DYNAMIC CHANGES TO INTER-ORGANIZATION COLLABORATION NETWORKS AND KNOWLEDGE CREATION: EVIDENCE FROM DRUG DEVELOPMENT

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June 2007

The study was funded by the Center for Innovation Management Studies (CIMS) at North Carolina State University.

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ABSTRACT

While theory has long suggested that the configuration of inter-organization collaboration networks and knowledge creation change over time, this assertion has remained largely unsubstantiated empirically. To this end, we explore the dynamic changes to organization ego network structure and knowledge creation. Two key questions guide our study: how do collaboration networks and knowledge creation change over time and what affects the changes. Our analysis provides empirical evidence that changes to the configurations of collaboration networks and knowledge are systematic. Importantly, our findings indicate that networks of organizations creating valuable drugs change differently from organizations creating less valuable drugs. Our study focuses on pharmaceutical firms, but has implications for other settings as well.

1. INTRODUCTION

Traditionally, strategic management researchers have examined the interplay between the external environment (Porter 1985) and the internal resources of the organization (Barney 1991; Penrose 1959; Wernerfelt 1984) to identify key factors to a sustainable competitive advantage. Increasingly, knowledge and knowledge creating resources have received focus as critical to obtaining competitive advantage (Spender and Grant 1996). Evidence exists that organizations that continuously create, utilize, and disseminate new knowledge in the form of new innovations outperform those which do not possess these capabilities (D'Aveni and Gunther 1994). Because knowledge is a crucial component to the innovation process, those that are capable of continuously producing new knowledge are better positioned to achieve a competitive advantage. In order to compete, organizations must acquire, retain, and integrate knowledge, and be able to facilitate the creation of knowledge (Nonaka and Ichijo 1997).

Strategy researchers have begun to question the traditional models of knowledge creation. Rather than focusing primarily on the internal resources of the organization, the key to creating new knowledge may lie in establishing and maintaining strategically important networks of alliances with external partners (see for example: Ahuja 2000; Gulati 1995; Gulati et al. 2000; Powell 1998; Walker et al. 1997). Herein, organizations must learn how to create new knowledge by managing knowledge and other essential assets that they do not own (Iansiti and Levien 2004). Hence, greater understanding of knowing *when*, *with whom*, and *how* to partner is critical as collaboration networks are considered key factors in understanding the knowledge creation process (Nahapiet and Ghoshal 1998).

We define inter-organization collaboration networks as the set of alliances or inter-organization collaborative arrangements that are established for the purpose of innovative activities. Collaborative arrangements or alliances have been increasing steadily, not only in numbers but also in importance. Indeed, in many industries, to remain competitive, forming an alliance is no longer an option, but a necessity (Parise and Henderson 2001). Further, some companies have reported that on average 35% of their stock market value depends on cooperative arrangements (deMan 2002). Yet, strong evidence exists that over 50% of alliances under-perform (Parise and Henderson 2001). Greater understanding of factors that lead to successful alliances is imperative.

We define knowledge creation as the process of generating knowledge that represents a new contribution to an existing body of knowledge (Arrow 1962). Extant theory explains how knowledge is created when diverse and redundant knowledge is combined and exchanged. The combination and exchange process, coupled with any new knowledge creations, alters the collective knowledge base of the organization and therefore impacts the knowledge resources needed for subsequent knowledge creating activities (Cohen and Levinthal 1990). When engaging in knowledge creation activities, evidence exists that organizations will seek new collaboration partners as the disparity increases between knowledge needs and knowledge resources available through the exchange network (Bouty 2000).

The purpose of our study is to examine changes to inter-organization collaboration networks over time as organizations establish and maintain exchange partnerships to obtain and develop resources when creating new knowledge. Although theory has long suggested that network change will occur (Boissevain 1974), and that knowledge creation is both an important antecedent to and outcome of network change (Nahapiet and Ghoshal 1998), little research has

empirically examined the dynamics of collaborative networks. We draw upon teleological process theory (Van de Ven 1992), which has been used extensively in examining management processes (see for example deRond and Bouchikhi 2004; Feldman 2000; Lee and Cole 2003 Merton 1968; March and Olsen 1976; Repenning 2002; Weick 1979). Teleological process theory assumes that the entity being studied is adaptive, has an intended purpose and an end state, but no prescribed path to that end state (Van de Ven 1992). For the purposes of our study, we examine how organizations adapt the structure of their collaboration networks as they strive to create new knowledge.

Theory suggests that organizations establish networks of exchange partners to obtain and develop resources (Lin 2001) and that attributes associated with network structure provide insight into these activities (Burt 1992; Coleman 1988; Nahapiet and Ghoshal 1998). For example, ***network density*** provides insight into the potential resources to which an organization may have access. ***Network centrality*** provides insight the organization's ability to control the flow of information or exchange of resources. Finally, ***tie strength*** reflects the history of interactions an organization has had in developing held resources. Previous research provides evidence that these three elements of network structure are cross-sectionally correlated to knowledge creation (Powell et al. 1996; Reagans and McEvily 2003; Tsai 2001).

