along each step of my research progress. Learning and knowledge acquisition always requires frequent exchange between the sources and recipients. Wenpin has always been among the first I ask for advice, not only because he is my favorite knowledge source but also because he is always willing to devote excessive time during the communications over the years.

Ravi Madhavan is among the earlier Katz graduates I look up to. I read his dissertation and was impressed in his study before I met him in person. I would like to say that my dissertation project is influenced by Ravi's research stream. Ravi has been always able to help me address key problems and provided insightful suggestions. Though it is suggested that weak ties help people to search for new knowledge and strong ties facilitate the transfer of new knowledge, I have found that my tie to Ravi is an exception – one that combines the advantage of both. Ravi is always a rich source for new ideas as well as a reliable source to learn the new knowledge.

I have been very fortunate to have the opportunity to take the courses and learn from David Krackhardt. I came to Katz's doctoral program with an economics-oriented background, and David's course inspired my interest to explore social network theory and to put in as among

the focuses of my dissertation project. Kuan-tzu, a Chinese philosopher noted, if you give a man a fish he will have a single meal. If you teach him how to fish, he will be able to catch and enjoy the meals all his life. David is one who teaches people how to fish. David's expertise on network theory and analysis methodology is a highly valuable resource I benefited from.

I sincerely acknowledge the help and support of the doctoral office at the Katz Graduate School of Business. Carrie and Jake are among the first group of people I have always turned to for help, both on topics regarding research and on issues related to personal life. The highly professional and caring team, Carrie, Charmaine, Mary, Kay, and Ryan have made my life in Katz and Pittsburgh much more comfortable.

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CHAPTER 1: INTRODUCTION

"Today, chief executives of the leading pharmaceutical companies have a huge headache in common: How can they keep research and development pipelines primed and pumping out innovative products. The CEOs who master this challenge will put their companies in position to dominate the future. Those who come up short will see their enterprises fall into decline or become subject to industry consolidation."

Scholars in a variety of disciplines, including organizational theory, strategic management, and economics, have devoted substantial attention to the question: *why are some firms more innovative than others?* This question warrants attention because innovative firms are critical drivers of technological progress and long-term economic growth. Scholars have widely accepted the idea that the ultimate source of a firm's competitive advantage is its ability to upgrade existing products and service, with novel and more sophisticated features, through continuous technology innovation and improvement (Schumpeter, 1934, 1939; Porter, 1980). However, developing new product or technological competence in a field is difficult, time-consuming, and expensive. As a result, firms, especially those in high-tech and knowledge intensive industries, frequently seek external collaborations to leverage their existing resources, pool complementary capabilities, and shorten development time (Powell, Koput, and Smith-Doerr, 1996; Baum, Calabrese, and Silverman, 2000; Sampson, 2002). It has been largely accepted that when the knowledge base of an industry is both complex and expanding and the sources of expertise are widely dispersed, the locus of innovation will be found in networks of inter-organizational collaborations than individual firms (Powell, Koput, and Smith-Doerr, 1996). Strategy researchers have recently begun to explore how inter-firm networking affects organizational innovation performance, and reported intriguing yet conflicting findings. For example, Shan, Walker, and Kogut (1994) found the number of partners a firm maintains positively affects the number of innovations it produces. However, McEvily and Zaheer (1999) found that non-redundant contacts (i.e. alliance partners unconnected with one another) contribute to firms' acquiring new capabilities and may be more important than the simple number of contacts. At the same time, Ahuja (2000) found redundancy positively affects innovative output. These conflicting findings suggest that further research is needed to sort out contingencies that influence how network variables affect organizational innovation.

1.1 Research questions and motivations

In general, any efficient and effective alliance strategy needs to address two fundamental issues: 1) How does the structure of a firm's alliance network affects its *rate* of innovation? and 2) How does the structure of a firm's alliance network affects its *value* of innovation? My approach to address these two broad questions is motivated by several gaps in related literature.

First, the few existing studies have only focused on the rate of innovation as the outcome, but have not examined whether alliance relations affect innovation value (e.g., Ahuja, 2000; Shan, Walker, and Kogut, 1994; Powell, Koput, and Smith-Doerr, 1996). Innovations could differ in value because of its contribution to the technology advancement. Innovations also differ in value because of its uniqueness and the difficulty for others to develop technology substitutes. In general, a firm could invest in many R&D directions and bring in technology advancements accordingly in those areas. Melissa Schilling (1998) illustrated that Nexgen, a CPU manufacture, faced technological lockout when it chose to produce own variant CPU that was different from Intel's dominant standard and was rejected by market. These show that selecting the right technology direction could be vital to a firm's success. Though innovation value is viewed as a very important indicator of technology performance (Trajtenberg, 1990; Hall, Jaffe, and Trajtenberg, 2000), there has not been any publicly known study examining whether firms are more capable of producing innovations of high value due to their network connections.

Second, it is unclear whether certain network attribute enhancing the rate of innovation will also contribute to the value of innovation at the same time. Recently strategic configuration of alliance networks has generated great interest among strategy scholars. The central theme is how a firm should select its network location and manage efficient alliance connections with others. Two key network attributes have been extensively studied in prior work: *degree centrality* and *structural holes* (Ahuja, 2000). Degree centrality is essentially the size of a firm's alliance network, and is believed to afford access to a greater volume of information (Koka and Prescott, 2002). Structural holes exist between a firm's contacts if they are not connected to one another (Burt, 1992). Since information circulates less frequently among loosely connected firms, spanning structural holes provides a firm with more distinctive information. These two dimensions require different resource commitments and carry distinct strategic implications. Different network attributes bring divergent information benefits and may provide different types of innovation opportunities. Being central in an alliance network, or have rich connections to others, leads to rich information, but such information may be redundant. Spanning structure holes contributes to distinct knowledge access and novel technology opportunities (Burt, 1992), as they help firms to develop new knowledge combinations that are built from existing but previously unconnected ideas (Hargadon and Sutton, 1997). The distinction between these two structural dimensions implies that they might have distinct impact on organizational innovation rate and value respectively.

Third, studies have not examined the interactive contribution of centrality and structural holes to technology innovation. A firm's selecting certain technology directions could lead to high rate of innovation, while choosing some others may lead to high value of innovation. More importantly firms with both high centrality and spanning many structural holes at the same time may tend to focus on a narrow set of innovations of high value. McGrath and Nerkar (2004) suggested that pharmaceutical firms' R&D function encompass many projects across many therapeutic and scientific areas. Decisions about technology investment are always made in the context of a portfolio of other alternative investments. Connecting to large number of partners increase the opportunity to transfer new knowledge to learn about new innovation possibilities; while spanning structural hole greatly helps a firm to better evaluate those potential opportunities and to focus on the set of high valuable technologies.

Last but not the least, previous studies have narrow sample ranges as they have mainly focused on a small number of the largest (or leading) firms in certain industry(ies), which makes the findings less generalizable (e.g., Ahuja, 2000; Gulati, 1995b; Gulati and Gargulio, 1999). In this study, I made an effort to collect data related to of a population of pharmaceutical firms during the year 1990 to 1999 to test my proposed ideas.

1.2 Theory and hypothesis development

1.2.1 Network centrality and innovation rate

Resources based view maintains that a firm is composed by a bundle of tangible and intangible resources and firms differ in their capabilities to utilize such resources to generate economic returns (Barney, 1991; Peteraf, 1993; Maritan, 2001). The recent relational view arguments further suggests that firms can also make use of the resources outside its own boundary through alliance relations (Dyer and Singh, 1998). Alliance and network studies have strongly suggested the effect of embedded relations on inter-firm knowledge transfer. Koka and Prescott (2002) suggested that being central in alliance networks enables organizations to access and acquire larger quantity of valuable knowledge by virtue of their alliance connections. Madhavan, Koka, and Prescott (1998) further argued that central firms are exposed to richer external resources and have higher control and flexibility of resource allocation to achieve their organizational goals.

Nevertheless, the contribution of network centrality to a firm's innovation rate may not be linear. A firm that maintains ties to more alliance partners in order to access a given amount of expertise will likely incur higher coordination cost. Such coordination cost arises from the complexity of ongoing coordination of activities to be completed jointly or individually across organizational boundaries and the difficulties associated with decomposing tasks and specifying a precise division of labor across partners in alliance (Gulati, 1999). Beyond certain point the cost of maintaining linkages may increase significantly, because firms not only have to devote time and resource to the managing of the individual alliance, but also have devote resource to the coordinating across alliance partners (Harrigan, 1985).

Thus, I propose:

H1: The centrality of a firm in the alliance network will have an inverted U relationship with the rate of its technology innovation.

1.2.2 Structural hole and innovation value

Burt (1992) has argued that spanning 'structural holes' is especially likely to expose a firm to novel information and entrepreneurial opportunities. These are social relationships that bring into contact organizations that have relatively infrequent encounters with one another. Firms bridging boundaries or spanning structure holes may enjoy the advantage of having unique information access related to certain technology development (Ancona, and Caldwell, 1992). Particularly, firms spanning structure holes are more capable of detecting distinct technology directions and recombining knowledge from various unique sources. "Broker" firms are more capable of producing innovations of high value, as they are better advised of distinct technology opportunities that are difficult for others to develop substitutes.

At the same time, I view that there could exist diminishing returns to a firm's spanning structure holes. In order for a firm to be able to communicate with a wide range of other organizations with various technology expertise, it has to be knowledgeable at these broad areas itself to maintain any meaningful communication (Cohen and Levinthal, 1990). If a firm spreads its attention across too wide technology domains, its ability to integrate distant knowledge might decrease (Fleming, 2001). Hence I predict:

H2: The efficiency of a firm's network connections (spanning structure holes) will have an inverted U relationship with the value of its technology innovation.

1.2.3 The moderating effect of network centrality on the relationship between structural hole and innovation value

The value of a firm's innovations sometimes depends on how the peer organizations view and acknowledge its technology advancement. Network centrality can greatly enhance such technology recognition and reduce the market risk. On the one hand, centrally located firms have the most opportunity to communicate with other firms, to spread out the technology advancement, and to make others recognize the new technology and developing complementary products. On the other hand, having rich connections helps the focal firm to accumulate reputation and generate visibility to the public. As Podolny (1993) argued, when there is uncertainty about the quality of certain product, evaluations of it are strongly influenced by the social standing of the actors associated with it. Firms in the central network locations have higher social status and have substantial influence over other firms' knowledge recognition and technology adoption.

In terms of knowledge transfer and exploitation, once a firm identifies valuable new knowledge recombination opportunities, having rich connections to others can help realize such innovation potential as well as utilize the new knowledge to the best advantage. The transfer of tacit and complex knowledge requires frequent source-recipient exchange, because the recipient most likely does not acquire the knowledge completely during the first interaction with the recipient but need multiple exchanges to assimilate and internalize (Polanyi, 1966; Szulanski, 1996). Centrally connected firms have more chance to interact and exchange frequently with multiple sources to foster the knowledge transfer.

H3: A firm's network centrality will positively moderate the relationship between its network efficiency and the value of its technology innovation.

1.2.4 The moderating effect of structural hole on the relationship between network centrality and innovation rate

Pharmaceutical firms' R&D function encompasses many projects across many therapeutic and scientific areas. Decisions about technology investment are always made in the context of a portfolio of other alternative investments (McGrath and Nerkar, 2004). "Knowledge inventory" perspective deals with the issue of making decisions under uncertainty about a firm's portfolio of technologies. A central theme holds that managers approach these decisions in an uncertain manner regarding about which technologies may be most appropriate for current and future use. To protect against such uncertainty, firms may add technologies to their knowledge inventories without deploying them immediately, or make idle investments necessary to maintain them for reactivation in the future. The main advantage is the increased strategic flexibility to switch technologies in the future. Nevertheless, the tradeoff is that sometimes organizations may invest in some wrong directions or hold some wrong technologies that are not very meaningful in future.

Nevertheless, such assumption is based on the fact that the managers do not have enough knowledge about the potential strength and weakness of alternative technologies and their performance trajectories when they make technology decisions. In another word, sometimes firms don't have enough information regarding what alternative technologies others are capable to explore and introduce to the market. Spanning structural holes can help a firm to better understand which direction could be more valuable, because "broking" helps a firm to better assess and evaluate different technology directions. In this case, firms can make wise choices by narrowing down and focusing on new technologies that are difficult for others to develop substitutes and that are more valuable.

H4: A firm's network efficiency will negatively moderate the relationship between its network centrality and the rate of its technology innovation.

1.3 Research design and findings

1.3.1 Research context

The pharmaceutical industry is an ideal context for this study for several reasons. The industry has undergone fast technology advancement over the decades and product innovation is critical for firms' steady growth. Also, this industry is one of the few in which patents are effective and widely used to protect inventions (Mansfield, 1961; Levin et al., 1987; Cohen, Nelson, and Walsh, 1997). Public patent documents allow us to readily analyze the roles played by inter-organizational network relations and specific partner attributes in product innovation.

The pharmaceutical industry has experienced a series of fundamental technology changes during its relatively short history, starting with the development and gradual acceptance of the germ theory of disease and accelerating during the chemo-therapeutic revolution of the 1930s and 1940s. More recent breakthroughs in DNA technology and molecular genetics has spawned the biotech revolution, and again substantially accelerated the pace of scientific advance. The research and development activities of pharmaceutical firms are complex, costly and time-consuming endeavors. Indeed, the development of a new drug can take 10-15 years and cost well above $350 million (Henderson and Cockburn, 1994). Moreover, there is no guarantee of success, since only one in 600,000 compounds synthesized by pharmaceutical laboratories could be regarded as highly successful.

Nevertheless due to the complexity of technology involved, firms often find they lack necessary knowledge and resources, and hence seek alliance partners to cooperate in product and development. To develop new capabilities in research and development, and to access a growing and complex body of scientific and technological knowledge, pharmaceutical firms have increasingly relied on networks of alliances with other organizations, and put a much greater emphasis on joint research and development. Those forms of cooperation are some times demonstrated as research cooperation, product co-development, technology licensing and transfer, co-promotion, distribution and commercialization, and to the high degree of corporate joint venture. From my observation on a sample set of pharmaceutical firms, I found that there is a continuously increasing pattern of alliance activities among them throughout the 90's. However, little systematic evidence exists to explain how and whether the knowledge properties of external alliances affect a firm's innovation performance.

1.3.2 Data

I identify firm's alliance networks as consisting of all pharmaceutical companies with which a focal firm has a research-related agreement. This is consistent with prior research on networks. Knoke (1994) summarized three decision rules for defining network boundaries for empirical examination: attributes of actors, such as membership in an organization or industry; types of relations between actors, such as strategic alliances or interlocking directorates; and participation in a set of events or issues, such as proposed plans to deregulate a highly regulated industry. I use the criterion that the actors share a common attribute to identify network boundaries. Industry membership has been used as one such attribute, to identify constituents of alliance networks (Powell, Koput, and Smith-Doerr, 1996; Rowley, Behrens, and Krachardt, 2000; Ahuja, 2000). My focus is on firms that list as their primary business the SIC code 2834, pharmaceutical preparation. These designations were taken from COMPUSTAT, and the Global Worldscope and Compact Disclosure databases. The content of a network (i.e. the purpose of actors' relations) can affect how certain network variables influence members' behaviors and hence performance outcomes (Ahuja, 2000). I restrict our attention to alliances formed among firms that directly affect a firm's research and development activities. Firms have ties with one another if they are parties to a technology licensing or sharing agreement, are engaged in a joint venture or R&D consortium to develop a technology, establish formal contractual product research and co-development alliances.

I made an effort to take firms of the whole industrial population into consideration. About 228 firms are identified as from COMPUSTAT designations during the period from 1990 to 2000 (only 68 of those consistently showed up for each of the 10 years). Information related to the alliance activities of these firms will be gathered from a variety of sources: Recombination Capital, and Bioscan (Lerner 1994; Lane and Lubatkin, 1998); U.S. Securities and Exchange Commission (SEC) filings; and a list of industrial newspapers and journals, such as Drug Store News, Healthcare Financial Management, Health Industry Today, Natural Health, Pharmaceutical Executive, Pharmaceutical Technology, R & D Focus Drug News. I restrict my attention to alliances formed among firms that directly affect a firm's research and development activities. I collected patent data from USPTO, the official U.S. patent database containing the searchable patent records of all firms since 1790.

1.3.3 Model and findings

I used fixed-effects negative binomial models (Hall, Hausman, and Griliches, 1984) to estimate above proposed relations. Fixed-effects approach is preferred because such approach addresses two issues that could affect the regression validity: serially correlated errors and heterogeneity across firms. The fixed effects model is a conservative test of the hypotheses, as modeling each firm as a dummy variable may be so powerful that the dummy capture most difference in performance leading to inconclusive results (Koka and Prescott, 2002). A general negative binomial probability function is given by the following formula:

$$P(X = k) = \frac{\Gamma(\partial + k)}{\Gamma(\partial)\Gamma(K+1)} (\frac{1}{1+\theta})^{\partial} (\frac{\theta}{1+\theta})^{k}$$

$$\begin{cases} \partial > 0 \\ \theta > 0 \\ k = 0,1,2,... \end{cases}$$

I present my main findings related to the rate of innovation based on the full sample in table 7 and table 9, and list the results related to the value of innovation in table 8 and table 10.

INSERT TABLE 7, 8, 9 AND 10 ABOUT HERE

The results largely support the hypotheses relate to innovation rate put forth in this paper. In general my findings indicate that network centrality affects a firm's rate of innovation, while network efficiency affects the value of its innovation. And more importantly, firms taking the central network positions and maintaining efficient connections at the same time tend to focus on a narrow set of innovations of higher value. This suggests that, for an optimal network configuration, we need to exam the combined effects of centrality and structural hole at the same time.

I also draw three-dimensional graph in figure 3 and figure 4 based on model estimations to illustrate the interaction effect of network centrality and network efficiency on the innovation output.

INSERT FIGURE 3 AND FIGURE 4 ABOUT HERE

Figure 3 clearly shows that when we hold network centrality consistent, innovation rate decreases with a firm's network efficiency. The graph gives a salient demonstration of the negative moderating effect of network efficiency on centrality-innovation rate relationship. Figure 4 illustrates the positive moderating effect of network centrality on relationship between network efficiency and innovation value. The graph shows that innovation value increases with network centrality, when network efficiency is held consistent.

1.4 Contributions

The broad contribution of this study is line with the literature gaps I have identified in the beginning. This study contributes to the current network research by suggesting that there are two levels of information benefits provided by network connections. Centrality leads to rich information inflow and increases a firm's scope of innovation opportunities. Nevertheless, spanning structural holes gives the firm unique information access to better evaluate and select from various technology directions. McGrath and Nerkar (2004) suggested that pharmaceutical firms' R&D functions encompass many projects across many therapeutic and scientific areas, and decisions about technology investment are always made in the context of a portfolio of other alternative investments. This suggests that firm may not invest in all possible directions due to its resource limitations. I view that centrality enriches the opportunity for firms to generate innovations, but spanning structural holes can help firms to better identify valuable technology directions to invest.

In addition, I examine the proposed relationships based on a population of pharmaceutical firms in SIC 2834 industry instead of the few leading ones. This study implies that firms could gain better innovation opportunities through exploiting embedded network relations, and those firms with better network configurations could enjoy the competitive advantage and improve their innovation performance.

This study also carries certain limitation because of the research setting and sample coverage. The main limitation is the relative generalizability of the research context. Attention needs to be paid to the fact that our research setting is a high tech industry in which industrial knowledge base is complex and widely spread across firms. The findings of this study may not be readily applicable to certain other traditional industries (for example, global steel industry) in which firms have less technology divergence.

