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An examination of transaction interdependency: a perspective in the animal health and nutrition industrial system

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RESEARCH ARTICLE

Abstract

The research examining bioscience networks has been studied from two perspectives. One view comes from economics and the other sociology. We examine the technical (material flows) and people aspects (information sharing) of interdependency in the context of economic exchanges in a bioscience network. The empirical contributions are the techniques used to explain the network structure of a burgeoning animal health and nutrition bioscience network and the portability of network analysis concepts that provides the potential to manage diverse business networks. The results suggest the economic exchanges can be traced back to the underlying interactions that safeguard transactions and influence the flow of resources and information.

Keywords: transaction costs, networks, bioscience, social

1. Introduction

Knowledge creation occurs in the context of a community that is social, fluid and not tightly bound or static (Powell, 1990). Evidence of this can be found in the technological advancements of the bioscience industry in which new rivals, potential partners, and network organizations have formed to reduce inherent uncertainties and resource constraints (King *et al.*, 2010; Menard, 2010). The broader bioscience industry comprises more than 70,000 establishments that employ over 1.6 million people earning an average of $74,700 per year collaborate across bioscience subsectors. This includes agricultural feedstock, drugs and pharmaceuticals, medical devices and equipment, research testing and medical labs and bioscience-related distribution. Importantly, the bioscience industry does not fall neatly into one standard industrial classifications code. Rather, it consists of groupings of diverse industries that fall into a broad array of higher-level industries, such as chemical and food manufacturing, professional, scientific and technical services, and distribution services, and that share a common link – the development and utilization of biological scientific knowledge. The interpretation often given for bioscience networks is the overlapping of interdependent organizations, which suggests that a multidisciplinary approach is needed to investigate the relationship between the tangible and intangible exchange of biological scientific knowledge and other economically relevant considerations.

Network forms are becoming more flexible and complex, more decentralized and yet reliant on collective action and cohesiveness (King *et al.*, 2010). In the midst of this growing complexity is an evolving mixture of cooperative relationships with upstream and downstream partners. The interdependent relationships offer the potential for bioscience to profoundly alter the way new products are created. By taking into account the importance of information and novel interdependencies, this study seeks to provide an understanding of how interdependent relations affect economic exchanges within the bioscience industry by combining transaction cost and social exchange frameworks. Transaction cost analysis (TCA) provides insights into the formal relations among network participants, while social network analysis (SNA) provides an interpersonal explanation for the transaction of a good or service. Our research question is as follows: how do interdependent relations within the bioscience industry affect economic exchanges, especially the exchange of materials, ideas and information?

As a frame of reference, we begin with Powell's typology of network forms (1990). Starting with Evan (1966), researchers began with the notion that the business environment consists of numerous players, interacting independently with the focal organization. However, Powell (1990) extended the discussion on organizational configurations that did not fit the conventional definitions of markets or hierarchies. Powell's research identified three types of network forms: (1) craft industries, such as

construction, publishing, film, and recording industries; (2) regional economies and industrial districts, such as German textiles, Silicon Valley or Route 128 in Massachusetts; and (3) strategic alliances and partnerships, which are common in technology-intensive industries. What network structure does the bioscience industry most resemble? As we explain below, a combination of TCA and SNA provides insights into network relationships and can inform on the characteristics of Powell's three network types.

In addition to providing an important theoretical contribution to network analysis, this research combines interdependent aspects of economic exchanges with an objective (1) to produce a reliable and valid measure of a network's capacity to create knowledge and (2) to determine whether the configuration of ties existing within a specific bioscience network differs from other networks (Burt, 1992; Coleman, 1990; Powell, 1990). The study builds on this literature, proposing a conceptual framework that allows the tangible and personal aspects of interaction to be explored using data collected from 22 localized firms in the animal health and nutrition industries.