Our study attempts to further explore these three elements. We consider the inter-temporal association, or how network density, network centrality and tie strength change over time as organizations obtain and develop resources. We contribute to existing research in the following ways. As mentioned, our study examines changes to network density, network centrality and tie strength over time. While most past research has focused on static networks, our study captures the dynamic nature of networks. We find empirical support that network

density, network centrality and tie strength are in a "constant state of flux" (Boissevain 1974:141) for organizations developing innovative new drugs. However, the fluctuations are not random, but follow patterns over time as organizations alternately seek, and then develop, resources held within their networks (Lin 2001). In addition, our study provides evidence that networks of high-value creating organizations change quite differently from networks of low value creating organizations.

To begin, we briefly review theory to provide an explanation of the roles of network density, network centrality and tie strength to knowledge creation. We develop hypotheses predicting how network density, network centrality and tie strength change over time. We then present our methodology, empirically examine the hypotheses, and discuss the results. Conclusions and directions for future research end the paper.

2. THEORY AND HYPOTHESES

2.1. Knowledge Creation

Important to our study is the assertion that knowledge is created cumulatively over time along a path dependent trajectory as individuals combine and exchange previously held knowledge with each other (Dosi 1988). Therefore, knowledge created in prior periods provides the foundation for new knowledge creation (Schumpeter 1934; Kuhn 1962; Lakatos 1970). To be sure, when individuals within the organization engage in knowledge creating activities, they rely on their prior cumulated knowledge, or previously acquired information, know-how, and capabilities, to recognize, obtain, and utilize new knowledge (Cohen and Levinthal 1990). Because one organization will rarely hold all the needed knowledge, individuals will seek knowledge resources outside the organizational boundaries (Kogut and Zander 1996). Previous

interactions with exchange partners will subsequently have a direct impact on the organization's future knowledge creation opportunities.

We propose that knowledge creation is a teleological process, therefore; we anticipate that organizations will purposefully seek exchange partners to achieve a socially-constructed desired end state. For the purposes of this study, the end state is new knowledge in the form of new drug discoveries. The knowledge creation process involves goal-seeking behavior (Schmookler 1966), and as the end state guides an organization's behavior, the organization will adjust his or her actions in order to fulfill its goals (Van de Ven and Poole 1995). During the knowledge creation process, we propose that organizations will adapt or alter its network of exchange partners as it seeks to obtain and develop needed knowledge resources.

Organizations will seek exchange relationships with others who hold needed resources that it does not possess as it engages in knowledge creation activities (Zucker et al. 1995; Bouty 2000). The creation process demands complex search activities as some resources are widely available, while others are scarce and held by a relative few. In general, organizations will create new knowledge as they obtain and develop tacit and explicit, diverse and redundant knowledge resources through shared experiences with others (Nonaka 1994). Because the level of new knowledge creation is limited by the availability of and access to needed resources (Schmookler 1966), organizations will select from alternative courses of action as more than one course of action exists for an individual to achieve the desired end state (Van de Ven and Poole 1995).

The knowledge creation process is such that organizations must combine and exchange resources with others. Interactions with other organizations are critical because they permit the exchange of tacit knowledge (Polanyi 1966; Nonaka 1994). Paradoxically, over time, when organizations interact with the same others, their individual resources become homogeneous,

thus constricting the ability of each to gain diverse inputs from the others. Therefore, repeatedly engaging in interactions with the same others reduces the marginal benefit of the exchange, as previous exchanges may have exhausted jointly held resources. In other words, as exchange partners work together for an extended period, the likelihood of novel knowledge creation from their exchanges decreases (McFadyen and Cannella 2004).

Because knowledge is built cumulatively over time, once the goal of creating knowledge is obtained, new knowledge creating goals are socially reconstructed based on previous knowledge creations (Weick 1979). As knowledge obtained or created through the exchange process is integrated with previously cumulated knowledge, the cumulative knowledge base of the individuals within the organization changes, and the need for new exchange partners may increase as the organization continues to seek resources in pursuit of new knowledge creation. The organization is motivated to seek new exchange partners when existing exchange partners do not possess the needed inputs (Bouty 2000).

2.2. Hypotheses of the relationship between inter-firm collaboration network dimensions and knowledge creation

During the knowledge creation process, we propose that organizations purposefully develop inter-organization networks to obtain and develop needed resources. Important to our study is the point that networks are not static; rather they change and evolve over time. Theory predicts that networks evolve as organizations engaged in the creation process seek to develop existing resources and obtain new ones (Boissevain 1974). We study changes to network density, network centrality and tie strength of inter-organization networks for high and low value knowledge creating organizations because theory suggests that an organization's network of exchange partners will influence its knowledge creations, and in turn, an organization's previous

knowledge creations influence its choice of exchange partners. Over time, resource needs change, causing an organization to also change its exchange partners as the organization continues to seek needed resources (Granovetter 1973; Lin 2001; Marsden and Campbell 1984; Nahapiet and Ghoshal 1998). Change and adaptation are inherent in a teleology process (Van de Ven and Poole 1995); therefore, we expect organizations to adapt their network of exchange partners to further their ability to create new knowledge. The dynamic implications of networks are seen along three elements of network structure, namely network density, network centrality and tie strength. These dimensions provide insight into the types of resources that may flow through the network as well as the subsequent development of the resources (Burt 1992; Coleman 1988; Lin 2001).