CHAPTER 2: LITERATURE REVIEW

2.1 Embedded ties, social capital, and knowledge transfer

2.1.1 The embeddedness of organizational behavior

The emerging concept of embeddedness has become much broader than what was introduced by Polanyi (1957) to describe the social structure existing in concurrent markets in his work "The Great Transformation". Polanyi (1957) initially suggested that "the embeddedness of economic action in pre-industrial societies was for all intents and purposes supplanted in modern life by the logic of efficient markets". Marsden (1988) referred to embeddedness as "the fact that exchanges and discussions within a group of typically have a history, and that this history results in the routinization and stabilization of linkage among members. As elements of ongoing social structures, actors do not respond solely to individualistically determined interests". He further pointed out that "a structure of relations affects the actions taken by the individual actors composing it. It does so by the constraining the set of actions available to the individual actors and by changing the dispositions of those actors toward the actions they may take". Such notion distinguishes itself from the "independence" assumption about individual or organizational behavior in classic economics. Granovetter's (1985) classic work refined and set up the modern foundation of embeddedness research. He argued that "behavior and institutions to be analyzed are so constrained by ongoing social relations that to construe them as independent is a grievous misunderstanding". Granovetter's (1985) put forth a stronger statement than Polanyi's proposition by suggesting that virtually all economic behavior in modern life is embedded in networks of social relations. Granovetter stated that the economic activity or market exchange is embedded in, and defined by, large and more complex social processes, and organizational activities is shaped by social relations. Granovetter's work stimulates a stream of studies on how the social relations of organization play roles in economic activity and how they affect the corresponding performance. The general argument from economic sociology is that the embedded relations build up trust, facilitate information sharing and transfer among organizations, and decrease monitoring cost. Uzzi (1997) further advanced our understanding of embeddedness and drew closer link to organizational behavior and performance. He suggested that transactions can take place through loose collections of individuals who maintain impersonal and constantly shifting exchange ties, as in markets, or through stable networks of exchange partners who maintain close social relationships. In a study of New York apparel industry, he found that embedded ties play more important roles in developing trust, transferring fine grained information, and helping joint problem solving. Researches on embeddedness so far have shown the power of this concept to explain and analyze the complicated phenomenon of economic activities constrained by social context or social activities influenced by economic concern. Enlightening studies has been done on its application to human resource management, immigration (Portes and Sensenbrenner, 1993), entrepreneurship (Larson, 1992), organizational adaptation (Baum and Oliver, 1992), technology and innovation (Ahuja, 2000), and firms' performance (Uzzi, 1996; 1997). The new directions of embeddedness research no longer focus on the debate whether economic activities are contingent on social context, or the justification of embeddedness, but focus on the consequences --- how the embedded social relations affect organizational performance and survival (Dacin et al., 1999). Zukin and DiMaggio (1990) also broadened the concept by proposing that embeddedness refers to the contingent nature of economic activity on cognition, culture, social structure and institutions. In this study I focus more on the dimension of structure embeddedness.

2.1.2 Embedded relations and social capital as sources of competitive advantage

Social capital represents the resources attainable by individual actors through networks of embedded relationships. Scholars have long recognized the value of social capital and provided various definitions and explanations to its performance effects. Baker(1990) noted that social capital is a resource that actors derives from specific social structures and then use to pursue their interest, and social capital is created by the changes in the relationship among actors. Bourdieu (1985) defined social capital as the aggregate of the actual or potential resources which are linked to possession of a durable network of more or less institutionalized relationships of mutual acquaintance or recognition. Portes (1998) referred to social capital as the ability of actors to secure benefits by virtue of membership in social networks or other structures. Nahapiet and Ghoshal (1998) explain it as the sum of actual and potential resources embedded within, available through, and derived from the network of relationships possessed by an individual or social unit. In their view, social capital comprises both the network and the assets that may be mobilized through that network Perhaps the most widely cited explanations by strategy scholars were offered by Coleman and Burt. Coleman (1990) emphasized the function of social capital and its distinction from other forms of capital such as physical, financial, and human capital. Coleman (1990) suggested that "Social capital is defined by its function. It is not a single entity, but a variety of different entities having two characteristics in common: They all consist of some aspect of social structures, and they facilitate certain actions of individuals who are within that structure. Like other forms of capital, social capital is productive, making possible the achievement of certain ends that would not be attainable in its absence. Like physical capital and human capital, social capital is not completely fungible, but is fungible with respect to certain activities. A given form of social capital that is valuable in facilitating certain actions may be useless or even harmful for others. Unlike other forms of capital, social capital inheres the structure of relations between persona and among persons. It is lodged neither in individuals nor in physical implements of production". He highlighted that unlike human capital that is related to individual education and background, social capital builds on close connections among individuals or organizations".

While Coleman's concept highlights the role of cohesive connection among members, Burt (1992) offered a different view based on the structure hole argument in that firms bridging disconnected units enjoys competitive advantage. He suggested that non-redundant offer information benefits that are additive rather than redundant, and structure holes are the gaps between non-redundant contacts. Social capital is affected by the structure of network connections, and networks rich in structure holes present opportunities for entrepreneurial behavior.

Woolcock and Narayan have identified three dimensions of social capital: bonding, bridging and linking capital (Woolcock, 1999; Woolcock and Narayan, 2000). 'Bonding' capital refers to social connections that build on similarity, informality and intimacy. Some illustrations of this form of capital include the bonds between family members and close friends. Cattell (2001) identifies that this dimension of social capital contributes to quality of life by promoting mutual understanding and support (Woolcock 1999). 'Bridging' capital refers to links amongst diverse individuals. Bridging networks are characterized by both formal and informal relationships as well as strong and weak ties. Bridging capital is vital for linking individuals and communities to resources or opportunities outside their personal networks. In his seminal work on job seeking, Granovetter (1983) found that ties linking individuals and communities outside one's personal network and local community are particularly important for enhancing individuals' access to long-term sustainable employment. Drawing on Granovetter's research, social network research has repeatedly shown that members of impoverished communities lack access to the bridging networks that significantly contribute to educational and employment opportunities (Reingold, 1999). While bridging capital is associated with horizontal networks, 'Linking' capital is more related to vertical relations and refers to alliances with sympathetic individuals or groups in positions of power, particularly power over resources needed for social and economic development. Linkages enable individuals and communities to speak directly to those with formal decision-making power rather than have their views filtered via 'experts'. Most strategy studies on network connections fall within the first two categories: bonding and bridging social capital. The bonding social capital emphasizes cohesive network membership and similar member identity, whereas the bridging social capital focused on the inequality of the members in the same network.

Traditional industrial organization studies view firms as independent and the industry structure, such as industrial concentration, determines individual performance. Resource based view offers a distinct explanation and stresses the role of firm specific resources as the sources of competitive advantage (e.g., Barney, 1991; Wernerfelt, 1984). These theorists viewed firms as heterogeneities that are differentially endowed with firm-specific capabilities and resources. Classic resource based view studies focus on resource available or controlled by firms within organizational boundary. As Gulati argued, "while scholars developing the resource-based perspective have highlighted the importance of social factors and also the role of unique firm history, no attention has been given to network resources that emerge from firms' participation in inter-organizational networks" (Gulati, 1999). More recent extensions on resource based view maintain that competitive advantage derives not solely from firm level resources but also from the difficult-to imitate capabilities embedded in dyadic and network relationships (Dyer and Singh, 1998; Lane and Lubatkin, 1998).

2.1.3 Embedded relations, trust and inter-organizational knowledge transfer

Knowledge has emerged as the most strategically significant resource of the firm and contributed to competitive advantage (Grant, 1996). A number of theoretical perspectives related to the role of firm specific knowledge in competitive strategy have contributed to our understandings of knowledge transfer across organizations. These include organizational learning, management of technology, resource based view of the firm, dynamic capabilities, and knowledge based view of the firm (e.g., Spender and Grant, 1996). Embedded relations are often viewed as effective means to help organizations to overcome certain barriers to knowledge transfer.

Embedded ties assist in the transfer of knowledge, because connected actors develop mutual trust and commitment. A firm can only acquire knowledge from another party if that party is willing to reveal what it knows. Without trust, a potential source may be reluctant to share its knowledge "for fear of losing ownership, a position of privilege, superiority; it may resent not being adequately rewarded for sharing hard-won success; or it may be unwilling to devote time and resources to support the transfer" (Szulanski, 1996). Pisano (1989) also pointed out that the ability to learn through others does not simply rest on the focal firm's internal absorptive capabilities; it also depends on the willingness of the external sources to fully cooperate. Tatsuno (1986) documented the early cooperative problems of Japan MITI's VLSI project when researchers from various companies were brought together at the same time --- "Company rivalries created serious barriers to the free flow of information. The mutual distrust was so great that some engineering installed locks on their doors. Although the Association held monthly seminars to exchange information, this arrangement was too formal. Finally Nebashi resorted to talking to taking small groups of scientists out for drinks in the evening to break the ice. After a while, the barriers began to dissolve".

Generally trust is viewed as an expression of confidence between the parties in an exchange of some kind --- confidence that they will not be harmed or put at risk by the possible opportunistic behavior of the other party (Alelrod, 1984; Bateson, 1988; Zucker, 1987), or confidence that no party to the exchange will exploit the other's vulnerability (Sabel, 1993). Studies have widely acknowledged that trust can lead to cooperative behavior among individuals, groups, and organization (e.g., Gambetta, 1988; Good, 1988; Mayer, Davis and Schoorman, 1985, McAllister, 1995). The trust literature suggests that the successful resource sharing of two previously separated organizations is again naturally affected by the trust and mutual commitment of the partners involved. Inter-organizational exchanges are believed to suffer from the possible opportunistic tendencies of each partner. Without required mutual trust and commitment, firms may find it impossible to carry out whatever projects they have planned ahead. While inter-firm trust is not developed from vacuum, it is usually path dependent and evolves gradually through past interactions. Embedded long term relations provide an ideal platform for the mutual trust formation between firms. When assessing trustworthiness, people often consider the track record of others, or how they have carried out role-related duties in the past (Cook and Wall, 1980; Granovetter, 1985). Repeated inter-organizational exchange and interaction build mutual trust and commitment. When one entity is unsure of the other's trustworthiness, it may refrain from actively exchanging and sharing knowledge and information because of its uncertainty about how others will use this information and because possessing that knowledge is a source of power (Jones and George, 1998). As Uzzi argued, trustworthiness facilitates the sharing and exchanging of resources and information that are crucial for high performance but are difficult to value and transfer via market ties (Uzzi, 1996).

2.2 Strategic alliance, social networks, and firm strategy

2.2.1 Strategic alliance and firm strategy

Strategic alliance is usually defined as voluntary arrangement between firms involving exchange, sharing, or co-development of products, technologies, or services, and they can occur as a result of a wide range of motives and goals, take a variety of forms, and occur across vertical and horizontal boundaries (Gulati, 1998). Capability and resource theories postulate that a firm's business strategies and organizational practices create competitive advantage to the extent that they address these issues more successfully than do rivals' (Grant, 1991). Better coordinated, more-cooperative organizations that create, acquire, and most importantly use knowledge more effectively should do a better job of converting inputs into customer satisfaction, and hence should be more profitable.

In his review of joint venture studies, Kogut (1988) classified the motivations of inter-organizational cooperation into three categories: 1) transaction cost; 2) strategic behavior; and 3) knowledge sharing and learning. A transaction cost explanation for inter-organizational cooperation involves the questions of how a firm should organize its boundary activities with other firms. Two properties are particularly distinctive: joint control and the mutual commitment of resources. Collaboration creates superior monitoring mechanism and alignment of incentives to reveal information, share technology, and guarantee performance. Strategic behavior explanation, on the other hand, views that firms are motivated by strategic reasoning to deter entry or erode competitor's positions. Vicker's (1985) study showed that, for small innovations, a joint venture is an effective mechanism to guarantee the entry-deterring investment. While for large innovations, it is in the interest of each firm to pursue its own research, because the expected payoff justifies the costs. Kogut (1988) suggested that though the transaction cost and strategic behavior can address the question why sometimes firms choose to cooperate, the knowledge sharing and learning explanation seems to be the most important. This view holds that inter-organizational cooperation is a means by which firms seek to retain their capabilities. When firms consist of tacit knowledge based on organizational routines that are not easily diffused across the boundary within organizations, joint ventures are effective means to transfer the un-codified knowledge. Kogut (1988) noted that the three perspectives of transaction cost, strategic behavior, and organizational learning provide distinct explanations for cooperative behavior. "Transaction cost analyzes joint ventures as an efficient solution to the hazards of economic transactions. Strategic behavior places joint ventures in the context of competitive rivalry and collusive agreements to enhance market power. Finally, knowledge sharing and learning views joint ventures as a vehicle by which organizational knowledge is exchanged and imitated" (Kogut, 1988) .

In high technology industries, the knowledge sharing and learning seems to be the dominant motivation for firms to set up cooperative relations. Recent studies have shed new insight on firms' motivation to cooperate. Brockhoff, Gupta, and Rotering (1991) found from their survey of German firms that the most important reason for cooperative R&D agreements is the possibility of developing synergy from the exchange of technological knowledge. From his analysis of a journal article data base, Hagedoorn (1993) found that technology complementary is one of the most frequently cited motivations for cooperation. By examining Japanese R&D

consortia participants, Sakakibara (1997) found that skill sharing is a major motivation which leads firms to cooperate. Sakakibara (1997) suggested that the heterogeneity of firms' capabilities is a major motivation which leads firms to cooperate in R&D. When highly sophisticated innovations often depend upon advance across several areas of since and technology, few firms have the breadth of knowledge required for such undertaking, and so a new combination of competency is necessary to build core competencies (Hagedoorn, 1993; 1995). Partners with a skill sharing motive may find it easier to reach an agreement to cooperate without a clear end result in mind than firms whose primary motive for cooperation is cost sharing. Hamel, Doz and Prahalad (1989) early suggested that mutual gain is possible if partners can complement each other's weakness since each partner in an alliance can access the complementary capabilities of their partners. From a study in global automobile industry, Norhria and Garcia-Pont (1991) also found that firms in certain strategic groups form alliances in a complementary manner with those in other strategic groups to increase the benefits of cooperation. Since R&D requires lots of time and energy, firms usually select their own narrowed niches for product innovation rather then engaging themselves in a wide variety of areas at the same time. When the capability building is path dependent, some firms might find themselves locked outside of certain domains it did not touch before (Cohen and Levinthal, 1990). It could be because either they lack the insight of the technology path in the areas and the lack of required understanding of the field to appreciate and recognize important knowledge in those areas, or they lack the capability to assimilate such knowledge if all technologies are built on the past ones in the specific fields. Alliance partners that can point out new opportunities in other directions and bring in desirable new knowledge inflow may be particularly valuable. Especially in high-growth industries, firms need to form alliances with partners with complementary capabilities to ensure timely product introduction and to marshal a full array of capabilities (Teece, 1986).

2.2.2 Network relations and competitive advantage

A social network is composed of a set of actors and their connections among one another (Wasserman and Faust, 1994). Each actor is a potential source of information that is pertinent to a firm's product development activities. Thus, social networks affect a firm's external opportunities to access and acquire new knowledge. Literature suggests that network ties can not only play conductive roles in knowledge transfer, but also play directive roles in knowledge search and recombination process.

A firm needs to build shared understanding around the knowledge to be transferred, because interpretation is crucial for the firm to exploit knowledge from outside. Network connections contribute to the internalization and utilization of new knowledge through the frequent interactions among partners. Since most firm-specific knowledge is tacit, internalization requires constant communication, feedback and exchange between the sources and recipient. Social ties provide a context within which the individuals involved in knowledge transfer can develop the shared understanding that is necessary for the recipient to fully comprehend the function of the knowledge provided by a source. This makes it easier to incorporate new knowledge into research and development activities. Social ties may thus help a firm to exploit new technological and scientific knowledge.

Development of a knowledge base or technological competence in a field is difficult, time-consuming, and expensive (Ahuja, 2000). For many technologies, participation in later stages of technological development is conditioned by knowledge accumulation in previous stages, hence a lengthy presence in the technology domain is often necessary to develop significant technical capital (Dosi, 1988) and there are time-compression diseconomies in developing technological competence (Dierickx and Cool, 1989). Firms may want to look to others that have made such commitment in the past and seek to learn from their accumulated knowledge (Mitchell and Singh, 1992). Alliance partners can provide insight into which approaches have been tried and failed in the scientific and technological areas in which they have experience. The greater their experience, the better able they are to help their alliance partners select the most promising approaches. Innovative partners are familiar with the research process and may have better insight into how to carry out the various search and experimentation processes needed to find a solution. Thus, they not only bring a wealth of empirical data, problem-solving strategies, and partial solutions to a collaborative venture, they also contribute their adeptness at the process of doing research.

Network connections play important roles in directing firms to new knowledge. To sustain competitive advantage, a firm needs to constantly seek out new opportunities for upgrading and renewing their capabilities through their alliance relations, however acquiring capabilities entails uncertainty regarding the value of the social resources of the partner and the extent to which it can benefit the firm (McEvily and Zaheer, 1999). Not all potential partners possesses comparable levels of network resources, specifically, firms' networks vary in terms of structure, or the pattern of ties, and nodal heterogeneity, or the variation in the mix of contacts in firms' networks (Galaskiewicz and Zaheer, 1999). A particular partner that maintains a large number of but redundant social ties might not benefit the focal firm more than another partner with a small set but efficient contacts. The value of knowledge sometimes lies in whether it is unique and accessible from other sources or not. The value of a social relation also depends on whether such relation is unique and whether the benefits through such alliance are obtainable from other sources or not. Burt raised the point of network efficiency from observing whether some social ties are necessary in terms of information benefit (Burt, 1992). In redundant networks the information flow among members is highly frequent and each piece of information might be repeatedly accessible by every member. As a result the value of the information contained within the network decreases because either the lack of uniqueness of the information by itself or all members might develop similar knowledge assets in the long run. Burt (1997) has argued that ties that span 'structural holes' are especially likely to expose a firm to novel information and entrepreneurial opportunity. These are social relationships that bring into contact people who have relatively infrequent encounters with one another. As such, a firm's network ties may increase its opportunities to recognize new technological possibilities. Further, absorptive capacity allows a firm to make better use of its social network by enabling it to identify those opportunities most likely to enhance its innovative success.

2.2.3 Value creation and rent realization in strategic alliance

The pursuit of value through the alliance also compels firms to make tradeoffs against opportunism-related risks (Madhok and Tallman, 1998). The tension of learning competition and value appropriation has long been suggested by various scholars. In his seminal work, Hamel (1991) pointed out that collaborative process might lead to reapportionment of skills between alliance partners because of the asymmetry of learning and bargaining power. He claimed that asymmetries in learning change relative bargaining power within the alliance. Successful learning may lead to a pattern of unilateral than bilateral dependence. As a result, a partner that understands the link between inter-firm learning, bargaining power, and competitiveness will tend to view the alliance as a race to learn (Hamel, 1991). The recent stream of research on common and private benefits in strategic alliance has deliberated such asymmetric learning and appropriation power. Scholars (for example, Khanna, 1998; Khanna, Gulati, and Nohria, 1998) have proposed that there are two quantitatively different kinds of benefits available to alliance partners: "common benefits" that accrue collectively to all alliance participants and "private benefits" that accrue to subsets of participants. Khanna, Gulati, and Nohria (1998) proposed that "Private benefits are those that a firm can earn unilaterally by picking up skills from its partners and apply them to its own operations in areas unrelated to alliance activities. Common benefits are those that accrue to each partner to in an alliance from the collective application of the learning that both firms go through as a consequence of being part of the alliance". There have been indications that strategic alliance may suffer from unfavorable knowledge leakage, such as the risk of uncontrolled information disclosure and asymmetric diffusion of core competencies to partner firms (Inkpen and Beamish, 1997). Hamel's (1991) work suggested that being a good partner possibly invites exploitation by partners attempting to maximize their individual appropriation of the value creation. This will result in a trade-off between the common interests in efforts spent on producing a greater joint outcome and conflicting interests in efforts spent on securing a greater individual part of this joint outcome (Larsson, Bengtsson, Henriksson, and Sparks, 1998).