The Animal Health Corridor is a geographic concentration of more than 174 organizations consisting of government institutions, management skills, and research adroitness to commercialize animal health products for agriculture and companion animals. The region has a tradition in animal health and nutrition that dates back to 1871 when the Kansas City Stockyards were established for trading cattle, sheep, horse, mule and hogs. The Kansas City Animal Health Corridor, hereafter the 'Corridor', is a national epicenter of animal health and nutrition. The region is home to a trifecta of major government biotechnology resource facilities, including the National Bio and Agro-defense Facility's biodefense laboratory, Animal Disease Research Laboratory, and a center of excellence on zoonotic animal diseases. These advantages are added to the other resources already dedicated to animal health and nutrition in the region, including six of the nine largest firms in the world in animal health and top-tier veterinary schools. In 2009, the United States House of Representatives passed federal legislation officially naming the area as the 'Kansas City Animal Health Corridor', thus cementing its reputation as a leading national district in the prevention of animal diseases. Geographically, it is in the middle section of the country and is localized between Manhattan, Kansas, and Columbia, Missouri as the nation's animal health corridor (Figure 1).

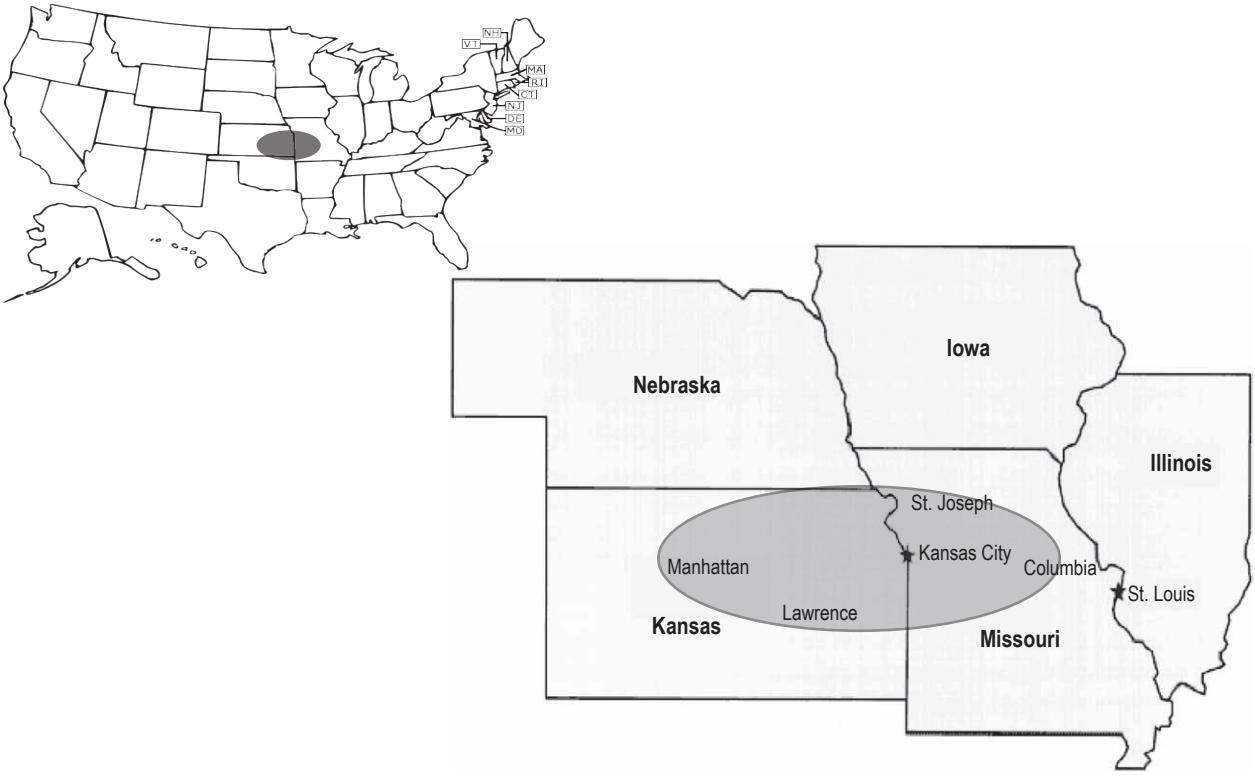

Figure 1. Map of the Kansas City animal health corridor.

A study of the Corridor is uniquely positioned to deal with the complementarities between SNA and TCA. In turn, an analysis that combines insights into interdependent relationships using TCA and SNA can inform on the nature, structure, and effectiveness of the Corridor as a network. A study of networks helps supplement our understanding of the relative importance of different types of organizations involved in the bioscience network that are based on formal and informal interaction.