Because organizations are motivated to create new knowledge, obtaining and developing resources is a logical action and the actions taken are in the organization's self interest (Lin 2001). This resource-seeking behavior is the driving force behind the dynamic changes in network density, network centrality and tie strength of inter-organization exchange networks. An organization will make changes to its network based upon changes to circumstances as well as previous transactions during which resources were obtained or developed. Therefore, as organizations actively strive to create new knowledge, network density, network centrality and tie strength will change. We now consider how networks change and why these changes differ for high versus low valued innovative organizations.

2.2.1. The Relationship between Network Density and the Value of Knowledge Creation

Network density (see Figure 1) captures the extent of overlapping ties among exchange partners and provides insight into the types of resources to which an organization may have potential access (Granovetter 1973; Burt 1992; Coleman 1988; Lin 2001).

Insert Figure 1 about here

Organizations will engage in two types of interactions relative to obtaining resources – organizations may interact with others who hold similar resources, or with those that hold dissimilar resources. An organization is likely to adapt the level of density of its network based upon its need for diverse and redundant resources. For example, dense networks provide high levels of redundancy (Burt 1992). Redundancy provides common knowledge and understanding needed to encourage exchange and is a key component to the creation process.

Further, dense networks facilitate the development of group norms, expectations, and behaviors, decreasing the risk associated with exchanges (Coleman 1988) and increasing the ease of knowledge transfer (Erickson 1998). Reputations evolve and cooperative norms develop in dense networks (Coleman 1988), and it is because of this that dense networks encourage cooperation and communication among members (Ahuja 2000; Reagans and McEvily 2003). Dense networks facilitate exchange by establishing and enforcing sanctions, making it less risky for individuals to exchange with one another (Coleman 1988). In addition, dense networks are best able to transfer tacit knowledge among exchange partners (Hansen 1999).

On the other hand, organizations may also benefit from sparse networks. Few partners know one another (many indirect ties) in sparse networks, which provides an opportunity for the organization to obtain diverse resources and perspectives (Burt 2001). Dissimilar resources are more than likely held in less dense (more sparse) networks (Boissevain 1974; Burt 2003; Granovetter 1973) Moreover, because of the few overlapping ties found in a sparse network, an organization that spans several networks may develop unique advantages as it may act as a

broker of information between two or more networks (Burt 1992; Hargadon 2003). Further, evidence exists that sparse networks are most efficient in transferring explicit information between exchange partners (Hansen 1999). Because both dense and sparse networks provide the opportunity to obtain and exchange redundant and diverse resources, we propose that organizations will adjust the level of density in their networks, alternating between sparse and dense, as they produce valued knowledge creation. Thus:

Hypothesis 1*: For organizations engaged in high-value knowledge creation, the level of density will change between dense and sparse from time t to time t+1*

2.2.2. The Relationship between Network Centrality and the Value of Knowledge Creation

Network centrality is also an important component of network structure that goes beyond density or the extent of overlapping ties and or connecting ties in a network of organizations. Network centrality captures not only the opportunity to access resources from existing partnership but also provides insight into the focal organization's visibility and importance in the network as well as the organization's opportunity to benefit from others' relationships (Everett and Borgatti 2005; Smith-Doerr et al. 1999). A central organization is likely to have high involvement with many other organizations and is thus able to gain access to and/or influence others (see Figure 1).

Insert Figure 1 about here

An organization that has centrality can control the flow of information, acting as a gatekeeper, and thus has the opportunity to become a conduit for large volumes of resource exchange and becomes, in a sense, "in the thick of things" (Freeman 1979: 219). Centrality provides visibility and shapes the organization's reputation (Powell et al. 1996). Ultimately,

centrality in the network signals the organization's status in the network of exchange relations (Ibarra 1992). Moving toward a more central location within the network hastens the organization's ability to identify worthy projects and needed exchange partners (Powell et al. 1996).

The periphery position may also be beneficial as this position allows the organization to act as boundary spanners across organization. A peripheral position may allow the organization to connect with other organizations with disparate views and resources facilitate the organization to obtain and develop diverse inputs. Further, because of the isolated nature of the periphery position, the organization will be less restricted to following expected norms and obligations of a more central position. Fewer constrains provide the organization freedom to act "outside the box", which should positively impact creative endeavors. Occupying either a central or peripheral position in the network present potential benefits to an organization. Following theory proposed by Perry-Smith and Shalley 2003, we hypothesize that an organization will move between a central and peripheral position over time.

Hypothesis 2*: For organizations engaged in high-value knowledge creation, the level of centrality will change between high and low from time t to time t+1*

2.2.3. The Relationship between Network Density and Network Centrality

Network density and ***network centrality*** while similar, are distinct components of network structure. As discussed, network density provides access to redundant or diverse inputs and to the level of exclusivity of the available resources. Network centrality, on the other hand, provides insight into the organization's ability to obtain or channel available resources. We envision an inverse relationship existing between network density and network centrality.