Khanna, Gulati, and Norhia (1998) summarized that there are simultaneously cooperative and competitive drives in strategic alliance. The cooperative side results from the fact that each firm needs to access the other's specific resources and that both firms can collectively use their knowledge to produce something that is mutual beneficial. The competitive temptation arises from each firm's opportunism to use its partner's knowledge and resource for private gains, and the possibility that greater benefits may accrue to the firm with better learning competence (Khanna, Gulati, and Norhia, 1998). In their early work on dynamic R&D competition, Grossman and Shapiro (1987) pointed out that there are both positive and negative sides in technology joint ventures: while technology cooperation increases the joint expected profit by saving cost and sharing new knowledge breakthrough, firms will also need to endure the most intensive competition race as both are simultaneously racing to reap the final benefits. Zeng and Chen (2003) also suggested that alliance partners face a social dilemma in managing the inherent tension between cooperation and competition among themselves. As they pointed out, on the one hand, partners may bargain over economics benefits that come directly from alliance relations. Setting up and maintaining alliance ties is not certain one-time action, but involves dedicated and intensive resource commitment. Partners may often under-invest in alliance specific assets to avoid being hold up. On the other hand, firms may internalize each other's skills and apply them to areas outside the alliances (Hamel, 1991; Zeng and Chen, 2003). My main theory argument could directly apply to such question as whether firms with advantageous network positions are more capable of capture the value created through alliance connections. Due to current data limitation, I do not specifically address the distribution of common and private benefits among partners in this research project, but some of my theory argument supports the general idea that network structure can give firms strategic advantage in realizing and reaping the potential value creation.

CHAPTER 3: THEORY AND HYPOTHESES DEVELOPMENT

3.1 Network centrality and organizational innovation rate

In technology and innovation literature, innovation process is viewed as the process of exploring new ways of problem solving through recombining knowledge of ideas from various sources (Schumpeter, 1938; Clark, 1985; Fleming and Sorenson, 2001). This suggests that having more external knowledge sources can facilitate a firm's innovation process by enriching the channel of knowledge exchange. Actually, as a firm's technology development is a path-dependent, it may find necessary to be connected with others in order learn any knowledge outside its own domain. Levinthal and March (1993) view that the knowledge discovery and combination process is subjective to bounded rationality. Managerial myopia may arise when a firm lacks of awareness of other technologies available within or outside the organization.

Sociology literature also suggests that embedded social ties, rather than one time transaction connections, greatly shape organizations' activities and performance (Granovetter, 1985). Specifically Uzzi (1996) pointed out that embedded tie is closely related to fine-grained information transfer and networked firms hold the advantage in accessing and acquiring external tacit knowledge, which is the key standpoint I take in this study. Recent researches on alliance and networks have stressed the value of inter-firm cooperation for accessing resources and creating competitive advantage (e.g., Dyer and Singh, 1998; Gulati, 1998; Ahuja, 2000). Strategy scholars well acknowledged the need to examine the implication of a firm's structural relations to others while embedding it in a network context rather than limiting within dyadic view between alliance partners (Galaskiewicz and Zaheer, 1999).

Resources based view maintains that a firm is composed by a bundle of tangible and intangible resources and firms differ in their capabilities to utilize such resources to generate economic returns (Barney, 1991; Peteraf, 1993; Maritan, 2001). The recent relational view arguments further suggests that firms can also make use of the resources outside its own boundary through alliance relations (Dyer and Singh, 1998). Alliance and network studies have strongly suggested the effect of embedded relations on inter-firm knowledge transfer. By collaborating, each obtains access to the other partners' knowledge, which allows them to bring a much larger experience base to their research (Abrahamson and Rosenkopf, 1997; Ahuja, 2000). Those organizations maintaining many connections tend to take the center positions of the inter-organizational network. Networks assist a firm's innovative activities since alliance partners are important sources of knowledge inflow. Koka and Prescott (2002) suggested that being central in alliance networks enables organizations to access and acquire larger quantity of valuable knowledge by virtue of their alliance connections. A firm can use news of others' research objectives, their successes, failures, and specific discoveries to prioritize its own R&D objectives and search strategies. The richness of information access makes it easier to learn and acquire knowledge faster (Deeds and Hill, 1996). Madhavan, Koka, and Prescott (1998) further argued that central firms are exposed to richer external resources and have higher control and flexibility of resource allocation to achieve their organizational goals. Therefore, I propose that being central in an inter-organizational network leads to rich information access and is conductive to a firm's rate of technology innovation.

Nevertheless, the contribution of network centrality to a firm's innovation rate may not be linear. A firm that maintains ties to more alliance partners in order to access a given amount of expertise will likely incur higher coordination cost. Such coordination cost arises from the complexity of ongoing coordination of activities to be completed jointly or individually across organizational boundaries and the difficulties associated with decomposing tasks and specifying a precise division of labor across partners in alliance (Gulati, 1999). Lorenzoni and Lipparini (1999) also pointed out that, to better manage the complex relational sets organizations are embedded, they must develop the ability to combine and coordinate the technology exchange among a large number of firms (Kogut and Zander, 1996). The difficulty of managing multiple partners and corresponding projects may dilute the attention a firm gives to certain technology development. This could result in lower innovation rates if knowledge is not pooled or transferred across organizational boundaries as effectively as it could be (Szulanski, 1996). Ahuja (2000) also noted that every linkage that embeds a firm more deeply in the industry network also places a strain on its management and absorptive capacity. The cost of maintaining linkages increase significantly, because firms not only have to devote time and resource to the managing of the individual alliance, but also have devote resource to the coordinating across alliance partners (Harrigan, 1985). Thus, beyond certain point the learning and risk reduction benefits of network centrality will diminish.

H1: The centrality of a firm in the alliance network will have an inverted U relationship with the rate of its technology innovation.

3.2 Structure holes and organizational innovation value

Structural holes arise when some organizations/entities are separated from the inter-firm connections (Burt, 1992), and a firm could span structural holes by setting up ties to disconnected organizations at both ends to bridge the chasm (McEvily and Zaheer, 1999). Networks vary in terms of structure or the patterns of tie connections among organizations, and the variation of firms' bridging structural holes affects their individual opportunities to discover and exploit new knowledge (McEvily and Zaheer, 1999). Burt (1992) has argued that spanning 'structural holes' are especially likely to expose a firm to novel information and entrepreneurial opportunities. These are social relationships that bring into contact organizations that have relatively infrequent encounters with one another. Firms bridging boundaries or spanning structure holes may enjoy the advantage of having unique information access related to certain technology development (Ancona and Caldwell, 1992). McEvily and Zaheer (1999) also suggested that the range, novelty, and diversity of information and knowledge obtained from spanning structural holes are greater than from redundant connections, as redundant contacts are more likely associated with knowledge that is largely superfluous and unoriginal. The value of knowledge sometimes lies in whether it is unique and accessible to others or not. Novel knowledge is more valuable as new concepts offer opportunities for redefining relationships among existing components, challenge existing assumptions about extant components, and expose a firm to new applications for a technology (Henderson, 1995).

Firms spanning structure holes are more capable of detecting distinct technology directions and recombining knowledge from various unique sources. "Broker" firms are more capable of producing innovations of high value, as they are better advised of distinct technology opportunities that are difficult for others to develop substitutes. Studies on technology brokering also supported such argument. For example, Hargadon and Sutton (1994) suggested that Edison and his colleagues used their knowledge of electronic magnetic power from the telegraph industry, where they first worked, to transfer old ideas that were new to the lighting, telephone, phonograph, railway, and mining industries. They argued that the phonograph technology blended old ideas from products that these engineers had developed for the telegraph, telephone, electronic motor industry, as well as ideas developed by others that they had learned about while working in those industries. I also would like to raise a simple example to illustrate how firms could benefit from spanning structure holes to identify unique and valuable technology directions that are difficult for others to imitate.

INSERT FIGURE 1 ABOUT HERE

In the above graph, when broker firm C explores new directions of drug products dealing with cough. It is possible that firms connected in the left subgroup possess the technologies related to certain drugs that have a quick effect, but with some side effect for children, and with simple and plain designs. Firms connected in the right subgroup might be familiar with different type of technologies that produce drugs with better designs (with attractive colors, tastes and shapes so that children like them more), safe for under-aged children, but with slower treating effects. On the one hand, bridging the two groups enables firm C to better understand what technologies have already existed and to avoid simply replicating others' R&D efforts. For example, firm C could better recognize that merely developing a drug product with the same functions as those developed by firms in the left subgroup or right subgroup may not be valuable. On the other hand, C could have the unique opportunity to develop certain drug products that combine the strength of both types. As the two types are related to distinct product components and technology ingredients, it will be very difficult for other firms to develop substitutes as if they only have access to partial required knowledge. As such, I propose that a firm that spans many structural holes is more capable of identifying potential technologies that are difficult for other to imitate (instead of blindly investing in wide technology areas).

At the same time, I view that there could exist diminishing returns to a firm's spanning structure holes. In order for a firm to be able to communicate with a wide range of others of various technology expertise, it has to be knowledgeable at these broad areas itself to maintain any meaningful communication (Cohen and Levinthal, 1990). If it spreads its attention across too wide technology domains, its ability to integrate distant knowledge might decrease (Fleming, 2001). Since boundary spanning requires firms to keep knowledgeable in wide technology areas, they may not be able to utilize all the potential technology opportunities if they do not have related knowledge in certain areas. Tripsas (1997) also argued that the lack of related knowledge often limits a firm’s efforts to acquire new technological capabilities by learning from its alliance partners.

Hence I predict:

H2: The efficiency of a firm's network connections (spanning structure holes) will have an inverted U relationship with the value of its technology innovation.

3.3 The moderating effect of network centrality on the relationship between structural hole and innovation value

The value of a firm’s innovations sometimes depends on how the peer organizations view and acknowledge its technology advancement. Firms bridging structural holes enjoy the advantage of combining disconnected knowledge into unique technologies that are distinct and not substitutable by others. Nevertheless, if the new technologies are not well recognized by peer organizations, the value of such technologies is not realizable. The market potential will be best realized when other organizations widely recognize the technology advancement and build their products around such core technology. For example, Toshiba and Intel's introduction of flash memory for personal digital assistants was viewed as of great market importance, because their technology was quickly acknowledged by peer organizations and accepted by producers of PDA and widely viewed as of great market importance. Similarly, IBM's entry into the personal computer market in 1981 pushed most software developers to explore the new opportunity and to seriously devote R&D efforts to programs designed for the personal computer (Anders, 1981). Without recognition and acknowledgement from the social community, a firm with unique and highly advanced technology may find it difficult to get its product accepted by the public. Network centrality can greatly enhance such technology recognition and reduce the market risk. Highly embedded firms are viewed as reliable and prominent members of the network. On the one hand, centrally located firms have the most opportunity to communicate with other firms, to spread out the technology advancement, and to make others recognize the new technology and developing complementary products. On the other hand, having rich connections helps the focal firm to accumulate reputation and generate visibility to the public. As Podolny (1993) argued, when there is uncertainty about the quality of certain product, evaluations of it are strongly influenced by the social standing of the actors associated with it. Firms in the central network locations have higher social status and have substantial influence over other firms' knowledge recognition and technology adoption. Endorsement with rich network resources is also an effective market signal (Stuart, Hoang, and Hybels, 1999), because it helps convince the public that the central firm has super power and resources to continuously develop the product.

Spanning structure holes could make it easier for a firm to better recognize and explore unique knowledge recombination and technology opportunities. Though non-redundant connections are beneficial in the process of search for distant and unique knowledge, firms also need cohesive ties to facilitate effective knowledge transfer (Hansen, 1999). Network centrality, having rich connections to other organizations, could help further realize such innovation opportunities. Technological knowledge often contains tacit elements and hence requires sustained communications (Hagedoorn, 1993; Baum, Calabrese, and Silverman, 2000; Mowery, Oxley, and Silverman, 1996). The transfer of tacit and complex knowledge requires frequent source-recipient exchange, because the recipient most likely does not acquire the knowledge completely during the first interaction with the recipient but need multiple exchanges to assimilate and internalize (Polanyi, 1966; Szulanski, 1996). Though alliances could provide resource sharing, but such activities are not as highly planned and controlled as those happened within hierarchical organizational boundaries. It is possible that at times certain partner is not available to interact with because that partner is occupied with other activities. If the focal firm doesn't have other sources to rely on, it has to wait for future exchange when the specific partner is available. In this case, any change or termination of alliance relationship with the particular partner will leave the focal firm at great risk. Having multiple knowledge sources to interact with will reduce such vulnerability and increase a firm's flexibility. Research on the leveraging of inter-firm relationships also suggested that, when external uncertainty increases, firms tend to interact more with other organizations to increase the overall volume of their interactions (Lorenzoni and Lipparini, 1999). As a consequence, the main effect of uncertainty is not the absorption of the source of uncertainty within corporate boundary, but increased reliance on external partners who are known and trusted as reliable (Baker, 1990). Furthermore, interacting with multiple sources about the same core knowledge can also help the focal firm to explore multiple ways to interpret and utilize the new knowledge. As knowledge is embedded in organizational routines and viewed as firm specific, each partner may come up with its own way of solving the same problem based on its own experience. The central firm has the unique opportunity to exchange with multiple others about how the similar knowledge works in different organizational contexts. Thus, once a firm identifies valuable new knowledge recombination opportunities, having rich connections to others can help realize such innovation potential as well as utilize the new knowledge to the best advantage.

H3: A firm's network centrality will positively moderate the relationship between its network efficiency and the value of its technology innovation.

3.4 The moderating effect of structural hole on the relationship between network centrality and innovation rate

McGrath and Nerkar (2004) suggested that pharmaceutical firms' R&D function encompasses many projects across many therapeutic and scientific areas. Decisions about technology investment are always made in the context of a portfolio of other alternative investments. Miller (2002) also pointed out that firms always have to deal with a "knowledge inventory" issue --- making decisions under uncertainty about a firm's portfolio of technologies. Knowledge inventory management involves acquiring, retaining, deploying, idling, and abandoning technologies over time. Miller (2002) described technology decisions as very complex when investments require sunk cost and extended time horizons. "Managers cannot costlessly reverse current decisions if the state of the world changes. They face disposal or ongoing maintenance costs if technologies are idle. Further complicating this problem is the possibility that some technologies may be available for only a short time and become inaccessible if not acquired during the window of opportunity" (Miller, 2002). A central theme holds that managers approach these decisions in an uncertain manner regarding about which technologies may be most appropriate for current and future use. To protect against such uncertainty, firms may add technologies to their knowledge inventories without deploying them immediately, or make idle investments necessary to maintain them for reactivation in the future. The main advantage is the increased strategic flexibility to switch technologies in the future. Nevertheless, such assumption is based on the fact that the managers do not have enough knowledge about the strength and weakness of alternative technologies and their performance trajectories. In this study, I view that external network connections could substantially affect managers' understanding of alternative technologies and help reduce related uncertainty.

A firm could have a range of domains in which it accumulates required knowledge for future technology innovations. Nevertheless within these possible domains there are certain technology directions that are more valuable. By 1949, monochrome black-and-white television had become a commercial success, 10 million sets had been sold, and programs were available to the general public. RCA selected a different direction than the current black and white TV technology, and started to explore the opportunities related to color TV products. RCA, losing some $65 million over a decade, persisted. Finally, in 1964, the tide turned, and RCA began to profit tremendously from its investment in color television. Though both directions brought in technology innovations and advancement to the TV industry at that time, their value and impact are rather divergent. Similarly, Melissa Schilling (1998) illustrated that Nexgen, a CPU manufacture, faced technological lockout when it chose to produce own variant CPU that was different from Intel's dominant standard and was rejected by market. These show that selecting technologies have different value.

Firms in the central locations of alliance network have more knowledge sources to build inventories on. Such large knowledge inventories provide broad repertoires of organizational responses to future contingencies. Increasing the number of external connections helps bring more knowledge sharing and exchange, and could widen the domains it could potentially generate innovations. Spanning structural holes can help a firm to better understand which direction could be more valuable, because "broking" helps a firm to better assess and evaluate different technologies. It then could provide guidance on narrowing down technology choices. As a result of such reduced technology uncertainty, broker firms can mange more efficient knowledge inventories because they have better ideas not to pursue certain technology. I explain the moderating effect of structural holes on the relationship between network centrality and innovation rate by the following graph.

INSERT FIGURE 2 ABOUT HERE

H4: A firm's network efficiency will negatively moderate the relationship between its network centrality and the rate of its technology innovation.

CHAPTER 4: RESEARCH DESIGN

4.1 Industry setting

During the past century, the sources of innovation in global pharmaceutical industry have been decisively transformed. The industry has experienced a series of fundamental changes, starting with the development of the germ theory of disease in the beginning of 1900s and the further acceleration during the chemo-therapeutic revolution of the 1930s and 1940s. One of the most prominent breakthroughs in the second half of the century was brought forth by recombinant DNA technology and molecular genetics (which is usually referred to as biotech revolution). Scientific advancement generated significant opportunities for pharmaceutical innovations. Expanding markets enabled some of the manufacturing pharmacies of the late nineteenth century to grow in scale and scope, gradually evolving into the comprehensive and integrated pharmaceutical manufacturing firms.

INSERT TABLE 1 ABOUT HERE

Pharmaceutical company research spending has nearly doubled every five years since 1970. It is reported that, over the past three decades, the amount of sales allocated to R&D has increased from 11.4 percent in 1970 to 17.4 percent in 1999. The percent of sales allocated to R&D by the Drugs & Medicine sector of the Standard & Poor's Compustat database (which includes the research-based pharmaceutical industry and non-research-based companies) is 12.8 percent, which compares to 3.9 percent invested in R&D for all U.S. industries. According to corporate tax data compiled by COMPUSTAT, pharmaceutical manufacturers invest a higher percentage of sales revenue in R&D than virtually any other U.S. industry, including high-tech industries such as electronics, computers, and automobiles.

The research and development activities of pharmaceutical firms are complex, costly and time-consuming endeavors. These activities are also driving the restructuring of the industry away from a strict reliance on in-house innovative and toward a greater use of external relationships. In the past, companies were primarily dependent on their own in-house technique expertise in their efforts to develop new drug applications. All told, the development of a single new drug can take some 10-15 years and cost well above $350 million (Van Arnum, 2000). Moreover, there is no guarantee of success, since only one in 600,000compounds synthesized by pharmaceutical laboratories could be regarded as highly successful. Since R&D requires lots of time and energy, firms usually select their own narrow niches for product innovation rather than engaging themselves in a wide variety of areas at the same time. To take advantage of the changing market opportunities and to keep up with the industrial technology evolution, pharmaceutical firms often have to make strategic commitments to new capabilities and new products in research and development. By pooling own resources and capabilities with those of alliance partner's, firms can initiate projects that they could not have successfully done alone. The case is especially true in the pharmaceutical industry. For example, on July 1 of 1992, Ligand Pharmaceuticals Inc. and Allergan Inc. (NYSE:AGN) was reported to form a joint venture designed to research, develop and commercialize pharmaceutical products based on retinoid technology.