2. Theories of interdependent interaction

The literature on interdependent organizations has been studied in a wide range of scholarly fields, including organizational economics, economic sociology, organizational studies, as well as interdisciplinary work on subjects like competition, cooperation, and embeddedness. Hence, this literature sits at the intersection of many disciplines. Interpersonal network connections are comprised of relationships that are implicit, personal, and not fixed by any legal arrangements. Often the informal aspects of a transaction characterize the connections, including voluntary cooperative relationships between organizational actors and ties not determined by the organization's formal structure (Böröcz and Southworth, 1998). Informal cooperative aspects of a transaction involve organizations that do not function in a subordinate role to another organization. In contrast, the formal structure of an organization is intentionally created to minimize the cost of carrying out a transaction in the marketplace. The structure safeguards economic transactions with formal institutions like laws, rules, torts and contracts. The network of interdependent ties includes not only the relational configurations arising from the formal authority relationships composing the organizational hierarchy, but also the formal institutions that provide credible commitment to oversee the transaction. Interdependent network connections are regarded as the ex ante best solution between firms (Williamson, 1975, 1979), such as when one firm sells to or purchases from another firm, as well as other interactions, such as when one firm makes a competitive move against another firm in the exchange relationship.

The reciprocation between the traditions of new institutional economics and economic sociology describes the manner in which networks function and identifies a common variable of interest – interdependency. In economics, particularly TCA, the focus is on the formal structure of interdependency. In sociology, the informal, social dimension characterizes the nature of inter-firm agreements, especially within the context of SNA. These social science traditions focus on inductive methods and generally derive theories of social behavior through empirical means of observation, with less emphasis on optimization formulae based on assumptions of human self-interest and methodological individualism. The outcome of economic exchanges is therefore uncertain because they depend on how economic action is embedded in dynamic social structures.

Transaction cost analysis

Economic theory has paid attention to networks with TCA playing a pioneering role. The TCA literature focuses on sequential linkages and bilateral exchange relationships. TCA is most often associated with Oliver Williamson (1985, 1991), whose work has formed the foundation for analyzing formal transactions. The unit of analysis is the transaction and the focus is on the contracts used to govern the interaction when turning inputs into outputs. TCA's primary question is whether an exchange is between firms or is represented by a transfer of resources within a vertically integrated firm. The key insight from TCA is that firms will seek to minimize transaction costs by selecting governance structures – such as intra or inter firm transactions – that most efficiently facilitate the transactions.

Within the TCA framework are three attributes of transaction which are important when determining the appropriate governance structure: the degree of uncertainty surrounding the transaction, the degree of asset specificity, and the frequency of the transactions (Williamson, 1988). These concepts are important because they affect the costs of engaging in transactions. Uncertainty is a result of incomplete information. A low level of uncertainty lends itself to spot market transactions. When aspects of the transaction are highly uncertain, a more formal arrangement may result, such as a contract or vertical integration. Asset specificity exists when transactions require investments in assets that are specific or unique to the relationship. A high degree of specificity would lead to a more formal type of an interdependent relationship, such as vertical integration. Dyer and Hatch (2006) point out that knowledge sharing routines are a form of human asset, which is often found in knowledge intensive relationships. Transactions repeated frequently tend to be carried out in the spot market, because the buyer and seller will not have a strong incentive to act opportunistically by tarnishing their reputations. As transactions become more infrequent, however, the incentive to act opportunistically increases as buyer or seller look to take advantage of asymmetric information. This behavior lends itself to vertical integration as a means of mitigating potential opportunistic behavior.

Social network analysis

Measuring the relative strength of an interaction in the interdependent relationship is a primary concern of SNA. Borgatti and Foster (2003) highlight two dimensions of network research that are viewed as explanatory mechanisms of the individual position of an organization. They emphasize a connectionist and structural approach of Lin *et al*. (1981), Coleman (1990), and Burt (1992) to explain the interpersonal network. A connectionist approach focuses on the content that flows through the network ties. The ties represent entities at various levels of collectivity, such as firms or persons. The ties among actors can be between competitors or cooperators and can be characterized along multiple dimensions, such as frequency and duration. The ties are seen as conduits to allow content to flow between actors, such as ideas and information. The fundamental truism in network analysis is the notion that actors are interdependent and influence each other.