As an organization becomes more central within the network, the organization will inherently gain more power and status. Yet, the central organization also faces the challenge of becoming more embedded in the existing network and less connected to others outside which will potentially constrain creativity (Perry-Smith and Shalley 2003). The central organization would benefit by decreasing the level of density within its network so as to obtain access to diverse inputs.

Conversely, as the organization becomes less central, the organization becomes more isolated and has less access to channels of information. While the peripheral organization provides the opportunity to act with less restrictions to obtain perspectives and resources that differ from others that hold a more central position within the network, the peripheral organization, because it lacks access to channels of information, would benefit from a more dense network as dense networks provide overlapping ties which increase communication and provide access to redundant resources. Thus:

***Hypothesis 3**: For organizations engaged in high-value knowledge creation, there is an inverse relationship between network density and network centrality from time t to time t+1*

2.2.4. The Relationship between Tie Strength and the Value of Knowledge Creation

Finally, tie strength provides insight into the development of jointly held resources through the actual history of interactions (Boissevain 1974). In addition, tie strength refers to the closeness and frequency of interactions of exchange partners (Granovetter 1973). Ties therefore strengthen over time as an organization repeated interacts with the same exchange partner.

If an initial interaction between exchange partners proves to be mutually beneficial, individuals will interact again to further develop jointly held resources (Bouty 2000). Through repeated interactions with the same others, shared experiences increase, as does the strength of

the ties. Importantly, knowledge creation is dependent upon the exchange and combination of tacit knowledge, which can only be accomplished through repeated interactions with others (Nonaka 1994). This is particularly true for the scientific discovery process when replication techniques are not widely known (Zucker et al. 1995). It is through collaborative interactions that organizations freely share exclusive knowledge and develop a joint tacit understanding. Organizations which have interacted with the same others are, up to a point, better able to acquire, absorb and assimilate externally developed new knowledge (Bower and Hilgard 1981; Lindsay and Norman 1977) and are thus able to better combine and exchange knowledge to create new knowledge (Polanyi 1966).

Conversely weak ties provide few opportunities for frequent interactions, and interaction is crucial for the combination and exchange of tacit knowledge. Further, evidence suggests that weak ties provided less assistance and support to one another (Seibert et al. 2001). Organizations that create valued knowledge would thus rely heavily on strong ties and will actively work to cultivate them. Therefore we would anticipate an increasingly positive relationship between tie strength and value creation.

Hypothesis 4*: Tie strength will increase from time t to time t+1 for high-value knowledge creating organizations.*

In sum, as the organization seeks unique inputs to produce valuable new innovation, we expect oscillation between high and low levels of density and centrality and consistently strong or increasing strength of ties as organizations obtain and develop resources when creating knowledge (Boissevain 1974; Lin 2001). Clearly, an organization's knowledge base also changes as it participates in the knowledge creation process. Specifically, as newly obtained and developed knowledge is integrated with existing knowledge the organization's knowledge base

changes, and therefore its need for resources (inputs to the knowledge creation process) also change. This, we believe, is the driving force behind network dynamics for organizations, as network stability eventually tends to constrain creativity (Lin 2001; Perry-Smith and Shalley 2003). We expect for organizations to take necessary action by adjusting their network of exchange partners to achieve their end goal of knowledge creation.

3. METHODOLOGY

3.1. Sample

We obtained a sample of pharmaceutical and biomedical firms actively engaged in the drug development process from the Adis R&D Insight database of Wolters Kluwer. The Adis R&D Insight database contains detailed reviews of new chemical entities under active research and development as pharmaceutical agents by the international pharmaceutical industry. New profiles are added to the database as soon as compounds are first identified as being in active development and the profiles created are continually updated as new information becomes available. We identified 52 organizations with active drug development programs that had been assigned Adis scores (explained in depth below) during the period of 1995 – 2000.

3.2. Measures

3.2.1. Dependent Variables

3.2.1.1. Density

Density is a gauge of the overlapping ties in a professional exchange network (Boissevain 1974). The density for each scientist's network was gauged for two, three-year windows: 1995 – 1997 and 1998 - 2000. We chose a three-year window based on previous empirical studies (Hansen 1999). For each three-year window, an organization by partner matrix was created to represent the relationships between the organizations and their partners. The matrix was then

used to calculate Borgatti, Everett and Freeman's (1999) density score to proxy network ties. The density score is calculated as follows:

$$Density = \frac{Ties}{Pairs}$$

In the above equation, the number of actual *ties* are defined as the number of an organization's partners who have published at least one other paper with another of the organization's partners during the three years and *pairs* are defined as potential ties (Borgatti et al. 1999).

3.2.1.2. Centrality

Our ***centrality*** measure is the betweenness measure (Freeman 1979). It is a measure of the extent to which an actor mediates, or falls between, any other two actors on the shortest path between those two actors. We also estimated centrality for each organization for two, three-year windows. The measure is averaged across all possible pairs in the network.

$$Centrality_v = \sum_{s \neq v \neq t \in V} \frac{\sigma_{st}(v)}{\sigma_{st}}$$

Where $\sigma_{st} = \sigma_{ts}$ is the number of shortest paths from $s \in V$ to $t \in$ V where $\sigma_{ss} = 1$ by convention. Let $\sigma_{st}(v)$ denote the number of shortest paths from *s* to *t* that some $v \in V$ lies on (Anthonisse, 1971; Freeman, 1977). As Gulati and Gargiulo 1999:1448) state, "The more central an organization's network position, the more likely it is to have better information".