INSERT ILLUSTRATION 3 ABOUT HERE

The joint venture is viewed to bring together Ligand's strength in hormone-activated intracellular receptor technology and Allergan's expertise in discovering and developing retinoinds for topical use. David E. Robinson, Ligand President and Chief Executive Officer, said the joint venture will form one of the largest retinoid drug discovery programs in the industry, making the joint venture more competitive than either Ligand or Allergan alone.

> *"This agreement is consistent with Ligand's strategy of forming major corporate alliances to accelerate the development and commercialization of our leading-edge discoveries," he said. "This also gives Ligand unique profit-making potential by giving us the ability to share in worldwide profits for all applications of retinoid technology developed by the joint venture..."(Source: RECAP)*

Shepherd, a member of the top manager team of Allergan, said the joint venture represents a key step in Allergan's efforts to accelerate the development and commercialization of the company's portfolio of patented retinoid compounds.

> *"Technology is an integral part of Allergan's strategic direction," he said. "Allergan has made several external investments this year in various biotechnology research programs to enhance our internal pipeline and R&D efforts. Our strategy of seeking alliances that will enhance the rapid development of any of our products or businesses will continue..."(Source: RECAP)*

In general, companies have responded to shorter product-life cycles, cost-containment pressures, and research opportunities by increasingly forming strategic alliances. Those forms of cooperation are some times demonstrated as research cooperation, product co-development, technology licensing and transfer, co-promotion, distribution and commercialization, and to the high degree of corporate joint venture.

4.2 Sample and data collection

The pharmaceutical industry is an appropriate research setting for several reasons. Patents have been linked to expert ratings of the technological strength of pharmaceutical companies (Comanor and Scherer, 1969; Narin, Noma, and Perry, 1987), and this industry is one of the few in which patents are effective and widely used to protect inventions (Mansfield, 1961; Levin et al., 1987; Cohen, Nelson, and Walsh, 1997). These factors suggest that patents are a good measure of pharmaceutical firms' inventions. In addition, alliances are known to be an important avenue for accessing external knowledge in this industry (Powell, Koput, and Smith-Doerr, 1996; Lane and Lubatkin, 1998; Baum, Calabrese, and Silverman, 2000).

Knoke (1994) summarized three decision rules used for constructing networks for empirical examination and defining boundaries: attributes of actors, such as membership in an organization or industry; types of relations between actors, such as strategic alliances or interlocking directorates; and participation in a set of events or issues, such as proposed plans to deregulate a highly regulated industry. My criterion used to identify network boundaries is that the actors share a common attribute (Marsden, 1988; Knoke, 1994). Industry membership has been used as one such attribute, to identify constituents of alliance networks (Powell, Koput, Smith-Doerr, 1996; Rowley, Behrens, and Krachardt, 2000; Ahuja, 2000).

Since usually tracing the networking activities on a population of firms within an industry demands huge effort, almost all prior research on alliance networks has focused on leading companies (Gulati, 1995; Gulati and Gargulio, 1999; Ahuja, 2000). For example, Gulati (1999) indicated that he "collected data on a sample of 166 firms in new materials, industrial automation, and automotive products. I selected a panel of 50–60 of the largest publicly traded firms within each sector, estimating a firm's size from its sales in that sector as reported in various industry sources". In Ahuja's(2000) study on chemical industry, he chose a sample of 97 leading firms across Western Europe, Japan, and the United States and stated "the sample was selected to include the largest chemicals firms in these three areas, which constitute the core of global chemicals industry, to insure the availability and reliability of data". In Rowley, Behrens and Krackhardt's (2000) study the sample was designed based on two criteria: membership in the target population (industry) and at least one strategic alliance with another member of that industry. Nevertheless, I think there is much need to include all firms within a certain industry to better capture the overall picture regardless whether an individual firm has alliance or not.

My focus is on firms that list as their primary business the SIC code 2834, pharmaceutical preparation. These designations were taken from COMPUSTAT, and the Global Worldscope and Compact Disclosure databases. The content of a network (i.e. the purpose of actors' relations) can affect how certain network variables influence members' behaviors and hence performance outcomes (Ahuja, 2000). I restrict my attention to alliances formed among firms that directly affect a firm's research and development activities. Firms have ties with one another if they are parties to a technology licensing or sharing agreement, are engaged in a joint venture or R&D consortium to develop a technology, establish formal contractual product research and co-development alliances.

Information related to the alliance activities of these firms was gathered from a variety of sources: Recombination Capital and Bioscan, some databases that lists various alliance activities a firm has engaged in since 1978 (Lerner 1994; Lane and Lubatkin, 1998; George, Zahra and Wood, 2002); U.S. Securities and Exchange Commission (SEC) filings; and a list of industrial newspapers and journals that tend to report pharmaceutical firms' activities, such as *Drug Store News, Healthcare Financial Management, Health Industry Today, Natural Health, Pharmaceutical Executive, Pharmaceutical Technology, R & D Focus Drug News.* This design combines the advantages of different approaches used. For example, Koka and Prescott (2002) mainly relied on major newspaper for alliance information as they indicated "The primary alliance data source is the American Metal Market (AMM) that is a trade journal of the steel industry". In Gualti's (1999) study, he reported that the basic source is the Cooperative Agreements and Technology Indicators data base, collected by researchers at the University of Maastricht. He also sought industrial newspapers like Automotive News, Ward's Automotive Reports, US Auto Industry Report, Motor Industry of Japan, and Japanese Auto Manufacturers Forum.

Patent data was collected from USPTO, the official U.S. patent database containing the searchable patent records of all firms since 1790. I examined each patent's document recorded in the USPTO database. For each patent, I recorded the patent's application date, issue date, assignee name, patent holder, technology classification, and the times cited by other citations.

INSERT ILLSTRATION 1 ABOUT HERE

The above illustration shows the front page information of patent 5585495, titled "Dorrigocin antitumor agents" as obtained from the USPTO database. The abstract part mainly identifies new key findings/ideas related to drug product development and technology. The inventor item shows the researcher information. This one is shared by several inventors, which is a commonly seen among the patent profile I investigated. The assignee item indicates the company or agency the patent is granted to. Since it also includes the company's geographic location, I use this to cross check and to match with related company profile in Compustat database --- to make sure that the firm I identified in the patent information is the same one I gathered financial information on from Compustat. The next two items include the initial patent application number and application date. This particular patent file indicates that it was applied on April 25 of 1995 and was granted on December 31 of 1996. The next two show related technology (sub) classifications, both US and international, this patent belongs to. The patent cited item indicates previous patents cited by the current one. In this case, only one previous patent, 5002959 by Konishi et al. granted in March of 1991, and the previous patent is classified in group 514/326. The "other reference item" reports scientific articles cited by the current patent. Most of the science references come from papers published in Journal of Antibiotics. The next two items contain patent examiner and attorney information. The claim section reports the specific elements by which the current patent distinguishes from previous products/technology.

INSERT ILLUSTRATION 1 ABOUT HERE

In addition, for each patent, I conduct a search in the USPTO patent database to examine the citations from other patents received after the grant date. In the following table I illustrate a search result by "patents citing # 5175183, Lipoxygenase inhibiting compounds".

INSERT TABLE 2 ABOUT HERE

In order to focus on firms' innovations directly related to new drug development, I narrowed down to two corresponding patent main classes, 424 and 514, by USPTO standard definition. Patent classes 414 and 514 are defined as "DRUG, BIO-AFFECTING AND BODY TREATING COMPOSITIONS". Such consideration rules out certain innovations that are not directly related to drug developments, for example, drug product distribution. I illustrate the standard USPTO class definition below:

INSERT ILLSTRATION 2 ABOUT HERE

To investigate a firm's technology/class distribution, I record patent subclass identity based on US classification as well as IPC classification system (Lerner, 1994). All together there are hundreds of subclasses under the main class 424 and 514, and such investigation at subclass level provides a valid base for firm technology heterogeneity. In addition, I also match their US classifications to IPC scheme in order to better examine firms' technology distance among one another. I list below the US to IPC concordance for class 424 and 514.

INSERT TABLE 3 ABOUT HERE

4.3 Variables and measurements

Rate of technological innovation: Number of new patents applied by a firm in a given year. Patents are associated with inventiveness and technological novelty, because they are granted only for 'non-obvious' improvements or solutions with discernible utility (Walker, 1995; Ahuja and Katila, 2001). In addition, they represent an externally validated measure as they confer property rights upon the assignee and therefore have economic significance (Baseberg, 1982; 1983; Ahuja and Katila, 2001). Hence I count the number of new patent applications a firm filed each year as the indicator for its innovation rate.

Value of technological innovation: Number of citations to a firm's patents. The number of citations a patent receives is a valid indication of its technological importance and potential economic value (Deng, Lev, and Narin, 1999; Hall, Jaffee, and Trajtenberg, 2000). Technologic innovation differs in term of its value because of its uniqueness (Trajtenberg, 1990). Several incremental innovations might not be as valuable as a single technology breakthrough. Through the research and development track, some firms might choose a specific knowledge niche to develop its unique technology. While in some other circumstance several firms might enter somehow similar or over-lapping domains, and those firms might gain shared understanding upon the set of technology. Then the value of such knowledge may decrease since it lacks uniqueness and relatively easy for others to come up with comparable substitutes or simply imitate. The value of such a specific knowledge resource lies in the fact that they may be not available elsewhere and can be sustainable. Inventions also differ in their value because of its market potential. Some innovations are more readily to commercialize in the market and generate revenues and profits. While others might not be as mature and have to go through rounds of trial and testing before the technology can be embedded into production.

Thus, a firm's technology strength might not be fully demonstrated by the size of its knowledge or patent stock. And its status is often reflected through others' view and references, and frequently granted by the common recognition of peers and public. In the patent literature, a well-established tradition has been often suggested is to use citations as an index of the importance or value of technological innovations. Past studies have found positive relations between the citations and the cited patents' economic impact. Trajtenberg checked the patens related to CT scanners and reported that there is high association between the citation weighted measure and the social value of patents in the technology field (Trajtenberg, 1990). Lanjouw and Schankerman (1999) used citation as the proxy for patent quality and found such value measure has significant power in predicting which patents will be renewed and which will be litigated. Harhoff et al. (1999) even predicted from a large-scale survey study that the most highly cited patents are very valuable, "with a single US citation implying on average more than $1 million of economic value". Shane (1999) also demonstrated that more highly cited MIT patents are more likely to be successfully licensed, and also more likely to form the basis of starting a new firm. Hall et al. (2000) found that citation-weighted patent stocks are more highly correlated with market value than patent stocks themselves. They interpret the finding as due mainly to the high valuation placed on firms that hold very highly cited patents (Hall, Jaffe, and Trajtenberg, 2000). The citation data is gathered from the bibliographic information available on front pages of patents issued in a particular time frame (Harhoff, Francis, Scherer, and Katrin, 1999). I count the total number of citations to the patents that a firm has received since 1990. For each patent granted to a firm in a particular year, I count the number of citations to a patent over the subsequent years. Thus, each sample observation is a citation count to a firm's active patents. In model estimations I also control for the number of patents with the potential to be cited (patent stock) as the sum of all patents received since 1990 up to the current year.

Degree centrality. I use firm-level degree centrality in this study and calculate it as the number of active partners a firm maintains (Ahuja, 2000). In order to determine whether an alliance is still active, I traced each alliance and its status every year since its formation, using the information sources mentioned above. For example, in 1991 COR Therapeutics (NASDAQ: CORR) and Eli Lilly (NYSE: LLY), two global research-based corporations, initially set up a four-year joint research agreement to discover and develop a class of new drug compounds that treat cardiovascular disorder, including myocardial infraction and angina. In this case, I treat their alliance as beginning in 1991. According to the initial terms of the agreement, it was to dissolve in 1995. In fact, in 1993 COR and Lilly decided to expand their original agreement to include the joint research, development and commercialization in North America, Europe and Japan of all intravenous and oral products resulting from their collaboration indefinitely. Therefore, I do not consider their alliance to have dissolved in 1995. For each year, I identify all active alliances related to research and technology development. I use firm-level degree centrality (Freeman, 1977) in this study. To create this measure, an n-by-n matrix X is first generated from the alliance connections among firms. The elements in the matrix are set as:

$$X_{ijt} = \begin{cases} 1 & \text{if firm } i \text{ and firm } j \text{ are connected} \\ 0 & \text{if firm } i \text{ and firm } j \text{ are not connected} \end{cases}$$

Then the degree centrality for firm i in year t is calculated as:

$$D(n_{it}) = \sum_{i=1}^{n} X_{ijt} = \sum_{j=1}^{n} X_{jit}$$

Structural holes/efficiency. A structural hole is a relationship of non-redundancy between two contacts (Burt, 1992). Redundancy exists where two contacts connect a firm to the same third actor (in this case the actors are structurally equivalent) or where the two contacts have ties with one another (this indicates cohesion). I focus on direct ties only, as these contacts likely have the greatest influence on a firm's R&D activities, and use the cohesion measure of structural holes (Burt, 1992). For each year, I identify active alliance relations of the sample firms, and construct inter-firm alliance network. I then set up the ego network for each firm by year, whose structure is my key concern. I calculate this measure using standard UCINET routine and refer to Wasserman and Faust's (1994) book for the formula and procedure. The exact formula used in this paper is also essentially the same as the one used in Ahuja's (2000) study.

$$\sum_{j=1}^{n} \frac{1 - \sum_{q=1}^{n} p_{iq} m_{iq}}{C_j}$$

where *i* firm has contacts *j* and *q*, p_{iq} is the proportion of *i*'s relations invested in contact *q*, m_{jq} is the marginal strength of the relationship between contact j and contact q, and C_j is the total number of contacts for firm i.

In previous studies, authors have either excluded firms with no contacts, or set this ratio to 0 (Rowley, Behrens, and Krachardt, 2000; Ahuja, 2000). However, my objective is to measure opportunities for a firm to span structural holes within its network, and thereby gain access to diverse information and new recombination and brokerage opportunities. I exclude firms that have no contacts because it does not make sense to compare the relative access that their alliance network provides to these opportunities. I assign a value of zero to firms with one alliance contact because their alliance network provides no opportunity to span structural holes. Although this one contact is not redundant, and therefore would technically receive a value of 1, this is not an inaccurate estimate of structural holes in the firm's network. Assigning a value of 1 to firms with a single alliance partner would indicate that it has the maximum number of structural holes, which is clearly not the case.

Partner patent stock. I measure the total amount of knowledge a firm's partners possess as the total number of patents that they have received starting from the observation window up to a given year. Scholars have suggested that an organization's patent portfolio provides a means for mapping an organization's knowledge, since the patents owned by a firm represent the knowledge that the firm is acknowledged as having created (Jaffe, Trajtenberg and Henderson, 1993; Ahuja and Katila, 2001). A firm's patent profile represents a collection of discrete, distinct units of knowledge. Identifying a set of patents that a firm has demonstrated familiarity with, or mastery of, can be a basis for identifying the 'revealed' knowledge base of a firm, the distinct elements of knowledge with which the firm has some proficiency (Kim and Kogut, 1996).

Technology distance to partners (Partner knowledge complementarity). The knowledge distance between a firm and its alliance partners was measured using Jaffee's (1986) approach. Each firm is given a vector to represent the distribution of its patents across the set of possible patent classes. The value in each cell for a firm is the proportion of its patents that fall within that class. In a study on the important of patent scope, Lerner (1994) proposed a measure for patent breadth based on IPC classification scheme provided by the World Intellectual Property Organization (WIPO). Since 1969 US patents have been classified according to both the U.S. Department of Commerce, Patent, and Trademark Office (USPTO) and IPC schemes (WIPO, 1981; USPTO, 1971), but the IPC approach is preferred for patent breadth examination because of its nested structure (Lerner, 1994). In his study he simplified the investigation by focusing on the first four digits of IPC classes only. To allow for greater variation among firms, I used the first eight digits of the IPC classes. For example, Lerner (1994) counted the classes C12N 1/14 and C12N 9/60 as the same since they both have the identical first four digits C12N; I viewed these two as different classes since I included all first eight digits.

The Euclidean distance is used to calculate the technological distance between firms, according to variation in the distribution of their patents across these classes. The exact formula for the distance between any two firms is:

$$Distance_{ijt} = \sqrt{\frac{1}{m_t}\sum_{k=1}^{m_t}\left(\frac{n_{ikt}}{\sum_{k=1}^{m_t} n_{ikt}} - \frac{n_{jkt}}{\sum_{k=1}^{m_t} n_{jkt}}\right)^2}$$

where *i* indicates a particular firm and *j* is an alliance partner of firm *i*, *t* is the current year, *k* is a patent class, and m_t is the total number of patent classes in year t, and n_{ikt} is the number of patents firm *i* has in patent class *k*, in year *t*.

To calculate the technology distance value, I first map firms' patent profile with technology (sub)class distributions. I generate a patent (sub)class by firm matrix for each year using the IPC scheme.

INSERT TABLE 4 ABOUT HERE

Below I illustrate a final "firm by firm" technology distance matrix.

INSERT TABLE 5 ABOUT HERE

To create the distance from a focal firm to its direct alliances, I average each dyadic distance from the firm to each of its alliances. The total stock of patents held by a firm's alliance partners represents the collection of knowledge the focal firm is exposed to, and each partner contributes a different amount to this knowledge stock. Accordingly, I weight each dyadic focal firm-direct alliance distance by the proportion at which the alliance contributes to the total patent stock of alliance patents. The formula is:

$$Dis\tan ce_{it} \quad = \quad \sum_{j=1}^{J_{it}} \left(\frac{n_{jt}}{\sum_{j=1}^{J_t} n_{jt}} * \sqrt{\frac{1}{m_t} \sum_{k=1}^{m_t} \left(\frac{n_{ikt}}{\sum_{k=1}^{m_t} n_{ikt}} - \frac{n_{jkt}}{\sum_{k=1}^{m_t} n_{jkt}} \right)^2} \right)$$

where *i* indicates a particular firm and *j* is an alliance partner of firm *i*, J_{it} is the total number of direct alliances a firm has in year t, *t* is the current year, *k* is a patent class, and m_t is the total number of patent classes in year t, and n_{ikt} is the number of patents firm *i* has in patent class *k*, in year *t*, and n_{jt} is the total number of patents issued to firm *j* in year *t.*

Technology distance among partners (Partner knowledge diversity). The diversity of knowledge residing in a firm's network is the average distance among a firm's partners, excluding the firm itself. I take the sum of each dyadic distance between a firm's direct contacts and divide the value by the total number of direct alliances of the firm. Since each pair of firms is counted twice, I also divide the value by 2 to get the final technology distance among a firm's alliance. This is calculated as:

$$ADis\tan ce_{it} \; = \; \frac{1}{2 * J_{it}} * \left[\sum_{j=1}^{J_{it}} \sum_{g=1}^{J_{it}} \left(\sqrt{\frac{1}{m_t} \sum_{l=1}^{m_t} \left(\frac{n_{jlt}}{\sum_{l=1}^{m_t} n_{jlt}} - \frac{n_{glt}}{\sum_{l=1}^{m_t} n_{glt}} \right)^2} \right) \right]$$

J_{it} is the total number of direct alliances a firm has in year t, j,k is the jth and gth direct alliance of the focal firm i, $j \neq i, \, and \; g \neq i$)

Technology Scope. A firm's own technology scope represents its own knowledge breath that affects the easiness of its recognizing and realizing new knowledge. Previous studies that refer to technological scope (Lerner, 1994) or breadth have typically used simple counts of the number of distinct types of knowledge a firm possesses (e.g. number of different classes it has patented in) or an inverse concentration ratio, which rises as the number of classes a firm's patents are assigned to increases and as patents are dispersed more equally dispersed across those classes (Fleming, 2001; Sampson, 2002; Ahuja and Katila, 2001). I use the latter approach to measure the breadth of a firm's absorptive capacity (Dess and Beard, 1984). This measure is based on the distribution of the patent's a firm has received within the three-year window preceding the date of the dependent variable, across patent classes. As innovation is an uncertain and nonlinear process, annual patents are unlikely to fully represent the composition of a firm's knowledge. I selected a three-year window with which to construct the breadth measure to make the best use of my data. As the focus of firms' innovative activities typically does not change dramatically from year to year, this window should enable us to capture the relative technology scope. Specifically, I adopt an entropy index measure.

$$Breadth_{it} = \sum_{k=1}^{m_t} \left[\frac{n_{ikt}}{\sum_{k=1}^{m_t} n_{ikt}} * \ln\left(\frac{\sum_{k=1}^{m_t} n_{ikt}}{n_{ikt}} \right) \right]$$

where i indicates a particular firm, t is the current year, k is a patent class, and mt is the total number of patent classes in year t, and nikt is the number of patents firm i has in patent class k, in year t. This measure is based on the distribution of the patent's a firm has received within the three-year window preceding the date of the dependent variable, across patent classes. As innovation is an uncertain and nonlinear process, annual patents are unlikely to fully represent the composition of a firm's knowledge. For patent classification reference, I adopted Lerner's (1994) approach and used IPC classification scheme.