Mark Granovetter (1985) extended the discussion on social exchange theory, which reinforces the importance of the position of a firm in the network. The reason is that its position impacts the firm's strategic actions and consequently affects network dynamics. Granovetter's work on interpersonal ties suggests that some relationships are important for safeguarding exchanges needed to transform inputs into outputs. Granovetter explains how weak and strong ties structure the network. He conceptualizes a weak tie as frequency of interaction (McEvily and Zaheer, 1999), whereas strong ties sustain relations within the group or organization. His use of the concepts of frequency, reciprocity and emotional intensity help to operationalize the weak and strong tie concepts.

Weaknesses of transaction cost analysis and social network analysis

According to both TCA and SNA, the structure of a network has a significant impact on how resources, including information and products, flow between trading partners. SNA emphasizes the nature of the network relationships (weak or strong ties). Although the network describes the relational perspective and shows the economic advantages of the relationship (Coleman, 1990), in the absence of a reliable third-party enforcer there is often no firm basis for deciding whether an acquaintance or friend is trustworthy. The enforcement of institutional arrangements is 'necessary to back informal constraints in modern economies where the payoff from malfeasance and opportunism is high' (Nee, 1998: 23). TCA, however, focuses on getting the governance structure right (market, network, hierarchy) with less emphasis on the specific nature of network relationship. Thus, TCA overlooks issues of power, embeddedness, social relationship, networks or other sociological concepts. Moreover, Granovetter (1985) implied that strong interpersonal relations prevent opportunistic behavior better than institutional arrangements.

Thus, SNA is helpful in understanding network relationships and what they look like, but not the formal structures governing them. TCA is helpful in understanding the formal structures of relationships, especially why certain relationships are more costly to manage than others, but not relationships linked in network chains. Combining insights from TCA and SNA can therefore inform the formal and informal nature of interdependency in a network.

Overlapping constructs for transaction cost analysis and social network analysis

Social exchange theory asks several main questions, but of importance to this study is a focus on the informal network structure that influences exchange partners. Cook and Emerson (1978) and Cook *et al.* (1983) demonstrate that organizational power is a result of links with other firms in the network. Informal connections create influence in a network. Transaction costs analysis works toward an understanding of the formal structure of interdependent relationships. TCA provides a purely dyadic perspective of transactions between a buyer supplier or other trading partners like a company and a trade union. SNA's view of an exchange includes but goes beyond the dyad explanation of an exchange. It systematically considers triadic exchange as explanations for interdependency. A triadic perspective consists of a focal actor, with any other tie to other actors, and all ties between the actors, such as friend-of-a-friend.

Both TCA and SNA converge to include the interdependent factors governing the exchange of goods or services. Furthermore, the primary theories overlap when explicating the structure and the extent of interdependency in the network. In this framework, we note two areas of overlap: uncertainty and frequency. The level of uncertainty results in unanticipated change in the environment because of unforeseen eventualities or changes that affect trust between partners, which causes either party to the agreement to underperform or renegotiate better terms for them. The level of frequency is determined by how often actors transact with each other. The higher degrees of frequency indicate stronger ties and frequent market exchanges where the transactions costs are less than the cost of vertical integration. Although we focus primarily on uncertainty and frequency in this study, we also consider other characteristics. Figure 2 shows the points of convergence and differences of each theory as explanations of network structure.

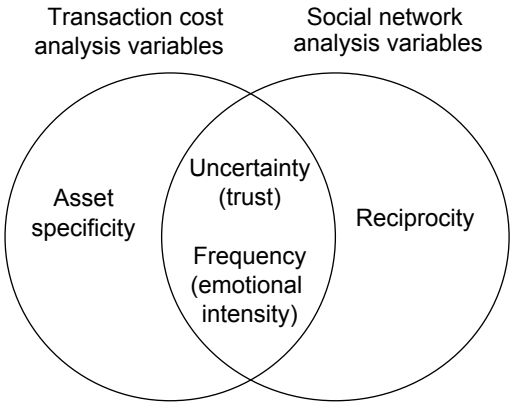

Figure 2. Overlapping constructs in social network analysis and transaction cost analysis.