3.2.1.3. Tie Strength

Tie strength is a reflection of the frequency of interactions. Like density and centrality, we estimated tie strength for each organization for two, three-year windows. This measurement captures the investments that organizations have made in one another through repeated interactions. We operationalized tie strength using a two-step approach based on definitions

posed by Granovetter (1973) and previous use in empirical research (Uzzi 1996; Hansen 1999; McFadyen and Cannella 2004). Conceptually, tie strength was measured as the average number of collaborations per partner that a given organization achieved during the three years. Specifically, we summed the total number of partners that an organization collaborated with during the three years (double counting those partners with whom the organization collaborated twice, triple counting those with whom the organization had collaborated three times, and so forth) and divided by the number of unique co-authors.

$$Relational\ Strength = \frac{\text{Total Count of Coauthors}}{\text{Number of Unique Coauthors}}$$

3.2.3. Independent Variables

3.2.3.1. Collaboration Window

As stated previously, we split the study into two, three-year windows. The first window spanned from 1995 to 1997 and the second from 1998 to 2000. Accordingly, we included a dummy variable for the second period (***Time Period 2***) to assess the change from period one to period two.

3.2.3.2. Value of Knowledge Creation – ADIS Ratings

We used the Adis drug rating to measure the value of knowledge creation. Adis has developed a highly structured system to provide a valid and reproducible rating guide for the clinical potential of new agents undergoing research and development. The system is based on the assignment of a numerical score to up to 20 key evaluation criteria. The ratings are derived from the literature available at the time the evaluation is undertaken; Ratings are specific to a particular indication and/or route of administration (or dosage form). Thus, a drug may have multiple, different ratings.

The ratings for the drugs are scaled from 0 to 100, with the following break points:

Ratings 80-100% indicate potential major therapeutic advance in providing substantially greater clinical advantages in comparison with existing therapies, and/or no effective alternatives currently available. Ratings 60-79% indicate the drug provides important patient benefits in comparison with existing therapies, e.g. greater effectiveness or safety (or both), or has particular attributes that will potentially provide important benefits. Ratings 45-59% suggest the drug provides equivalent efficacy and/or some/modest benefits in comparison with existing therapies, e.g. greater patient convenience, usefulness in particular populations, fewer adverse effects or interactions. Ratings 0-44% provide little or no advantages evident in comparison with existing therapies.

Because the companies often had substantial drug portfolios, and each drug could have multiple Adis ratings, we averaged the ratings of the portfolio for the organizations for each window, deriving an overall score. To guard against outlier effects, we included as a control variable the standard deviation of the Adis ratings in the organization's portfolio. From these scores we determined which organizations had drugs that were rated at 80 percent or above, which indicated the organizations were the engaged in the most innovative and impactful research in the field. This variable is listed as ***Exceptional Adis Scores***.

3.2.4. Control Variables

In addition to the variables of interest, we utilized several control variables. First, we controlled for whether or not the organization was a university or institute (***University / Institute***), given that these organizations often have different objectives than profit-based organizations. Second, we controlled for the number of drugs that each organization had during the window (***Drug Count***). This helps to remove any bias introduced by organizations with many drugs as compared with those with only a few. Third, we controlled for the number of

therapeutic areas (***Therapeutic Area Count***) an organization was in (as designated by the World Health Organization's Anatomical Therapeutic Chemical Classification System). This controls for the breadth of drug development of the organization. Finally, we controlled for the variance of the organization's Adis scores (***Adis score variation***). Because the company may have many drugs, this was necessary to ensure that the organization did not simply have one outstanding drug that pulled its overall average up (or, conversely, one very poor drug that pulled the average down).

3.3. Statistical Methods

We estimated the models using negative binomial models. This method is appropriate given the distribution of our dependent variables. Because several companies had limited collaboration networks during our study windows, their density, centrality, and tie strength scores were rather low, positively skewing the distribution of the variables. Under these conditions normal regression models are inappropriate. A negative binomial model was selected over a Poisson regression model because the negative binomial does not have the requirement that the mean and standard deviation are equal.

To test our hypotheses, we conducted post estimation Wald tests to evaluate the differences between different coefficients. For Hypothesis 1, Hypothesis 2, and Hypothesis 4, interacting two binary variables (one for the organizations with ***Exceptional Adis Scores*** and the other for ***Time Period 2***), we are able to construct a 2 x 2 matrix where three coefficients are compared against a base category. By interacting the coefficients, the three comparison categories are non-exceptional Adis score organizations for time period 2, exceptional Adis score organizations for time period 1, and exceptional Adis score organizations for time period 2, with the base category specified as non-exceptional Adis score organizations for time period 1. The

post estimation Wald test is able to compare any of the reported coefficients against another to determine if it is statistically different. In the case of Hypothesis 1, Hypothesis 2, and Hypothesis 4, the coefficient for exceptional Adis score organizations for time period 1 (***Exceptional Adis Scores***) is compared to the coefficient for exceptional Adis score organizations for time period 2 (***Time Period 2 x Exceptional Adis Scores***). If there is a statistically significant difference between these two coefficients, the hypothesis is supported.