Own patent stock. A firm's own knowledge stock is also an important predictor of its ability to learn from alliances, and the number of patents a firm holds will also affect the number of citations it receives each year (Cohen and Levinthal, 1990; Lane and Lubatkin, 1998). This variable also controls for unobserved firm-specific factors that affect its propensity to produce and patent inventions (Stuart, 2000). I control for this by including a firm's own stock of patents in the models. The cumulative count of a firm's patents, up to the year prior to the dependent variable, also controls for unobserved differences in a firm's ability and propensity to patent. I again used USPTO database to locate each firm's patent history. In each year I start by counting a firm's total active patent issued since 1990, and create its cumulative number of stock patents as $STPATENT_{it}$.

Patent tenure. I include a patent tenure measure to control the effect that old and recent patents might have different contribution to a firm's learning and developing new technology. This measure is a weighted average count of the age of a firm's active patents.

R&D investment. A firm's R&D effort directly affects its innovation output (Griliches, 1984; Goto and Suzuki, 1989; Helfat, 1994). As Cohen and Levinthal (1990) argued, a firm's investment in research and development not only contributes to its immediate technology productivity, but also contributes to its learning ability and the capacity to exploit future innovation opportunities. I experimented with including in my models annual R&D expenditure lagged by one year (Ahuja, 2000). Because in some of my models R&D investment is highly correlated with both sales and patent stock, and I do not include this variable in all models.

Firm size. Previous literature suggests that a firm's size may affect its technology and innovation behavior. Authors have proposed that small firms are more efficient because large organizations are often more bureaucratic and less entrepreneurial than small ones (Blau and Schoenherr, 1971). Others postulate that firm size is associated with the rate of innovation as large firms usually generate a disproportionate quantity of innovation (Cohen, Nelson, and Walsh, 1996). Yin and Zuscovitch (1998) also posed that because of the heterogeneity of R&D behavior, the large firm remains dominant for the original product in the post innovation market, but the small firm is more likely to be a leader in the new product market. I obtained a firm's sales data in each year obtained from COMPUSTAT database to control for its size.

Firm age. Innovative capabilities of established organizations are generally better suited to producing incremental innovations along existing technological trajectories. Previous studies also demonstrated that innovation spawning new technological fields often emerge from small, entrepreneurial organizations (Christensen, 1992). Sorensen and Stuart (2000) particularly suggested that aging has two seemingly contradictory consequences for innovation: on one hand as organization age the fit between organizational capabilities and environmental demands decreases, on the other hand organizational competence to produce new innovations appears to grow with age. Since firm's tenure in pharmaceutical industry has a confounding effect on its innovative outcomes, I control for firm's operating history in pharmaceutical preparation in my study. I use the first appearance date of the firm in pharmaceutical preparation industry as the baseline, then minus the current date of sample observation by the first appearance date as the firm's tenure in pharmaceutical preparation.

Year dummy. I also included in my models dummy variables by each year to control for unobserved confounding effects including firm level heterogeneity (Ahuja, 2000).

CHAPTER 5: ANALYSIS AND RESULTS

5.1 Model selection and descriptive statistics

As the dependent variables are constrained to non-negative integer values, I used fixed-effects negative binomial models (Hall, Hausman, and Griliches, 1984) to estimate above proposed relations. A general negative binomial probability function is given by the following formula:

$$P(X=k)=\frac{\Gamma(\partial+k)}{\Gamma(\partial)\Gamma(K+1)}(\frac{1}{1+\theta})^{\partial}(\frac{\theta}{1+\theta})^{k}$$

$$\begin{cases} \partial > 0 \\ \theta > 0 \\ k = 0,1,2,... \end{cases}$$

Since $\theta \geq 0$, the variance of the negative binomial distribution generally exceeds its mean, which is closely related to overdispersion. The main advantage of the negative binomial regression over the Poisson regression is that the former introduces substantial flexibility into the modeling of the variance function concerning heteroskedasticity (Winkelmann, 2000). The negative binomial regression particularly introduces overdispersion, a more general form of heteroskedasticity than the mean-variance equality implied by the Poisson distribution.

I used a panel data design to test the longitudinal effects to deal with heterogeneity across cross section units (Greene, 1993). Fixed-effects approach is preferred because such approach addresses two issues that could affect the regression validity: serially correlated errors and heterogeneity across firms (Koka and Prescott, 2002). Addressing the issue of serially correlated errors is important to get unbiased estimates when the data is time-dependent. The standard fixed effects approach controls for firm heterogeneity by assigning a dummy variable to each firm in the estimation model. The fixed effects model is a conservative test of the hypotheses, as modeling each firm as a dummy variable may be so powerful that the dummy capture most difference in performance leading to inconclusive results (Koka and Prescott, 2002).

Table 6 lists the mean, standardized deviation, and the correlations among variables. I detected that a firm's sales is highly correlated to its R&D investment, and dropping the sales or R&D variable from my regressions did not make much difference, so I didn't include the two together in the following result analysis and discussion. For technology distance related measures, I used a 3 year accumulative and moving window. I included innovation rate and value starting from 1993 (ending in 1999) as the independent variables. I also put one year lag to other independent variables. In general there are no significantly high correlations among the independent variables that might affect my estimations, and I also tried to take log transformation for several key variables to reduce correlations. Further analysis showed that the possible remaining multicollinearity did not cause significant problem to my model estimations. I conducted several supplementary analyses to test the robustness of this result, suggested by Green (1993). To test for sensitivity of standard errors on the network variables, I dropped each variable from the model in turn, and their standard errors were significantly affected.

INSERT TABLE 6 ABOUT HERE

As Ahuja (2000) noted, a sample focusing on large and prominent firms may contain selection bias because they receive more extensive press coverage on alliance activities than do small firms. My sample reduces such concern, as I included all firms in the SIC 2834 industry. In addition to the tests based on full sample, I also investigated proposed relationships based on a narrow set of prominent firms. There are only 68 firms consistently existing throughout the time window from 1990 to 1999. If public press coverage related to those firms is more complete and salient, then their alliance reports should be more comprehensive. A pool of those firms forms a balanced panel across the years. I present my main findings related to the rate of innovation based on the full sample in table 7 and table 9, and list the results related to the value of innovation in table 8 and table 10.

The results largely support the hypotheses relate to innovation rate put forth in this paper. In general my findings indicate that network centrality affects a firm's rate of innovation, while network efficiency affects the value of its innovation. And more importantly, firms taking the central network positions and maintaining efficient connections at the same time tend to focus on a narrow set of innovations of higher value. This suggests that, for an optimal network configuration, we need to exam the combined effects of centrality and structural hole at the same time.

5.2 Network centrality and innovation rate

INSERT TABLE 7 ABOUT HERE

In model 1 I show the outcomes from the baseline model. The results indicate that it is necessary to control those variables, such as sales and own patent stock, in the regression model to address the confounding effects. For example, I detect that sales has a significant and positive effect on the rate of innovation. This tends to suggest that large firms with more resource endorsements are more capable of producing innovations at high rate. Small firms may be restricted by resource limitations to certain degree because sometimes they lack the resources required to generate technological innovation. Firms are endowed with different levels of intent and ability with regards to alliance and will benefit differently from them (Madhavan, Koka, and Prescott, 1998; Park, Chen, and Gallagher, 2002). A firm's commercial capital affects its chance to realize and appropriate rents created through inter-organizational alliances. Commercial capital represents the supporting or complementary assets that a firm needs to commercialize new technologies accomplish this objective (Ahuja, 2000). Firms endowed with higher levels of commercial capital should find it easier to exploit the rent appropriating opportunities. Transforming technical innovations to products and services entails the development of manufacturing and marketing capabilities, and assets such as manufacturing facilities and service and distribution networks (Teece, 1988). This requires significant up-front development costs, and incurs fixed costs to maintain these networks and facilities (Ahuja, 2000). Firms with abundant commercial resources are free of such constraints and can quickly utilize the technology in their product development processes. As a result, they can expedite the market introduction process of and capture additional rents.

In hypothesis 1 I propose that network centrality could have an inverted U relationship with the rate of technological innovation. My findings on network centrality are inconsistent and there are no strong supports from the results. In model 2 I find that the coefficient of degree centrality is -0.064 and weakly significant at $\partial = 0.1$ level, and the square term of degree centrality is 0.003 and significant at $\partial = 0.05$ level. In model 4, I include structure hole items, and again detect similar results. A slight difference shows up in that the centrality effect became less significant. In model 5 I further add the interaction term of centrality and efficiency. The coefficient of the centrality is found to be non-significant, but the square term still has a positive sign. These three models suggest that the degree centrality of a firm in the alliance network contributes to the rate of its technology innovation, but such relationship could be U shaped, instead of inverted U. I view such effect could be caused by the self-enhancing nature of degree centrality. Resource dependency theory suggests that inter-organizational interaction arises because organizations seek access to critical resources (Hagedoorn, 1993; Eisenhardt and Schoonhoven, 1996), and as a result firms central in the network are more attractive as alliance targets to others seeking to establish new ties and foster new collaborations (Gulati, 1998; Kogut, 2002). Furthermore firms with more alliance experience might have better capability to coordinate and manage alliance relations. There could exist certain economics of scale effect, such that the pooling of resources from multiple partners generates high benefit.

An early study in biotechnology industry by Powell, Koput, and Smith-Doerr (1996) provides related logic and findings. On the one hand, a firm's centrality in an early stage affects its chance to develop new alliance ties in future. They suggest that once a firm begins collaborating, it develops experience at cooperation and a reputation as a partner. Firms develop capabilities for interacting with other firms, and previous experience provides a fertile ground for both further formal partnerships and an expanding array of informal relationships. A broader range of collaborative relations also provides greater opportunity to refine organizational routines for cooperating and render them more versatile. This implies that firms with high centrality will always enjoy the network advantage and tend to become more "central" as they are more capable of developing and managing new external ties. On the other hand, they also argue that central position help shapes a firm's reputation and generates visibility. Such a reputation can improve its ability to attract talented new employees. In addition, they suggest that firms more centrally located should have more timely access to promising new ventures, while those with more collaborative experience should be better positioned to exploit them. As a result, experience at managing ties allows a firm to move quickly in identifying new projects, funneling them inside the organization, and generating more innovations. Taken together, their theory statement supports the idea that high centrality not only provides a firm with more opportunity to develop new partnership and to become more central, but also increases the speed of its subsequent technology growth. This suggests that centrality may positively affect the rate of innovation at an increasing rate.

INSERT TABLE 9 ABOUT HERE

In table 9 I report the findings based on the 68 consistently existing firms from 1990 to 1999. The results show slight difference compared with those of the full sample models. From model 12 I find that the simple main effect of degree centrality is not significant, both for the linear term and square term. In model 14 I add structural holes as additional control, and also obtain the similar result. Nevertheless, in model 15, after including the interaction term of network centrality and structure hole, I find that the linear term of centrality is positive and significant. These seem to suggest that those leading firms do benefit from network centrality and increase their rates of innovation, but the second order relationship is not significant. Thus results from the 68 leading firms only show a positive linear relationship than a curvilinear one.

Such findings are consistent with those of Ahuja's (2000) study on chemical firms. Ahuja (2000) proposed three types of innovation benefits a firm can affect receive because of its central position: knowledge sharing, complementarity, and scale. First, direct ties enable knowledge sharing. Each partner can potentially acquire a greater amount of knowledge from a collaborative project than it would obtain from a comparable research investment made independently. Second, collaboration helps bringing together complementary skills from different partners. Collaboration can enable firms to enjoy economies of specialization without the prior investments entailed by internal development. The third positive effect results from scale economies that arise when larger projects generate significantly more knowledge than small projects. "When the transformation technology is characterized by increasing returns, such an investment will lead to a more than proportionate return in terms of innovation output, benefiting both firms significantly" (Ahuja, 2000). I do not necessarily agree with the complementarity logic as number of ties may not guarantee knowledge complementarity. A close examination of the knowledge base of a firm and its partners is required before we can tell whether partners actually bring in distinct knowledge or resources. In term of empirical findings, I detect much similarity between Ahuja's study and the current one in that there is a positive and significant relationship between centrality and innovation rate.

5.3 Network efficiency and innovation value

INSERT TABLE 8 ABOUT HERE

In my hypothesis 2 I propose that there is a curvilinear relationship between a firm's spanning structural hole and the value of its technological innovation. The results largely support such idea.

Model 6, the baseline model, shows several interesting findings on some control variables such as technology scope and firm age. For example, results from model 6 suggest that technology scope has a significant positive effect on innovation value. This is consistent with Lerner's (1994) finding that a firm technology breadth is substantially related to the importance of its technological innovations. Literature suggests that the impact of diversification on innovation is rather ambiguous. For example, Cohen and Levin (1989) have summarized that diversification can encourage innovation by providing a stimulus of multiple knowledge bases within a single firm, leading to cross-fertilization of ideas, but diversification can also imply increased bureaucratization and operational controls within firms and inhibit innovation. Previous research on the effect of diversification on innovative activity has generated mixed findings of both positive and negative effects of diversification (Cohen and Levin, 1989). My findings provide a strong support for the positive one.

The model suggests that there is a significant inverted U relationship between firm age and innovation value. This indicates that a firm with more industrial experience can better understand, assimilate, and utilize the new knowledge. Scholars have proposed conflicting arguments regarding the effect of firm age on innovation output. If aging leads to increased rigidity of communication patterns and resource allocations, organizations are less capable of moving toward new direction of technology change that might improve the value of its innovation output. Nevertheless, organizational competence also improves over time and experience. For example, Stinchcombe (1965) suggested that older organizations may be more efficient than younger firms because they have more production experience, stronger relationships with vendors and customers, and a more experienced workforce. Such efficiency can be translated into better innovation performance. Sorenson and Stuart (2000) suggested that the gains from experience with the innovation process should outweigh any negative consequences of bureaucratization. First, new ideas are more efficiently assimilated if a solid base of knowledge has been established in old firms. Second, experienced high-technology firms will have perfected the routines, structures, and other infrastructure that are needed to develop new technologies and commercialize them. “In short, high-technology firms that have survived a long period of time are likely to have developed the competence to innovate, particularly in their established innovative domains” (Sorenson and Stuart, 2000). Our findings suggest that the relationship between firm age and innovation may not be linear. It seems that organizations need to accumulate certain level of industrial experience before their positive gains outweigh the cost of bureaucratization. There is a threshold point below which firms with less experience might suffer from insufficient competence.

Results from model 8 and 9 do not show significant main effect of structure holes. Nevertheless, I find support in model 10 when I include the interaction term of centrality and structural holes. In model 10 the linear term of structure hole is positive and significant. This suggests that broker firms benefit from their bridging ties and enhance the value of their innovations. In addition, I found that the square term of structural holes is negative and weakly significant. This also supports my proposed idea that the return from spanning structural holes should be diminishing, as recombine knowledge from distinct sources pose higher and higher demand on organizational combinatory capability.

A related study on the effect of structural hole on innovation performance was conducted by Ahuja (2000) in chemical industry. Ahuja (2000) postulated two competing hypotheses: one on the positive effect of structural hole and the other on the negative effect. The rationale for the positive effect also result from Burt (1992) argument that spanning structural holes brings in non-redundant information and increases the opportunities for firms to absorptive and assimilate new knowledge. A negative effect might show up when there is not enough trust among the partners, so that there is high degree of opportunism concern. A network with rich structural holes may not be helpful for firms to develop mutual trust when the network connections are not dense and cohesive. Ahuja (2000) summarized the contradiction as “many structural holes in ego's network will increase ego's access to diverse information and, hence, enhance innovation output. Conversely, ego networks with fewer structural holes might promote trust generation and reduce opportunism, leading to more productive collaboration from the perspective of resource sharing”. The findings from his study on chemical industry support the negative prediction. In this study I move one step further by checking whether there is a non-linear relationship between structural hole and innovation. Broadly speaking, my result suggests an inverted U shape. At low levels of structural holes the benefits of unique information flow outweigh the cost of reduced trust among partners; while at high levers the opportunism argument takes a stronger stand and the negative effect of reduced trust may loom larger.

INSERT TABLE 10 ABOUT HERE

In table 10 I report the findings related to innovation value based on the 68 leading firms. The results from those prominent firms did not provide corresponding support as did the full sample. Both the linear term and the square term of the structural holes are not significant across the models. This seems to suggest that for those prominent firms, the structural hole effect is relatively weaker.

5.4 The joint effects of network centrality and network efficiency

My hypothesis 3 suggests structural hole negatively moderates the centrality-innovation rate relationship. Following the standard approach, I centralized centrality and structure holes before creating the interaction item. Again, I found robust supports for this proposition. In model 5 I examine the moderating role of structural hole on the relationship between centrality and innovation rate based on full sample observations. The coefficient of the interaction term is negative and significant.

Such finding is rather consistent in both full sample and 60 firm models. In model 15 I check the same relationship based on 68 leading firms. I also detect similar negative moderating effect for the leading firms. This indicates that structural hole negatively affects the contribution of centrality to innovation rate for both leading and small firms.

In figure 3 I draw a three-dimensional graph, based on date simulated with parameters obtained from related model estimations, to illustrate the interaction effect of network centrality and network efficiency on innovation rate.

INSERT FIGURE 3 ABOUT HERE

Figure 3 clearly shows that when we hold network centrality consistent, the number of innovation rate decreases with a firm's network efficiency. The graph gives a salient demonstration of the negative moderating effect of network efficiency on centrality-innovation rate relationship.

In model 10 I investigate how centrality moderates the relationship between structural holes and a firm's innovation value. The result suggests a significant positive effect, as the coefficient of the interaction term between centrality and structural hole is 0.318 and significant at $\partial = 0.05$ level. Thus my proposition 4 is supported. This indicates that centrality strengthen the contribution of structural hole on innovation value. Having rich connections on one hand creates ideal knowledge exchange context from multiple sources to realize the innovation opportunities, and on the other hand facilitates the public acceptance of the new innovation generated by the focal firm.

I find similar support from investigating the moderating role of centrality based on the 68 prominent firms. Results from model 20 demonstrate that the interaction term between centrality and structural hole is significant and positive.