3. Networks in animal health and nutrition industries

The organizations in the Corridor are categorized according to their primary activity or domain (Harris and O'Brien, 2013). The research domain consists of organizations that create and codify knowledge; the intermediary domain includes organizations involved in enhancing the reputation of the region by means of political advocacy and regional marketing; the enterprise domain includes organizations directly involved in processing, distribution, and marketing of the finished goods and services; the support domain includes organizations provide services that are indirectly involved in commercializing animal health and nutrition products. Table 1 enumerates the organizations in the Corridor by their primary activity or domain.

The concept of a domain is a useful term in the study of a diverse network (Omta *et al.*, 2001; Thompson, 1967). The domain approach to studying the Corridor provides an opportunity to explain the diversity of organizations involved and the probability that different and varying degrees of organizational ties influence the exchange of ideas and information. Through professional, social, and exchange relationships, these organizations share advice, information, and new solutions (Nohria and Eccles, 1992). Both TCA and SNA provide the framework for developing the hypothesis for this study. The strengths of each analytical lens help to explain the extent of interdependency, which informs on the nature of the network structure.

Table 1. Number of organizations in the corridor arranged by domain (Harris and O'Brien, 2013).

Support domain	Intermediary domain	Research domain	Enterprise domain	Total
110	18	10	36	174

Key concepts to explain the network structure

Interdependency takes place over short- or long-term periods of time. The duration of the exchange has an influence on the relationship between the organizations. For instance, in a spot market, relations are not enduring and are formed only for the purpose of a well-specified exchange of goods and resources. Spot markets have a more adversarial stance in relation to the exchange. After the exchange, the relationship ends. That is, one might operationalize a spot market as a population of isolates or as organizations that lack enduring ties to the other organizations. In contrast, in hierarchies, relations may endure for longer than a brief episode, but a clearly recognized legitimate authority exists to resolve disputes that arise among actors. One could operationalize a hierarchy as a centralized network and expect the vast majority of ties to flow to or from one particular organization.

Types of ties

The network perspective helps to conceptualize the extent of interdependency among a set of interrelated dyadic and triadic relationships. The interactions are characterized by the extent of the ties between transacting organizations. We use the interdependency concept – e.g. the strength of the actor's connections – to examine the Corridor as a multistage netchain (Lazzarini *et al.*, 2001) rather than as a stand-alone dyad. Using the top-level typology from Borgatti and Li (2009), the network ties are divided into two basic kinds: continuous and discrete. Continuous ties are strong ties that are formed over a long period of time and that influence the flow of information, such as confidential information conveyed in a timely manner. In contrast, discrete ties are based on a series of connections of discrete events, such as the number of projects or collaborations or the rate of occurrence in which information has been exchanged. As a measurement of the strength of ties, we use similarities of network connections between Corridor organizations as a description of the strong ties, and we use flows of information transfer as an indication of the degree of weak ties.

Considering that the Corridor organizations are spatially concentrated in defined geographical space, the organizations may not know each other, but they do have a heightened opportunity to establish ties given their

similar cultural understandings as well as the potential for memberships in the same organizations, attendance at the same conferences, or serving as directors on the same boards, that is, as interlocking directorates (Chatman *et al.*, 1998; Mizruchi, 1996). We look toward TCA and SNA to provide formidable explanations about the extent of interdependency characterized by weak versus strong ties, recognizing that weak ties induce improved performance whereas strong ties seem to have a negative effect (e.g. Rowley *et al.*, 2000; Ruef, 2002)

4. Hypotheses

How do the interdependent relations affect economic exchanges within the bioscience industry? We use TCA and SNA to hypothesize the type of interdependent ties we expect to find between firms within the Corridor. We then use these hypotheses to predict the strength, frequency and number of ties within the network, the purpose of which is to determine the extent to which the Corridor is similar to, or differs from, other established network structures, such as those identified by Powell (1990). This analysis will thereby provide insights into how interdependency within a network can create, or impede the creations, of knowledge.