Hypothesis 3 follows a similar format, but the matrix formed is 3 x 3 where the time period variable, the exceptional Adis score variable, and either the density or centrality variable (respectively) are triple interacted. For this hypothesis, a comparison of the ***Exceptional Adis Scores x Centrality*** and ***Time Period 2 x Centrality x Exceptional Adis Scores*** coefficients will test the first part of Hypothesis 3 (whether there is an inverse relationship between density and centrality). The second part of the hypothesis is tested by a comparison of the ***Exceptional Adis Scores x Density*** and ***Time Period 2 x Density x Exceptional Adis Scores*** coefficients (which determines if there is an inverse relationship between centrality and density). All models were run in Stata 9.2 SE (StataCorp 2005).

3.4. Results

Descriptive statistics for the variables used in the models are provided in Table 1. The models are presented in a stepwise fashion in Table 2.

Insert Tables 1 and 2 about here

First, Hypothesis 1 stated that the level of density will change (fluctuating between dense and sparse values) from time *t* to time *t+1* for high-value knowledge creating organizations. To test this hypothesis, we interacted the dummy variable for the second window with the dummy

variable for companies with exceptional Adis scores (Model 2). We then conducted a post-estimation Wald test to determine if the interaction coefficient was statistically higher than the coefficient for the interaction. This allows us to assess if indeed the density of the organizations with exceptional Adis scores changed from window one to window two. Our results indicated that, in keeping with our hypothesis, the density *decreased* from period one to period two (χ^2 = 3.13, p = .076). Therefore, hypothesis 1 was supported.

Hypothesis 2 predicted that the level of centrality will change (fluctuating between high and low values) from time *t* to time *t+1* for high-value knowledge creating organizations. To test this hypothesis, we interacted the dummy variable for the second window with the dummy variable for companies with exceptional Adis scores (Model 4). We then conducted a post-estimation Wald test to determine if the interaction coefficient was statistically higher than the coefficient for the ***Time Period 2*** variable. This allows us to assess if the centrality of the organizations with exceptional Adis scores increased from window one to window two. Our results indicated that, as we hypothesized, the centrality *decreased* from period one to period two (χ^2 = 26.65, p < .000). Therefore, hypothesis 2 also was supported.

Hypothesis 3 predicted that although we could not predict *a priori* the direction of change from time *t* to time *t+1*, we could and did hypothesize that density and centrality will be inversely (negatively) related for high-value knowledge creating organizations. To test this, we estimated a triple interaction where the various components of time period, exceptional Adis score, and centrality or density (respectively). We then conducted a post-estimation Wald test to determine if the triple interaction coefficient was statistically higher than the coefficient for ***Exceptional Adis Scores x*** (either ***Centrality*** or ***Density***). This allows us to assess if there is an inverse relationship between density and centrality and centrality and density. Our results

indicate in Model 3 and Model 8 that, as we hypothesized, the there is an inverse relationship between density and centrality ($\chi^2 = 218.82$, $p < .000$) and centrality and density ($\chi^2 = 6.67$, $p < .001$). Therefore, hypothesis 3 also was supported.

Finally, Hypothesis 4 predicted that tie strength will increase from time t to time t+1 for high-value knowledge creating organizations. To test this hypothesis, we interacted the dummy variable for the second window with the dummy variable for companies with exceptional Adis scores in Model 7. We then conducted a post-estimation Wald test to determine if the interaction coefficient was statistically higher than the coefficient for the interaction. This allows us to assess if indeed the tie strength of the organizations with exceptional Adis scores increased from window one to window two. Our results indicated that, the tie strength did increase from period one to period two ($\chi^2 = 3.25$, $p = .071$). Therefore, hypothesis 4 was supported.

To this point we have analyzed organizations that are engaged in high-value knowledge creation through drug discovery. We then engaged in supplementary analysis of the companies that were not creating high-value drugs, but rather were engaged in developing drugs that provide little or no advantages evident in comparison with existing therapies. It is important to note that although the knowledge produced by these organizations are not considered high-value, they are nonetheless innovations in their own right. We examined the networks of these organizations and found that there was no significant change in the density, centrality, or tie strength measures from one period to the other. We found this fascinating and comment upon it further in the following section.

4. DISCUSSION

Our purpose with this research is to examine how three elements of network structure change over time. We argued that because collaboration alliances are becoming increasingly

important to innovation, better understanding of factors that lead to successful alliances is imperative. Further, we proposed to provide further insight into alliances network structure as we believe that the structure of collaboration networks provides insight into a firm's ability to create high valued knowledge. We used the pharmaceutical industry as our setting and proxy the value of knowledge creation using Adis drug ratings. We examined three components of alliance network structure – network density, network centrality and tie strength.