INSERT FIGURE 4 ABOUT HERE

In figure 4 I draw a three-dimensional graph based on model estimations to illustrate the interaction effect of network centrality and network efficiency on the value of innovation. Again, I obtain some simulated data based on the parameters estimated from the current models. The picture illustrates the positive moderating effect of network centrality on relationship between network efficiency and innovation value.

Taken together, I find that the sign of interaction item between centrality and structure hole is negative for rate of innovation, whereas the sign for the same interaction item is positive for innovation value. This does not suggest that firms that are central in the network and span many structure holes at the same time will be less innovative. On the contrary, my interpretation is that those firms may not invest in widely dispersed technology domains. They tend to focus their innovation efforts within narrow set of technologies of higher value.

Spanning structural holes enables a firm to reach out for unique opportunities to recombine distinct knowledge from disconnected partners. Nevertheless, the value of innovation from such knowledge recombination is also affected by public acceptance. When uncertainty exists surrounding the technical and commercial future of new innovations, central connectedness give firms a substantial advantage in generating recognition and endorsement of their products (Stuart, 2000), thereby providing the additional benefit of reducing the perceived risk of the new technology.

“Knowledge inventory” perspective deals with the issue of making decisions under uncertainty about a firm’s portfolio of technologies. Miller (2002) suggested that, to protect against such uncertainty, firms may add technologies to their knowledge inventories without deploying them immediately, or make idle investments necessary to maintain them for reactivation in the future. The main advantage is the increased strategic flexibility to switch technologies in the future, in case certain technology shows up to be the favorable choice when industry conditions became more transparent. Spanning structural holes can help a firm to better understand which direction could be more valuable, because “broking” helps a firm to better assess and evaluate different technologies. So that firms can better recognize what technology directions others have already worked in and what directions others may not be able to explore because of their knowledge limitations. In this case, firms can make wise choices by narrowing down and focusing on new technologies that are difficult for others to develop substitutes and that are more valuable.

Comparing the findings from full sample and 68 firms’ model, I also detect that some variables, such as partner knowledge complementarity, demonstrated consistent effects on innovation performance in both sets of models, while others may not. This suggests that findings from industrial leading firms may not be readily generalizable to the whole population. In addition, most partner knowledge attribute variables are significant after I included the network structural ones as the controls. This directly suggests that network structure doesn't explain all and it is at least as important to check the knowledge relationships among firms.

CHAPTER 6: DISCUSSION AND CONCLUSION

6.1 Network positions and innovation opportunities

My results indicate that a firm's network position affect both its rate and the value of its innovation. Moreover, distinctive dimensions of a firm's network position, its centrality and efficiency – or spanning of structural holes, also interact to affect these outcomes. This study contributes to the current network research by suggesting that there are two levels of information benefits provided by network connections. Centrality leads to rich information inflow and increases a firm's scope of innovation opportunities. Nevertheless, spanning structural holes gives the firm unique information access to better evaluate and select from various technology directions. The interaction results are intriguing because they suggest some network structural variables will complement the effects of others, and other combinations of network attributes may cancel out the contributions of one another. Understanding the overall effects of a firm's network position requires attending to the dimensions affecting particular performance outcomes, both directly and jointly.

Much of the research linking network position to innovation has used an 'opportunity' logic – that network structure indicates the flow of information among organizations and advantageous positions within the flow provides access or exposure to certain types of opportunities. I have suggested that the innovation process may be shaped by the kinds of information a firm assimilates. In particular, I believe, selection processes within organizations are affected by the kinds of information a firm obtains from its network, and my results are consistent with this idea. Future studies could examine other attributes of the types of projects a firm undertakes, or other characteristics of its innovations (e.g. novelty of the technological foundations of a firm's innovations) to gain further insight into these relationships.

This study also extends research on networks and innovation by focusing on value. Despite evidence that innovation value is an important contributor to financial performance and social wealth (Capon, Farley, and Hoeing, 1990; Deng, Baruch, and Narin, 1999) and networks affect organizational innovation (Shan, Walker, and Kogut, 1994; Ahuja, 2000), researchers have not yet examined how alliance networks influence the value of the inventions a firm produces. Podolny and Stuart (1995) examined whether a focal invention becomes the foundation for future inventions, which is consistent with the way I define value; however, their focus was on the status of the innovator and competitive intensity of the niche, rather than a firm's network position. I feel this exploration is important for several reasons. First, it is unclear whether the network variables that enhance R&D productivity will also contribute to the value of each innovation. A firm might produce a greater number of patents by collaborating to reduce costs and share risks, but sacrifice both the uniqueness of its discoveries and its ability to appropriate rents from them (Mowery, Oxley, and Silverman, 1996). For example, network members might challenge the focal firm more aggressively in its core markets, after learning through alliance activities or acquiring information about its technological discoveries. Alternatively, they may build on a firm's discoveries to serve customers it has not yet attended to, locking the firm out of future market opportunities. Although these risks increase as a firm's network grows, a larger network might allow a firm to produce more inventions by reducing R&D effort.

Finally, I examine the proposed relationships based on a population of pharmaceutical firms in SIC 2834 industry instead of the few leading ones. Managerially, the results of my study suggest that firms could have better innovation opportunities through exploiting embedded network relations, and those with better network configurations could enjoy certain competitive advantage and make wise innovation choices. My findings reinforce Ahuja's (2000) argument in that the optimal network structure design and alliance portfolio management are contingent on the actions the structure seeks to facilitate. A network composed of partners with redundant ties and dense connections would facilitate the development of mutual trust and cooperation that is conductive to inter-organizational knowledge transfer; while a network of many non-overlapping ties, or rich in structure holes, would provide unique information benefits ideal for an organization that is interested in boundary spanning and recombining novel knowledge from unique sources. I move a step further by suggesting that being central in an alliance network leads to rich information access that contributes to the effectiveness of knowledge transfer and innovation rate, and spanning structural holes leads to unique information access that contributes to the efficiency of technology development and innovation value (such as identifying unique technology directions difficult for others to imitate, and avoiding replicating certain old technologies).

6.2 Partner knowledge attribute and innovation performance

Relatively less attention has been paid to partner resource attributes. Investing in alliance relations requires a long-term commitment and adequate resource allocation to the inter-firm collaboration. As Afuha (2000) has argued, partners' resources and capabilities can have vital effects on the success and competitive advantage of the focal firm – both positive and negative. Partners provide access to complementary resource and capabilities. However, if the value of those resources depreciates rapidly and unexpectedly, the focal firm's investment in such partnerships can become a liability, which the firm may find difficult to exit. In alliance networks, a firm may have greater leeway to adapt to such shifts, if it can identify novel ways to recombine the value provided by each partner. Though the value of each partner's knowledge changes over time, if a firm is embedded in a network characterized by diverse expertise, its opportunities for recombination and reprioritization are greater. Therefore, to more efficiently manage its alliance profile, a firm needs to determine how much additional contribution an additional partner will bring into the network – and both its knowledge portfolio and its network position are relevant. Moreover, this assessment should not only consider complementarities or overlap between a firm and each potential new partner; comparisons should be made across each new potential partner and the knowledge portfolio already resident in the firm's network.

Although examining the role of partner attributes is not among the focuses of the current project, some of the related findings also suggest that it is important to explore the knowledge configuration of a firm's alliance portfolio. In general, any efficient and effective alliance strategy needs to address two fundamental issues: 1) How to ally with others? e.g., what kinds of network connections to maintain and what network positions to take; and 2) Whom to partner with? e.g. which potential partners to select based on their knowledge or resource attributes and the relationship among firm resources? It is promising to extend the current research to study the effects of partner knowledge attributes on organizational innovation performance.

6.3 Limitations

While considerable effort has been made to ensure the reliability of the study, there are several limitations that need to be acknowledged while interpreting the results from this study. The first limitation is the relative generalizability of the research context. Attention needs to be paid to the fact that my research setting is a high tech industry in which industrial knowledge base is complex and widely spread across firms. The findings of this study may not be readily applicable to certain other traditional industries (for example, global steels) in which firms have less technology divergence, as those industries are more mature and standardized.

The second limitation is the network tie inclusion. Following Garcia-Pont and Nohria's (2002) approach, I limit my sample to horizontal alliances among the firms and exclude all suppliers, distributors, and other participants in the industry value chain. So far I have made an effort to observe a broad population of 228 firms, which covers most of the competitors in the pharmaceutical preparation industry and includes those firms generating the vast majority of patents. I don’t have complete information regarding ties to universities and research institutes. I agree that university ties should be very important. Nevertheless, I can demonstrate that those structure attributes of the horizontal network can at least explain a significant part of firm heterogeneity in innovation performance, which provides corresponding supports for my proposed ideas.

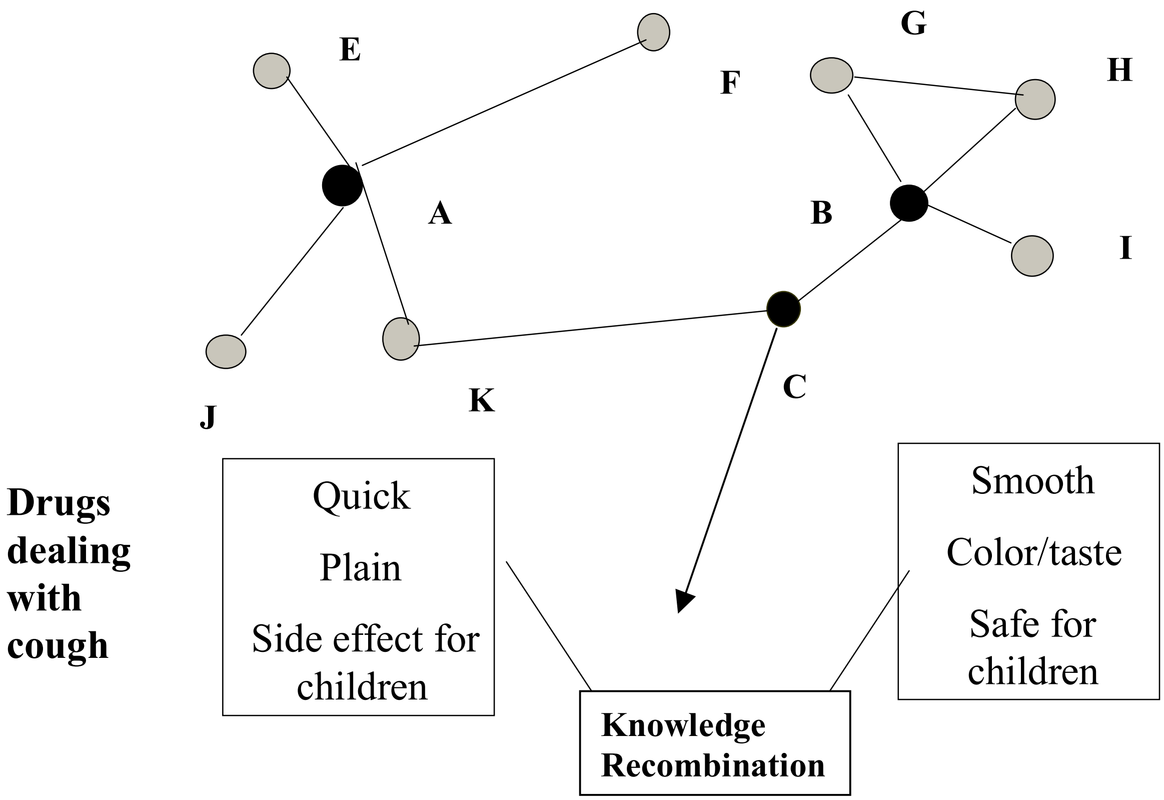


Figure 1: Networks Positions and Knowledge Recombination Opportunities.

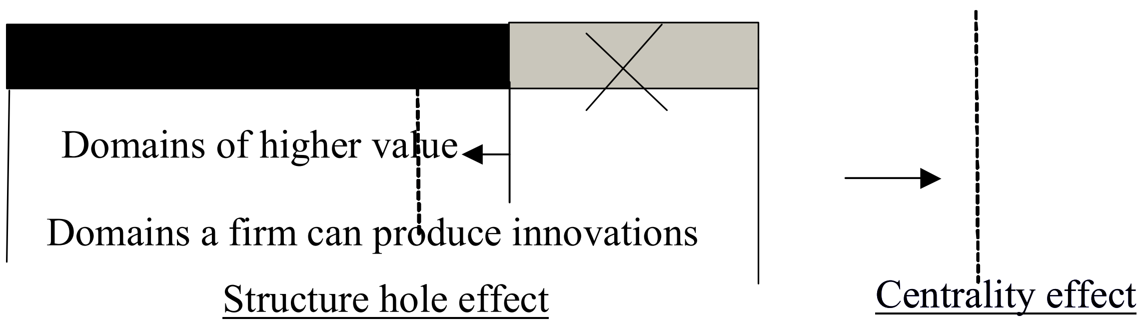


Figure 2: Network Connections and Innovation Opportunities.

Table 1: Growth in Domestic U.S. R&D and R&D Abroad, Research-based Pharmaceutical Companies, 1970-2001 (dollar figures in millions)

Year	Domestic U.S. R&D ($ mil.)	Annual Percent Change	U.S. R&D Abroad ($ mil.)	Annual Percent Change	Total ($ mil.)	Annual Percent Change
2001	$23,640.00	18.20%	$6,862.00	20.60%	$30,502.00	18.70%
2000	19,986.70	8.00%	5,692.20	34.90%	25,678.90	13.00%
1999	18,499.30	7.40%	4,219.60	9.90%	22,718.90	7.90%
1998	17,222.50	11.00%	3,839.00	9.90%	21,061.50	10.80%
1997	15,516.60	13.90%	3,492.10	6.50%	19,008.70	12.40%
1996	13,627.10	14.80%	3,278.50	-1.60%	16,905.60	11.20%
1995	11,874.00	7.00%	3,333.50	**	15,207.40	**
1994	11,101.60	6.00%	2,347.80	3.80%	13,449.40	5.60%
1993	10,477.10	12.50%	2,262.90	5.00%	12,740.00	11.10%
1992	9,312.10	17.40%	2,155.80	21.30%	11,467.90	18.20%
1991	7,928.60	16.50%	1,776.80	9.90%	9,705.40	1.30%
1990	6,802.90	13.00%	1,617.40	23.60%	8,420.30	14.90%
1989	6,021.40	15.00%	1,308.60	0.40%	7,330.00	12.10%
1988	5,233.90	16.20%	1,303.60	30.60%	6,537.50	18.80%
1987	4,504.10	16.20%	998.1	15.40%	5,502.20	16.10%
1986	3,875.00	14.70%	865.1	23.80%	4,740.10	16.20%
1985	3,378.70	13.30%	698.9	17.20%	4,077.60	13.90%
1984	2,982.40	11.60%	596.4	9.20%	3,578.80	11.20%
1983	2,671.30	17.70%	546.3	8.20%	3,217.60	16.00%
1982	2,268.70	21.30%	505	7.70%	2,773.70	18.60%
1981	1,870.40	20.70%	469.1	9.70%	2,339.50	18.40%
1980	1,549.20	16.70%	427.5	42.80%	1,976.70	21.50%
1979	1,327.40	13.80%	299.4	25.90%	1,626.80	15.90%
1978	1,166.10	9.70%	237.9	11.60%	1,404.00	10.00%
1977	1,063.00	8.10%	213.1	18.20%	1,276.10	9.70%
1976	983.4	8.80%	180.3	14.10%	1,163.70	9.60%
1975	903.5	13.90%	158	7.00%	1,061.50	12.80%
1974	793.1	12.00%	147.7	26.30%	940.8	14.00%
1973	708.1	8.10%	116.9	64.00%	825	13.60%
1972	654.8	4.50%	71.3	24.90%	726.1	6.20%
1971	626.7	10.70%	57.1	9.20%	683.8	10.60%
1970	566.2	--	52.3	--	618.5	--
Average		12.90%		17.00%		13.50%

** R&D Abroad affected by merger and acquisition activity.

Notes:

1. R&D expenditures for ethical pharmaceuticals only.
2. Domestic U.S. R&D includes expenditures within the United States by research-based pharmaceutical companies.
3. R&D Abroad includes expenditures outside the United States by U.S.-owned research-based pharmaceutical companies.
4. Numbers may not add exactly due to rounding.
5. Increases in U.S. and non-U.S. R&D are likely due to a more rigorous data collection methodology.

Source: Pharmaceutical Research and Manufacturers of America, PhRMA Annual Survey, 2001.

Illustration 1: A sample patent front page information

United States Patent 5,589,485, Dorrigocin antitumor agents Hochlowski , et al. December 31, 1996	
Abstract:	Novel antifungal and antitumor agents having the formula ##STR1## as well as pharmaceutically acceptable salts, esters, amides and pro-drugs thereof, wherein R is selected from the group consisting of ##STR2## Also disclosed are pharmaceutical compositions comprising such compounds, and methods of treatment and processes of manufacture relating thereto.
Inventors:	Hochlowski; Jill E. (Green Oaks, IL); Jackson; Marianna (Waukegan, IL); Kadam; Sunil K. (Kenosha, WI); Karwowski; James P. (Mundelein, IL); McAlpine; James B. (Libertyville, IL)
Assignee:	Abbott Laboratories (Abbott Park, IL)
Appl. No.:	429405
Filed:	April 26, 1995
Current U.S. Class:	514/315; 514/348; 546/243; 546/296
Intern'l Class:	C07D 211/40; C07D 211/76; A61K 031/44; A61K 031/445
Field of Search:	546/296,243 514/348,315
Patents cited:	U.S. Patent Documents 5002959 Mar., 1991 Konishi et al. 514/326.
Other References:	Chemical Abstracts, vol. 81(1) Abstract No. 2395d, Jul. 8, 1974. Urakawa, et al., Isolation, Structure Determination and Biological Activities of a Novel Antifungal Antibiotic, S-632-C, Closely Related to Glutarimide

	Antibiotics, Journal of Antibiotics, vol. 46, No. 12, pp. 1827-1833 (Dec. 1993). Otani, et al., New Glutarimide Antibiotics, S-632-B.sub.a and II. Isolution, Physico-Chemical Properties and Chemical Structure, The Journal of Antibiotics, May, 1989, vol. XLII, No. 5, pp. 654-661. Otani, et al., New Glutarimide Antibiotics, S-632-B.sub.1 and B.sub.2 I. Taxonomy of Producing Strain, Fermentation and Biological Properties, The Journal of Antibiotics, May, 1989, vol. XLII, No. 5, pp. 647-653.
Primary Examiner:	Rotman; Alan L.
Attorney, Agent or Firm:	Anand; Mona, Brainard; Thomas D.
Claims:	1. A method of controlling ras-gene dependent tumor development in a patient in need of such treatment, comprising administering to the patient a therapeutically effective amount of a compound having the formula ##STR5## or a pharmaceutically acceptable salt, ester, amide or pro-drug thereof, wherein R is selected from the group consisting of ##STR6## 2. A method of causing reversion of transformed, ras-gene dependent tumor-type cells to cells having normal morphology, comprising exposing the ras-gene dependent tumor-type cells to a compound having the formula ##STR7## or a pharmaceutically acceptable salt, ester, amide or pro-drug thereof, wherein R is selected from the group consisting of ##STR8## in a concentration sufficient to produce the desired reversion. 3. A method according to claim 1 wherein R is ##STR9## 4. A method according to claim 1 wherein R is ##STR10## 5. A method according to claim 2 wherein R is ##STR11## 6. A method according to claim 2 wherein R is ##STR12##

Table 2: Patents citing # 5175183, "Lipoxygenase inhibiting compounds".