> H1: According to TCA, the greater the reliance on asset specific relationships between firms, the stronger will be the ties connecting them.

TCA predicts a correlation between the extent of asset specificity and the hazards of opportunism. Asset specific relationships do not occur without some form of organizational arrangements, greater cooperation or joint activities. The formality of the organizational relationship is necessary to mitigate the potential for opportunistic behavior by one or both trading partners. Thus, the accumulation of relationship specific assets (e.g. a manufacturing facility, a specific tool, die, or machine), including intangible assets (e.g. tacit knowledge, a specific technology, or capability) in the network should culminate in the creation of a strong tie. Moreover, relationship specific assets are ostensibly developed from highly interdependent networks like partnerships, and they tend to have stronger ties than networks found in industrial districts and craft industries. Thus, we can also expect that the converse is true: the number of strong ties will correlate with the reliance on asset specific relationships.

> H2: According to SNA, the greater the number of reciprocal relationships existing with a network, the larger will be the number of inbound and outbound ties between firms.

The number of inbound and outbound ties provides evidence of the existence of relationships that are episodic or continuous. SNA posits that a large number of reciprocal ties are an indication of network stability. Organizations with more constant reciprocal ties between other constituent organizations have a greater opportunity to safeguard transactions (Granovetter, 1985; Nee, 1998). Within the Corridor, the spatially situated network of 174 organizations will be connected to other organizations in varying degrees of connectivity. The ties are represented by organizations identifying other firms that have performed a beneficial act to benefit other organizations in the Corridor, such as provided resources to solve a problem, sponsored an industry related activity, led or worked on a committee. High degrees of reciprocity suggest a lesser likelihood of opportunism. Reciprocity is an indicator of a social governance structure that does not rely on institutional arrangements to resolve conflict.

> H3: According to both TCA and SNA, the more interdependent organizations are within a network, the higher will be the frequency of ties existing among firms.

The connection between interdependency and frequency is clear from a TCA and SNA perspective, both of which posit that frequency is a key driver of organizational structure (Figure 2). The reason is, in part, because frequency is an indication of interdependency. More precisely, frequency allows the development of reputations and the strengthening of social norms. When considering that the Corridor is made up of public, private, and civic organizations, we can expect that organizations with different needs will have to interact. For instance, organizations whose primary focus is research might work closely with other research institutions. But these same research-oriented organizations might also benefit from the input of other organizations whose work is focused on support operations, such as financial services. Thus, firms will have to assess whether the costs of frequency produce offsetting benefits. If the costs of frequent interaction are too high, then firms may conclude it is more cost effective to vertically integrate; otherwise, they continue to carry out transactions in the marketplace. Due to the indefinite nature and frequency of the interaction, two or more firms may be involved in more organizational arrangements like interdependent projects and research agreements (Granovetter, 1973; Prahalad and Hamel, 1990; Simichi-Levi *et al.*, 1999; Thorelli, 1986; Williamson, 1991).

> H4: According to SNA, the more important the codification of knowledge (research) and the facilitation of a close working relationship between

other firms (intermediary), the greater will be the number of weak ties relative to strong ties between firms.

The social network perspective suggests the firm's connections will guide its interests in finding new trading partners (Gulati, 2007). If more weak ties represent the network, then we should see a greater willingness among organizations to participate in sharing public information or attend conferences related to the Corridor. Thus, conversely, the more important the sharing of information, the greater will be the need to rely on weak ties. The Corridor has organizations in each domain with process and design engineers. Specific knowledge refers to the special skills that are developed when designing a specific good or service. It could include the creation of a new product or the enhancement of a process or service. However, organizations in the research and intermediary domain have more performance-based incentives to collaborate with one another.

Expected outcomes

Uzzi (1997) pointed out that networks should include a collection of both strong and weak ties. In the network form of an organization, we do not expect to find interdependent relationships characterized as overtly episodic or with a legitimate authority to resolve disputes. We expect to find many triadic exchanges relationships. The triads include some important weak and strong tie strength commonalities. Not unlike the networks found in the Silicon Valley where the region's dense network of social, professional, and commercial relationships is an advantage, or not unlike the industrial districts in Europe where technical skill is widely diffused and the fluid environment promotes the diffusion of intangible technological capabilities and understandings (Saxenian, 1990). To explain the type of network ties we turn to Powell's three illustrative forms with the intention to compare the linkages to what we find in the Corridor. Table 2 summarizes the type and strength of ties for each network form.