Our study contributes to existing research in three important ways. First, we examine changes to collaboration networks over time. Previous research, while providing insights into the link between collaboration networks and knowledge creation, has not explored the dynamic nature of knowledge creation and networks. Second, we simultaneously explore three components of collaboration networks structure – network density, network centrality and tie strength. Finally, we provide evidence that high value knowledge creating organizations behave differently than low value creating organizations.

Our study provides evidence that collaboration networks for organizations creating high-value drugs do change over time and that the changes are systematic in accordance with theory. We argued that high value knowledge creating firms would alter the number of overlapping ties among networks partnerships. Over time, firms will change their need for resources, and changing levels of density reflect the need for diverse as well as redundant resources as they create new knowledge with exchange partners.

In addition, we hypothesized and found evidence that organizations will move between a periphery position to a central position within the network. The level of centrality reflects the organization's changing access to channels of information. As the organization becomes more central, the firm also becomes isolated to outside influences. Over time, this isolation has the

potential to decrease the organization's creativity. Therefore, the organization that seeks to continue to create high valued outputs will purposively seek a more periphery position as it seeks to obtain diverse inputs (Perry-Smith and Shalley 2003). We thus anticipate that the level of centrality will change as the organization creates high-value knowledge over time.

Finally, we found that changes in density and centrality are inversely related over time. We interpret this finding to suggest that density and centrality complement one other. While dense networks provide access to redundant knowledge, dense networks lack access to outside diverse inputs. Conversely, a peripheral position may lack communication flows from other network members, however, has the opportunity to span across other network boundaries to obtain unique perspectives. Similarly, sparse networks provide access to diverse inputs, however lack the norms and obligations of a dense network. Central organizations have access to channels of information, yet may lack outside perspective.

While these results are interesting, we found most intriguing the *post hoc* analysis that indicated density, centrality, and tie strength measures organizations engaging in low-value drug development did not significantly change. A central belief held by network researchers is that networks do change over time, but this belief has been largely untested. We do find significant network change for organizations creating high-value drugs, but we find no such changes for the other organizations. We had several ideas as we reflected upon this finding. First, from the perspective of the organizations are engaged in high-value research, they will need to seek out new partners (necessitating network change) to achieve results that are superior to those of other organizations, and therefore it would be reasonable to expect their networks to change. Second, from the perspective of the organizations engaged in low-value research, given that they are not seeking to achieve extraordinary results, following normal trajectories will provide satisfactory

results until this inertia is disrupted by some event (i.e., regulatory change, a dramatic technological breakthrough, etc.) that necessitates change. Finally, from an overall network perspective, organizations are at different stages; some may be beginning new relationships while others are well entrenched, while yet others are ending relationships and perhaps seeking new partners. In this caldron of activity, some firms may seek stable, long-lasting relationships while other seek relationships that quickly yield high-value results.

4.1. Limitations and Extensions

A clear limitation of our research is we have only two windows from which to evaluate network change. The implication of this limitation is that we may observe a change in the variable from a high point (leading to a decrease) or from a low point (leading to an increase). In other words, we are not able to capture multiple cycles that would allow us to see the oscillation of the network dimensions over time. Despite this limitation, it is important to note that all three dimensions did significantly change from one window to another for the organizations engaged in high-value drug development. This provides evidence that *some* networks do change meaningfully over time. But it is interesting to note that organizations engaged in low-value drug development there was no significant change in density, centrality, or tie strength. This stability is intriguing to us because it suggests that organizations collaborating on low-value drugs do not experience the same network changes as those that do.

Another clear limitation is that we do not have financial performance data, given that 34 percent of the sample organizations are either universities or institutes. While this would add an interesting dimension to this research, there are substantial disconnects between drug discovery and organization performance given the length of time it take to discover new drugs. Finally, while we believe our findings are generalizable to other high knowledge intensive industries, our

study was limited to the pharmaceutical industry. Additional research is needed to determine if the findings differ in other less knowledge intensive settings.

4.2. Conclusions

Our study demonstrates the importance of considering three separate components of collaboration network structure in relation to creating high value drugs as well as provides important evidence of the interdependencies between the components of the organization's network of alliance partners. The findings indicate that high value creating firms alter their collaboration networks systematically as they seek to obtain and develop resources during the creation process. In sum, we find that network density and network centrality are inversely related and that high value creating firms will alter the levels of these two components. In addition, we find that high value creating firms will continue their interactions with valued partners over time.

Our study has important managerial implications as more organizations engage in collaborative arrangements to increase creative output. Importantly, knowing *when*, *with whom*, and *how* to partner will critically impact the quality and value of jointly developed new knowledge. The results of our study have provided important direction into identifying and maintaining partnerships that increase the probability of creating highly valued knowledge. Importantly, managers should identify the structure of their alliance networks as strong evidence exists that collaboration network structure impacts the organization's innovative output. Furthermore, managers must become aware of not only their organization's current position (centrality) in the network of alliance partnerships, the extent of overlapping ties as well as the strength of alliance partnerships, but also, track changes to three components as alliance networks of highly innovative organizations must change over time.