	Patent	Patent Title
1	6541647	Methods of synthesis of substituted tetrahydrofuran compound
2	6420392	Compounds and methods for the treatment of cardiovascular, inflammatory and immune disorders
3	6403814	Method for synthesizing diaryl-substituted heterocyclic compounds, including tetrahydrofurans
4	6310221	Methods for synthesis of substituted tetrahydrofuran compound
5	6306895	Substituted oxygen alicyclic compounds, including methods for synthesis thereof
6	6294574	Compounds and methods for the treatment of inflammatory and immune disorders
7	6255498	Method for synthesizing diaryl-substituted heterocyclic compounds, including tetrahydrofurans
8	6080874	Synthesis and isolation of N-(aryl or heteroaryl)-alkyl-N-hydroxyurea
9	6025384	Compounds and methods for the treatment of cardiovascular, inflammatory and immune disorders
10	6011066	Method for treating septic shock
11	5968980	1,3-dialkylurea derivative
12	5856323	Compounds and methods for the treatment of disorders mediated by platelet activating factor
13	5792776	Compounds and methods for the treatment of cardiovascular, inflammatory and immune disorders
14	5780503	Compounds and methods for the treatment of cardiovascular, inflammatory and immune disorders
15	5750565	Compounds and methods for the treatment of cardiovascular, inflammatory and immune disorders
16	5741809	Compounds and methods for the treatment of cardiovascular inflammatory and immune disorders
17	5703093	Compounds and methods for the treatment of cardiovascular, inflammatory and immune disorders
18	5681966	Compounds and methods for the treatment of cardiovascular, inflammatory and immune disorders
19	5639782	Neolignan derivatives as platelet activating factor receptor antagonists and 5-lipoxygenase inhibitors

Illustration 2: USPTO's standard definition of patent class 424 and 514, DRUG, BIO-AFFECTING AND BODY TREATING COMPOSITIONS

STATEMENT OF CLASS SUBJECT MATTER

Class 424 includes the following subject matter, not provided for elsewhere, when a utility set forth below is either (a) claimed or (b) solely disclosed.

Class 514 is considered to be an integral part of Class 424. This Class retains all pertinent definitions and class lines of Class 424.)

A. DRUG AND BIO-AFFECTING COMPOSITIONS which are generally capable of:

1. Preventing, alleviating, treating, or curing abnormal and pathological conditions of the living body by such means as: (a) destroying a parasitic organism; (b) limiting the affect of the disease or abnormality by chemically altering the physiology of the host or parasite.

2. Maintaining, increasing, decreasing, limiting, or destroying a physiologic body function; e.g., vitamin compositions, sex sterilants, fertility inhibitors, growth promotors, etc.

3. Diagnosing a physiological condition or state by an in vivo test; e.g., X-ray contrast, etc.

4. Controlling or protecting an environment or living body by attracting, disabling, inhibiting, killing, modifying, repelling or retarding an animal or micro-organism. For example: (a) Nonfood baits, attractants, and lures; (b) Biocides including antibiotics of undetermined structure; (c) Warfare gases such as lachrymators, sternutators, etc.; (d) Chemical pest repellents and adhesive trapping agents.

B. BODY TREATING COMPOSITIONS generally intended for deodorizing, protecting, adorning, or grooming a body; e.g., cosmetics, dentifrices, embalming fluids, etc.

C. FERMENTATES (e.g., antibiotics, etc.), PLANT AND ANIMAL EXTRACTS, OR BODY FLUIDS OR MATERIAL CONTAINING PLANT OR ANIMAL CELLULAR STRUCTURE, PER SE, intended to be used for the purposes set forth in A and B above, and whose chemical structure is not sufficiently known to be classified elsewhere.

D. COMPOSITIONS OF THIS CLASS DEFINED IN TERMS OF SPECIFIC STRUCTURE; E.G., LAYERED TABLET, CAPSULE, ETC.

The lines generally prevailing between the composition classes and the article classes are applicable to Class 424, unless otherwise indicated, with the exception that Class 424 provides for a composition, per se, defined in terms of specific structure having a utility for Class 424 (see subclasses 400+).

E. PROCESSES OF USING the subject matter of the Class Definition, A through C above, and in Lines With Other Classes or Within This Class, Compositions Of This Class Defined In Terms Of Specific Structure; e.g., Layered Tablet, Capsule, Etc., A, above, or compounds, per se, for the purposes set forth in A and B of the Class Definition (See References to Other Classes, below, for those classes that that concern "processes." Note particularly the Search Notes for Use Processes involving Class 424 subject matter classified elsewhere.)

F. PROCESSES OF PREPARING subject matter of the Class Definition, A through C, and of Lines With Other Classes and Within This Class, Compositions Of This Class Defined In Terms Of Specific Structure; e.g., Layered Tablet, Capsule, Etc., part A.

G. ADJUVANT OR CARRIER COMPOSITIONS, PER SE, for perfecting compositions for this class.

(1) Note. This class is the generic home for compositions for treating a living body and for controlling a pest.

(2) Note. The terms "mere use" or "mere application" as employed in the definitions of Class 424 and the search notes in other classes which refer to Class 424 are defined to encompass only a single step process and include expressions such as applying, contacting, dipping, spraying, injecting, combusting, administering orally, etc., recited either along or with recitations such as dosage amount or the treatment of a specific environment, organism, or body part. Examples of expressions considered mere use or mere application are "injecting 3 cc. of compound x into a vein" and "burning 20 grams of a sulfur fumigant in a room".

Illustration 3: A sample article report on an alliance announcement between Ligand and Allergan (from Recap Database)

LIGAND AND ALLERGAN SIGN JOINT VENTURE AGREEMENT TO RESEARCH, DEVELOP AND COMMERCIALIZE RETINOID-BASED COMPOUNDS

SAN DIEGO --July 1, 1992-- Ligand Pharmaceuticals Inc. and Allergan Inc. (NYSE:AGN) have formed a joint venture designed to research, develop and commercialize pharmaceutical products based on retinoid technology.

All research, development and commercialization costs of the joint venture will be shared equally, as will any earnings from retinoid products developed by the joint venture. Ligand will have principal responsibility for marketing cancer products in North America, while Allergan will have worldwide responsibility for products in the areas of dermatology and ophthalmology, as well as responsibility for marketing cancer products in the rest of the world.

The joint venture brings together Ligand's strength in hormone-activated intracellular receptor technology and Allergan's expertise in discovering and developing retinoinds for topical use. Intracellular receptors are members of a family of hormone-activated proteins that act inside the cell to directly regulate gene expression. The combined medicinal chemistry resources of both companies, including discovered or patented retinoid compounds, will be applied to the joint venture.

Under terms of the joint agreement, research will be conducted concurrently at Ligand's laboratories in San Diego and Allergan's facilities in Irvine, utilizing the strengths of each company. Additionally, Allergan President and Chief Executive Officer William C. Shepherd has accepted Ligand's invitation to join its board of directors.

Allergan, which began its medicinal chemistry program in 1984, owns more than 400 patented retinoid compounds. Allergan is currently conducting human clinical trials on AGN190168, which are in Phase III for treatment for acne. In advanced Phase II studies for the topical treatment of psoriasis, AGN190168 has shown promising early results. AGN190168 for these indications is not included in the joint venture. The joint venture only has the rights to develop AGN190168 for systematic uses for skin cancers and in non-eye and skin care applications.

Allergan Inc., headquartered in Irvine, Calif., is a global provider of specialty therapeutic products; is expanding beyond skin care and its leadership position in eye care into adjacent markets; and is pursuing other core technologies.

Ligand Pharmaceuticals, founded in 1987, is a privately held company which is a leader in the area of intercellular receptor technology. Combining modern molecular biology with traditional drug discovery, Ligand's programs are directed at the discovery and development of non-peptide small molecule dwgs for the treatment of human disease.

Table 3: US to IPC concordance for class 424 and 514, "DRUG, BIO-AFFECTING AND BODY TREATING COMPOSITIONS"

US Class 424 to IPC Concordance			US Class 514 to IPC Concordance		
U.S. Subclass	IPC Subclass	IPC Group	U.S. Subclass	IPC Subclass	IPC7 Group
1.11 - 1.89	A 61 K	51 / 00	1	A 01 N	61 / 00
1.11 - 1.89	A 61 M	36 / 14	1	A 61 K	31 / 00
9.1 - 9.2	A 61 K	49 / 00	2	A 01 N	37 / 18
9.3	A 61 B	5 / 055	2	A 61 K	38 / 00
9.31	A 61 K	49 / 00	3 , 4	A 61 K	38 / 28
9.32	A 61 B	5 / 055	5	A 61 K	38 / 00
9.321 - 9.323	A 61 B	5 / 055	6 - 8	A 61 K	38 / 16
9.33	A 61 K	49 / 00	9 - 21	A 61 K	38 / 00
9.34 - 9.341	A 61 B	5 / 055	22	A 61 K	31 / 70
9.35 - 9.351	A 61 B	5 / 055	23 - 25	A 01 N	43 / 04
9.36	A 61 B	5 / 055	23 - 25	A 61 K	31 / 70
9.361 - 9.365	A 61 B	5 / 055	26	A 01 N	45 / 00
9.37	A 61 B	5 / 055	27 - 52	A 01 N	43 / 04
9.4 , 9.41	A 61 K	49 / 04	27 - 52	A 61 K	31 / 70
9.411	A 61 K	49 / 04	53 , 54	A 01 N	43 / 04
9.42 - 9.45	A 61 K	49 / 04	53 , 54	A 61 K	31 / 715
9.451 - 9.455	A 61 K	49 / 04	55	A 01 N	43 / 04
9.5	A 61 B	8 / 00	56	A 61 K	31 / 727
9.51	A 61 B	8 / 00	57 - 61	A 01 N	43 / 04
9.52	A 61 B	8 / 00	57 - 61	A 61 K	31 / 715
9.6 - 9.8	A 61 B	10 / 00	62	A 01 N	43 / 04
9.6 - 9.8	A 61 B	5 / 00	62	A 61 K	31 / 70
9.6 - 9.8	A 61 B	8 / 00	63	A 01 N	55 / 00
9.81	A 61 B	8 / 00	63	A 61 K	31 / 695
10.1	A 61 K	49 / 00	64	A 01 N	55 / 08
10.2	A 61 K	9 / 44	64	A 61 K	31 / 69
10.3	A 61 K	49 / 00	65 - 74	A 01 N	65 / 00
10.31	A 61 K	49 / 00	75	A 01 N	57 / 00
10.32	A 61 K	49 / 00	75	A 61 K	31 / 66
10.4	A 61 K	49 / 00	76 - 78	A 01 N	57 / 26
40	A 01 N	25 / 06	76 - 78	A 61 K	31 / 685
40	A 01 N	25 / 18	79 - 94	A 01 N	57 / 00
40	A 01 N	25 / 20	79 - 94	A 61 K	31 / 675
40	A 61 K	9 / 72	95 - 98	A 01 N	57 / 00
40	A 61 L	9 / 02	95 - 98	A 61 K	31 / 67

41 , 42	A 01 N	25 / 18	**99 - 101**	A 01 N	57 / 00
41 , 42	A 01 N	25 / 20	**99 - 101**	A 61 K	31 / 665
41 , 42	A 61 L	9 / 02	**102 - 108**	A 01 N	57 / 00
43	A 01 N	25 / 02	**102 - 108**	A 61 K	31 / 66
43	A 61 K	9 / 00	**109**	A 01 N	57 / 10
43	A 61 L	9 / 04	**109**	A 61 K	31 / 66
44 , 45	A 61 L	9 / 04	**110 , 111**	A 01 N	57 / 36
46	A 61 K	9 / 14	**110 , 111**	A 61 K	31 / 66
46	A 61 L	9 / 04	**112 - 136**	A 01 N	57 / 00
47	A 61 K	7 / 00	**112 - 136**	A 61 K	31 / 66
47	A 61 K	9 / 00	**137 , 138**	A 01 N	57 / 26
48	A 61 K	9 / 68	**137 , 138**	A 61 K	31 / 66
49	A 61 K	7 / 16	**139**	A 01 N	57 / 34
50	A 61 K	7 / 28	**139**	A 61 K	31 / 66
51	A 61 K	7 / 16	**140 - 142**	A 01 N	57 / 18
52	A 61 K	7 / 18	**140 - 142**	A 61 K	31 / 66
53	A 61 K	7 / 20	**143 - 148**	A 01 N	57 / 10
54	A 61 K	7 / 22	**143 - 148**	A 61 K	31 / 66
55	A 61 K	7 / 24	**149**	A 01 N	51 / 00
56 , 57	A 61 K	7 / 16	**149**	A 61 K	31 / 655
58	A 61 K	7 / 26	**150 , 151**	A 01 N	33 / 26
59	A 61 K	7 / 42	**150 , 151**	A 61 K	31 / 655
60	A 61 K	7 / 44	**152 - 154**	A 01 N	37 / 18
61	A 61 K	7 / 04	**152 - 154**	A 61 K	31 / 65
62	A 61 K	7 / 135	**155**	A 01 N	51 / 00
63	A 61 K	7 / 021	**155**	A 61 K	31 / 63
64	A 61 K	7 / 025	**156 - 158**	A 01 N	51 / 00
65	A 61 K	7 / 32	**156 - 158**	A 61 K	31 / 655
66	A 61 K	7 / 34	**159 , 160**	A 01 N	37 / 36
67	A 61 K	7 / 36	**159 , 160**	A 61 K	31 / 60
68	A 61 K	7 / 38	**161**	A 01 N	43 / 00
69	A 61 K	7 / 035	**162**	A 01 N	37 / 36
70.1	A 61 K	7 / 06	**163**	A 01 N	37 / 36
70.11 - 70.17	A 61 K	7 / 06	**164**	A 01 N	37 / 36
70.11 - 70.17	A 61 K	7 / 11	**165**	A 01 N	37 / 36
70.19	A 61 K	7 / 075	**165**	A 61 K	31 / 60
70.19	A 61 K	7 / 08	**166**	A 01 N	37 / 36
70.2	A 61 K	7 / 09	**167**	A 01 N	45 / 00
70.21 - 70.31	A 61 K	7 / 075	**167**	A 61 K	31 / 59
70.21 - 70.31	A 61 K	7 / 08	**168**	A 01 N	45 / 00
70.4 - 70.51	A 61 K	7 / 09	**169 - 171**	A 01 N	45 / 00
70.6 - 70.9	A 61 K	7 / 06	**169 - 171**	A 61 K	31 / 56

Table 4: A sample of firms' new patent distribution along various patent subclasses in 1990.

	Abbott	**Access**	**Alkermes**	**Allergan**	**Alza**	**Alpharma**	**AHP**	**Amylin**	**Atrix**	**…**
A01N 025/02	1	0	0	0	0	0	0	0	0	…
A01N 025/26	0	0	0	0	0	0	0	0	0	…
A01N 025/30	0	0	0	0	0	0	0	0	0	…
A01N 037/10	1	0	0	0	0	0	0	0	0	…
A01N 037/18	0	0	0	0	0	0	0	0	0	…
A01N 043/38	0	0	0	0	0	0	0	0	0	…
A01N 043/40	0	0	0	0	0	0	0	0	0	…
A01N 043/56	0	0	0	0	0	0	0	0	0	…
A01N 045/00	0	0	0	0	0	0	0	0	0	…
A23K 001/18	0	0	0	0	1	0	0	0	0	…
A61D 007/00	0	0	0	0	0	0	1	0	0	…
A61F 013/00	0	0	0	0	0	0	0	0	0	…
A61F 013/02	0	0	0	0	2	0	0	0	0	…
A61K 004/22	0	0	0	0	1	0	0	0	0	…
…	…	…	…	…	…	…	…	…	…	…

Table 5: A sample of technology distance among firms based on new patent distribution in 1990.

		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**…**
1	**ABBOTT**	0.000	0.935	0.089	0.232	0.243	0.089	0.126	0.089	0.089	0.089	…
2	**ACCESS**	0.935	0.000	1.000	1.143	1.159	1.000	1.054	1.000	1.000	1.000	…
3	**ALKERMES**	0.089	1.000	0.000	0.143	0.159	0.000	0.054	0.000	0.000	0.000	…
4	**ALLERGAN**	0.232	1.143	0.143	0.000	0.302	0.143	0.176	0.143	0.143	0.143	…
5	**ALZA**	0.243	1.159	0.159	0.302	0.000	0.159	0.195	0.159	0.159	0.159	…
6	**ALPHARMA**	0.089	1.000	0.000	0.143	0.159	0.000	0.054	0.000	0.000	0.000	…
7	**AMERICAN HOME PRODUCTS**	0.126	1.054	0.054	0.176	0.195	0.054	0.000	0.054	0.054	0.054	…
8	**AMYLIN**	0.089	1.000	0.000	0.143	0.159	0.000	0.054	0.000	0.000	0.000	…
9	**ATRIX**	0.089	1.000	0.000	0.143	0.159	0.000	0.054	0.000	0.000	0.000	…
10	**AVANIR**	0.089	1.000	0.000	0.143	0.159	0.000	0.054	0.000	0.000	0.000	…
…	**…**	…	…	…	…	…	…	…	…	…	…	…

Table 6: Mean, standard deviation and correlations

		Mean	S.D.	1	2	3	4	5	6	7	8	9	10	11	12
1	Innovation rate	13.22	26.30												
2	Innovation value	318.60	705.65	0.75											
3	Degree centrality	4.83	3.98	0.61	0.36										
4	Structural hole	0.93	0.12	0.09	0.10	0.08									
5	Partner patent stock	42.43	35.17	-0.34	-0.31	-0.32	-0.25								
6	Technology distance to partners	0.03	0.01	-0.47	-0.38	-0.65	0.07	0.23							
7	Technology distance among partners	0.01	0.03	0.58	0.42	0.75	0.25	0.33	0.62						
8	Technology scope	0.69	0.85	0.56	0.46	0.43	0.02	-0.28	-0.59	0.38					
9	Alliance tenure	2.29	1.75	0.19	0.15	0.19	-0.23	-0.02	-0.28	0.47	0.17				
10	Firm age	14.35	12.96	0.55	0.51	0.44	-0.01	-0.25	-0.43	0.25	0.47	0.37			
11	Sales	310.35	548.24	0.65	0.50	0.61	0.13	-0.31	-0.55	0.51	0.71	0.19	0.61		
12	Own patent stock	53.40	123.43	0.77	0.75	0.59	0.05	-0.32	-0.62	0.58	0.73	0.24	0.62	0.73	
13	Patent tenure	1.48	1.72	0.31	0.37	0.37	0.30	0.22	0.52	0.31	0.51	0.36	0.33	0.27	0.35

Table 7: Network positions and innovation rate (Fixed effects negative binomial)