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Table 1

Means, Standard Deviations, and Correlations

		Mean	SD	Min	Max	1	2	3	4	5	6	7	8
1	Density	17.38	31.76	0.00	100								
2	Tie Strength	1.20	0.41	1.00	3	0.456							
3	Centrality	0.79	1.71	0.00	10	-0.124	-0.049						
4	University/Institute	0.34	0.48	0.00	1	0.163	0.040	-0.032					
5	Adis Score Variation	0.75	1.94	0.00	10.36	-0.067	0.105	-0.004	0.177				
6	Therapeutic Areas Count	36.58	63.59	1.00	290	-0.155	-0.091	0.279	-0.298	-0.006			
7	Drug Count	2.63	4.02	1.00	29	-0.054	0.237	0.128	0.185	0.509	0.155		
8	Time Period 2	0.50	0.50	0.00	1	0.090	0.126	-0.095	0.000	-0.005	0.072	0.043	
9	Exceptional ADIS Scores	0.14	0.35	0.00	1	-0.020	-0.177	0.037	0.025	0.076	0.033	-0.163	-0.050

TABLE 2

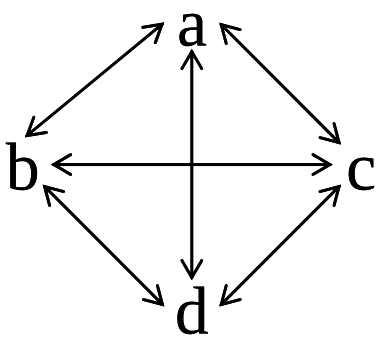
Negative Binomial Regression Models

	1 Density	2 Density	3 Density	4 Relational	5 Relational	6 Centrality	7 Centrality	8 Centrality
Constant	1.130	0.863	0.804	0.072	0.076	-0.850	-1.036	-1.093
	(0.146)	(0.293)	(0.353)	(0.123)	(0.115)	(0.145)	(0.074)	(0.067)
Density				0.348***	0.351***	-0.310**	-0.362**	-0.252
				(0.000)	(0.000)	(0.006)	(0.002)	(0.110)
Centrality	0.017***	0.020***	0.018***			0.054	0.062	0.068
	(0.000)	(0.001)	(0.001)			(0.599)	(0.522)	(0.489)
Tie Strength	-0.001	-0.001	0.006	0.019	0.025			
	(0.751)	(0.860)	(0.487)	(0.425)	(0.302)			
University / Institute	0.008	0.005	0.007	-0.098	-0.100	0.024	0.058	0.062
	(0.264)	(0.466)	(0.348)	(0.208)	(0.199)	(0.861)	(0.685)	(0.664)
ADIS score variation	-0.006	-0.015	-0.014	0.023	0.022	-0.114	-0.087	-0.108
	(0.580)	(0.207)	(0.375)	(0.717)	(0.724)	(0.391)	(0.517)	(0.438)
Therapeutic Areas Count	-0.016	-0.021	-0.019	-0.082*	-0.084*	0.318*	0.337*	0.328*
	(0.131)	(0.054)	(0.074)	(0.029)	(0.027)	(0.013)	(0.017)	(0.019)
Drug Count	-0.006	0.002	0.001	0.186***	0.187***	0.234	0.198	0.187
	(0.470)	(0.868)	(0.910)	(0.000)	(0.000)	(0.235)	(0.299)	(0.318)
Time Period 2	-0.000	0.002	0.006	0.066	0.054	-0.157	-0.067	-0.014
	(0.963)	(0.737)	(0.431)	(0.267)	(0.408)	(0.075)	(0.472)	(0.896)
Exceptional ADIS Scores	0.009	0.023	0.025	-0.112**	-0.142*	0.085	0.221	0.162
	(0.234)	(0.088)	(0.146)	(0.003)	(0.012)	(0.485)	(0.108)	(0.260)
Time Period 2 x Exceptional Adis Scores		-0.021	-0.019		0.047		-1.028***	-0.998***
		(0.094)	(0.199)		(0.305)		(0.000)	(0.000)
Time Period 2 x Centrality			-0.009					
			(0.053)					
Exceptional Adis Scores x Centrality			-0.008					
			(0.295)					
Time Period 2 x Centrality x Exceptional Adis Scores			-0.223***					
			(0.000)					
Time Period 2 x Density								-0.290*
								(0.044)
Exceptional Adis Scores x Density								0.071
								(0.693)
Time Period 2 x Density x Exceptional Adis Scores								-0.454***
								(0.000)
N	116.000	116.000	116.000	116.000	116.000	116.000	116.000	116.000
Chi2	44.306	38.899	816.748	100.318	107.841	32.291	80.059	440.060
Probability of Chi2	.000	.000	.000	.000	.000	.000	.000	.000

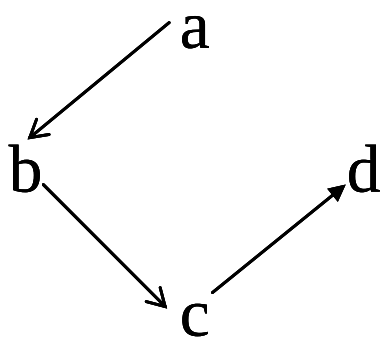
Standardized beta coefficients reported and *p* values reported in parentheses

Figure 1: Attributes of Network Structure

Dense Network



Sparse Network



Centrality