Variables	Model 1	Model 2	Model 3	Model 4	Model 5
Degree centrality		-0.064* (0.032)		-0.058* (0.033)	0.127 (0.097)
(Degree centrality) ^{2}		0.003** (0.001)		0.003** (0.001)	0.003** (0.001)
Structural hole			-1.046 (0.952)	-0.465 (0.988)	-4.02** (2.05)
(Structural hole) ^{2}			0.822 (0.886)	0.312 (0.915)	2.976** (1.631)
Degree centrality * Structural hole					-0.456** (0.225)
Partner patent stock	0.0006** (0.0003)	0.0006** (0.0004)	0.0007** (0.0003)	0.0006** (0.0003)	0.0005 (0.0004)
Technology distance to partners	2.431*** (1.141)	3.358*** (1.244)	2.805** (1.201)	3.569*** (1.293)	4.001*** (1.309)
Technology distance among partners	-0.895 (1.109)	-1.849 (1.316)	-1.262 (1.159)	-2.016 (1.344)	-1.984 (1.328)
Technology scope	0.129 (0.156)	0.188 (0.160)	0.146 (0.157)	0.194 (0.160)	0.231 (0.162)
Firm age	0.038 (0.236)	0.049** (0.024)	0.041* (0.024)	0.049** (0.024)	0.043* (0.025
(Firm age) ^{2}	0.001 (0.001)	0.0001 (0.0005)	0.0004 (0.0005)	0.0001 (0.0005)	0.0003 (0.0006)
Alliance tenure	-0.009 (0.076)	-0.005 (0.076)	0.041 (0.088)	0.030 (0.088)	0.033 (0.088)
(Alliance tenure) ^{2}	-0.003 (0.007)	-0.005 (0.008)	-0.008 (0.008)	-0.008 (0.009)	-0.009 (0.008)

Table 7: Network positions and innovation rate (Fixed effects negative binomial)

Variables	Model 1	Model 2	Model 3	Model 4	Model 5
Sales	0.00003*** (0.00001)	0.00005*** (0.00001)	0.00003** (0.00002)	0.00004*** (0.00001)	0.00004*** (0.00001)
Own patent stock	-0.0006*** (0.0002)	-0.0007** (0.0002)	-0.0006** (0.0002)	-0.0007*** (0.0003)	-0.0007*** (0.0002)
Patent tenure	0.075 (0.051)	0.092* (0.051)	0.071 (0.051)	0.088* (0.051)	0.082 (0.052)
Year 94	0.256** (0.105)	0.286*** (0.105)	0.258*** (0.105)	0.284*** (0.105)	0.301*** (0.106)
Year 95	0.721*** (0.104)	0.744*** (0.104)	0.729*** (0.105)	0.744*** (0.105)	0.755*** (0.105)
Year 96	0.064 (0.123)	0.109 (0.125)	0.068 (1.123)	0.106 (0.126)	0.128 (0.125)
Year 97	0.329** (0.127)	0.363** (0.131)	0.334** (0.126)	0.329** (0.127)	0.391** (0.133)
Year 98	0.179 (0.149)	0.218 (0.154)	0.190 (0.150)	0.217 (0.155)	0.246 (0.156)
Year 99	0.197 (0.170)	0.229 (0.175)	0.208 (0.171)	0.228 (0.175)	0.266 (0.177)
Constant	0.047 (0.190)	0.007 (0.192)	0.107 (0.201)	0.057 (0.204)	0.603* (0.340)
Chi-square	218.04***	219.10***	221.02***	220.83***	229.47***

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Table 8: Network positions and innovation value (Fixed effects negative binomial)

Variables	Model 6	Model 7	Model 8	Model 9	Model 10
Degree centrality		-0.073** (0.024)		-0.075*** (0.025)	-0.204*** (0.071)
(Degree centrality) ^{2}		0.003*** (0.001)		0.003*** (0.001)	0.003*** (0.001)
Structural hole			-0.175 (0.032)	0.215 (0.542)	2.365** (1.200)
(Structural hole) ^{2}			0.270 (0.496)	-0.079 (0.498)	-1.611* (0.906)
Degree centrality * Structural hole					0.318** (0.160)
Partner patent stock	0.0003 (0.0002)	0.0003 (0.0002)	0.0004* (0.0002)	0.0004* (0.0002)	0.0005** (0.0002)
Technology distance to partners	5.084*** (0.680)	5.848*** (0.732)	4.899*** (0.707)	5.610*** (0.751)	5.547*** (0.748)
Technology distance among partners	-0.719 (0.564)	-1.399* (0.744)	-0.666 (0.564)	-1.304* (0.739)	-1.306* (0.732)
Technology scope	0.989*** (0.091)	1.016*** (0.092)	0.983*** (0.092)	1.003*** (0.093)	0.994*** (0.092)
Firm age	0.045*** (0.023)	0.041** (0.020)	0.047*** (0.022)	0.042** (0.021)	0.046** (0.020)
(Firm age) ^{2}	-0.001** (0.0006)	-0.0007 (0.0005)	-0.001** (0.0006)	-0.0008** (0.0005)	-0.0009* (0.0005)
Alliance tenure	0.030 (0.046)	0.029 (0.045)	0.007 (0.052)	-0.001 (0.051)	-0.002 (0.050)
(Alliance tenure) ^{2}	0.002 (0.004)	0.0005 (0.004)	0.004 (0.005)	0.003 (0.004)	0.004 (0.005)

Table 8: Network positions and innovation value (Fixed effects negative binomial)

Variables	Model 6	Model 7	Model 8	Model 9	Model 10
Sales	0.00003** (0.00001)	0.00003** (0.00001)	0.00003** (0.00001)	0.00003** (0.00001)	0.00004*** (0.00001)
Own patent stock	-0.0001 (0.0002)	-0.0001 (0.0002)	-0.0001 (0.0002)	-0.0001 (0.0002)	-0.0001 (0.0002)
Patent tenure	0.036 (0.029)	0.041 (0.030)	0.039 (0.029)	0.045 (0.030)	0.047 (0.030)
New patents applied	0.0006 (0.0009)	0.00009 (0.00009)	0.0007 (0.0009)	0.0001 (0.0009)	0.0005 (0.001)
Year 94	-0.337** (0.117)	0.229*** (0.072)	-0.348** (0.118)	-0.449** (0.123)	-0.425** (0.123)
Year 95	0.148 (0.099)	0.332*** (0.077)	-0.158 (0.101)	0.219** (0.104)	-0.209** (0.103)
Year 96	-0.053 (0.089)	0.388 (0.085)	-0.061 (0.089)	-0.116 (0.093)	-0.113 (0.092)
Year 97	0.016 (0.069)	0.523*** (0.099)	0.02 (0.07)	0.056 (0.072)	-0.056 (0.071)
Year 98	0.102* (0.062)	0.517*** (0.109)	0.099* (0.062)	0.077 (0.062)	0.076 (0.061)
Year 99	0.089* (0.052)	0.444*** (0.123)	0.089* (0.051)	0.072* (0.051)	0.066 (0.051)
Constant	1.010*** (0.254)	0.689*** (0.185)	0.985*** (0.259)	1.096*** (0.259)	0.710** (0.321)
Chi-square	623.74***	625.54***	625.75***	627.24***	623.74***

*p < 0.1, ** p < 0.05, *** p < 0.01

Table 9: Network positions and innovation rate (Fixed effects, 68 firms)

Variables	Model 11	Model 12	Model 13	Model 14	Model 15
Degree centrality		-0.032 (0.038)		-0.031 (0.038)	0.220** (0.108)
(Degree centrality) ^{2}		0.002 (0.002)		0.002 (0.002)	0.002 (0.002)
Structural hole			-1.068 (1.363)	-0.889 (1.368)	-5.341* (2.323)
(Structural hole) ^{2}			0.848 (1.234)	0.693 (1.241)	3.931* (1.864)
Degree centrality * Structural hole					-0.619*** (0.252)
Partner patent stock	0.0005 (0.0004)	0.0004 (0.0005)	0.0006 (0.0005)	0.0005 (0.0005)	-0.00001 (0.0006)
Technology distance to partners	1.976 (1.567)	2.517 (1.653)	2.169 (1.596)	2.683 (1.682)	3.322** (1.701)
Technology distance among partners	-1.091 (1.307)	-1.773 (1.426)	-1.240 (1.351)	-1.888 (1.463)	-2.332 (1.483)
Technology scope	-0.070 (0.221)	-0.053 (0.226)	-0.068 (0.2223)	-0.050 (0.228)	0.028 (0.229)
Firm age	0.073** (0.031)	0.079** (0.032)	0.074** (0.031)	0.079** (0.032)	0.076** (0.032)
(Firm age) ^{2}	-0.00005 (0.0006)	-0.0003 (0.0007)	-0.0001 (0.0006)	-0.0003 (0.0006)	-0.00007 (0.0006)
Alliance tenure	0.046 (0.126)	0.035 (0.126)	0.087 (0.137)	0.072 (0.138)	0.052 (0.139)
(Alliance tenure) ^{2}	-0.006 (0.012)	-0.006 (0.013)	-0.011 (0.014)	-0.011 (0.014)	-0.010 (0.014)

Table 9: Network positions and innovation rate (Fixed effects, 68 firms)

Variables	Model 11	Model 12	Model 13	Model 14	Model 15
Sales	0.00004** (0.00002)	0.00005** (0.00002)	0.00004** (0.00002)	0.00005** (0.00002)	0.00004* (0.00003)
Own patent stock	-0.0004 (0.0003)	-0.0006** (0.0003)	-0.0005** (0.0002)	-0.0006** (0.0003)	-0.0005* (0.0003)
Patent tenure	0.009 (0.067)	0.025 (0.068)	0.005 (0.067)	0.021 (0.068)	0.009 (0.069)
Year 94	0.233** (0.121)	0.267** (0.125)	0.241** (0.121)	0.272** (0.125)	0.294** (0.123)
Year 95	0.616*** (0.122)	0.646*** (0.128)	0.633*** (0.126)	0.657*** (0.129)	0.684*** (0.129)
Year 96	-0.042 (0.147)	0.009 (0.158)	-0.026 (0.149)	0.021 (0.159)	0.070 (0.161)
Year 97	0.202 (0.159)	0.229 (0.178)	0.222 (0.163)	0.247 (0.181)	0.293 (0.182)
Year 98	0.031 (0.189)	0.059 (0.209)	0.062 (0.195)	0.086 (0.214)	0.135 (0.218)
Year 99	-0.059 (0.219)	-0.017 (0.241)	-0.019 (0.227)	0.016 (0.247)	0.088 (0.253)
Constant	-0.043 (0.341)	-0.033 (0.349)	0.081 (0.380)	0.083 (0.391)	0.872* (0.509)
Chi-square	156.75***	154.49***	155.76***	154.08***	169.04***

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

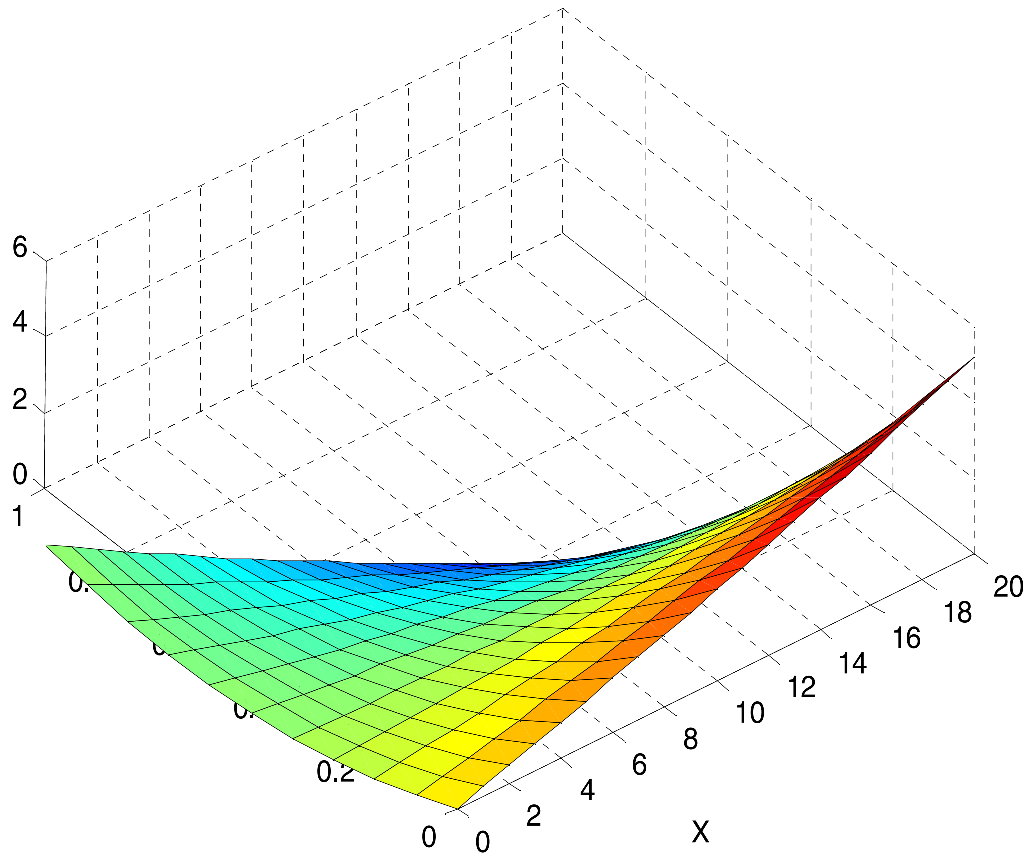
Table 10: Network positions and innovation value (Fixed effects, 68 firms)

Variables	Model 16	Model 17	Model 18	Model 19	Model 20
Degree centrality		-0.052** (0.020)		-0.051** (0.021)	-0.145** (0.057)
(Degree centrality) ^{2}		0.002** (0.001)		0.002** (0.001)	0.002** (0.001)
Structural hole			-0.370 (0.601)	-0.084 (0.608)	1.538 (1.095)
(Structural hole) ^{2}			0.488 (0.548)	0.238 (0.553)	-0.932 (0.854)
Degree centrality * Structural hole					0.228* (0.129)
Partner patent stock	0.0001 (0.0002)	0.00001 (0.0002)	0.0001 (0.0002)	0.00003 (0.0002)	0.0002 (0.0002)
Technology distance to partners	3.043*** (0.768)	3.310*** (0.779)	2.926*** (0.733)	3.150*** (0.781)	3.007*** (0.784)
Technology distance among partners	0.144 (0.454)	-0.076 (0.551)	0.219 (0.453)	0.006 (0.043)	0.127 (0.546)
Technology scope	0.709*** (0.109)	0.699*** (0.112)	0.696*** (0.109)	0.687*** (0.111)	0.667*** (0.112)
Firm age	0.096*** (0.019)	0.102*** (0.019)	0.099*** (0.019)	0.105*** (0.019)	0.106*** (0.019)
(Firm age) ^{2}	-0.0007** (0.0003)	-0.0007** (0.0003)	-0.0008** (0.0003)	-0.0008** (0.0004)	-0.0009** (0.0004)
Alliance tenure	0.061 (0.056)	0.035 (0.055)	0.019 (0.066)	-0.014 (0.066)	0.014 (0.065)
(Alliance tenure) ^{2}	-0.004 (0.005)	-0.004 (0.005)	-0.0004 (0.006)	0.0007 (0.0006)	0.0009 (0.007)

Table 10: Network positions and innovation value (Fixed effects, 68 firms)

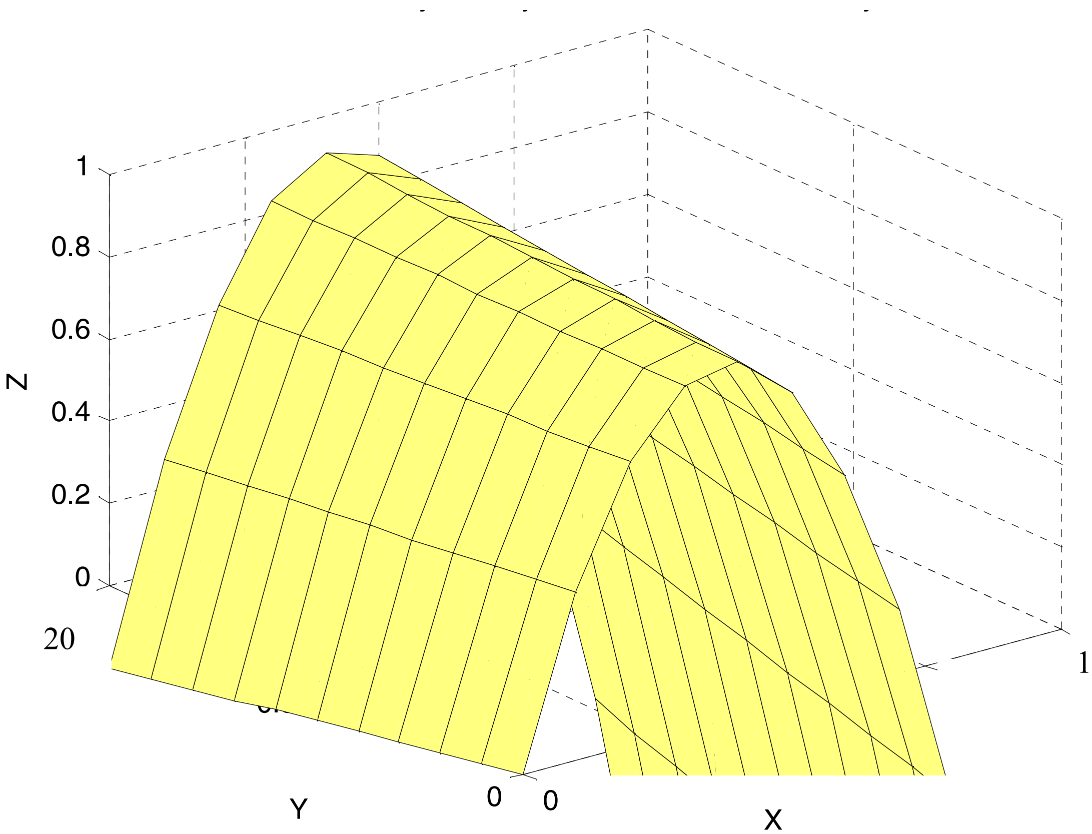
Variables	Model 16	Model 17	Model 18	Model 19	Model 20
Sales	-0.00001 (0.00001)	0.00001 (0.00001)	0.0001 (0.00001)	0.00001 (0.00001)	0.00001 (0.00001)
Own patent stock	0.0002* (0.0001)	0.0001 (0.0001)	0.0001 (0.0001)	0.0001 (0.0001)	0.0001 (0.0001)
Patent tenure	-0.078** (0.033)	-0.067* (0.035)	-0.075* (0.034)	-0.064* (0.036)	-0.057 (0.036)
New patents applied	0.0002 (0.0006)	0.0003 (0.0006)	0.0002 (0.0006)	0.0004 (0.0006)	0.0007 (0.0006)
Year 94	0.205*** (0.058)	0.242*** (0.059)	0.216*** (0.058)	0.252*** (0.059)	0.239*** (0.059)
Year 95	0.315*** (0.071)	0.352*** (0.071)	0.327*** (0.071)	0.366*** (0.071)	0.342*** (0.072)
Year 96	0.369*** (0.071)	0.440*** (0.075)	0.386*** (0.072)	0.455*** (0.075)	0.434*** (0.076)
Year 97	0.416*** (0.081)	0.503*** (0.087)	0.433*** (0.082)	0.517*** (0.088)	0.495*** (0.089)
Year 98	0.359*** (0.095)	0.456*** (0.102)	0.381*** (0.096)	0.474*** (0.102)	0.450*** (0.103)
Year 99	0.325*** (0.105)	0.437*** (0.114)	0.355*** (0.107)	0.461*** (0.116)	0.433*** (0.116)
Constant	0.893*** (0.209)	0.936*** (0.210)	0.847*** (0.212)	0.888 (0.214)	0.618** (0.267)
Chi-square	605.43***	617.09***	609.42***	614.96***	622.14***

*p < 0.1, ** p < 0.05, *** p < 0.01



Z- innovation rate; x-centrality; y-efficiency

Figure 3: Network Connections and Innovation Rate.



Z- innovation value; x-efficiency ; y- centrality

Figure 4: Network Connections and Innovation Value

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