Craft industries are characterized by project-based work where work process is informal and non-routine. The nature of craftwork implies a need to rely on others, both informally and formally, but work in craft industries also entails a relative degree of autonomy. Because of this autonomy, there is some need to rely on intermediary relationships. Thus, we expect a moderate number of weak and strong ties among such firms, since they entail indefinite and sequential transactions that are associated with early stages of the products life cycle. This in turn implies the need for a relatively high number of reciprocal ties, but these connections are utilized infrequently. According to TCA, the network should select appropriate organizational arrangements to manage the high to medium number of durable relationships that are needed to circulate confidential information.

Industrial districts are often characterized by a high degree of weak ties and reciprocal relationships, but a relatively low number of strong ties. The reason is that such networks rely extensively on the development and transfer of specialized knowledge. Moreover, they take a long-term perspective where security and stability encourages new ways of completing the tasks, particularly in places where production is widely decentralized and yet spatially concentrated. Thus, industrial districts foster collaboration and reciprocal innovation among networks of specialist producers (Saxenian, 1990). SNA identifies the social structure that allows actors in the district to respond to a positive action with a positive action, which leads to greater access to valuable resources.

Partnerships are formed to combine the strengths of two organizations to overcome their individual weaknesses, which in turn leads to more cooperative behavior and higher partnership performance. Such combinations often entail the commitment of specialized assets, thus necessitating the need for strong network ties. By definition, partnerships have such a relatively strong interdependency, thus producing a particularly high frequency of transaction.

Table 2. Powell's illustrative forms of network ties and characteristics of ties.

Network form	Number of weak ties	Number of strong ties	Number of reciprocal ties	Frequency
Craft industries	medium	medium	high	low
Industrial districts	high	low	high	medium
Partnerships	low	high	medium	high

As suggested by the hypotheses, TCA and SNA can help measure the Corridor's capacity to create knowledge and to determine if the configuration of network ties differs from other organizational relationships found in Powell's illustrations of networks. Moreover, understanding the degree to which the Corridor is similar to or differs from one or more networks, as described in Table 2, can help us understand the degree to which the Corridor is effective in knowledge creation. Know-how and detailed knowledge require little in the way of costly physical resources. Therefore, relative high amounts of weak and reciprocal ties and low amounts of frequent interaction and strong ties are relevant to Powell's notion of a network's ability to create knowledge.

5. Research methods

We tested the hypotheses by using network data to evaluate the patterns of relationships in the Corridor. The network analysis is a visual and mathematical perspective of networks. The visual portion maps the network connections, while the mathematical part of an analysis measures the relational ties and flows between organizations. This study uses the Lambert and Cooper (2000) method, which suggests establishing a smaller set of focal companies to examine the extent to which companies choose to exchange with other organizations in the network.

Since there have been few studies on the Corridor, this empirical research combines two methods, namely a case study method and a survey method as reference points with which to examine the relationship between the actual as opposed to the potential relationships that might exist within it. The case study was carried out using face-to-face interviews. Interview participants were asked questions related to the Corridor, and they were allowed to elaborate on their answers. The survey method was structured and formal. Each question required a specific answer. No elaboration or open-ended questions were included in the questionnaire.

Qualitative as well as quantitative methods were employed to provide a comprehensive understanding of the network relationships with the Corridor and how the structural characteristics of these relationships – i.e. uncertainty, frequency, and reciprocity – benefit organizations in different domains within the Corridor, as well as the performance of the Corridor as a whole.

Qualitative observations

We used a case study research methodology to provide an understanding of the real-life context of the Corridor. Between March 2010 and March 2012, 15 semi-structured interviews were conducted with individuals whose organizations make up the advisory and working group of the Corridor. The advisory group's role is to ratify and monitor the decisions of the 'working group.' The working group is responsible for initiation and implementation of the decisions related to public policy, branding, and technology transfer. The interview questions covered how the Corridor operates and its strengths and successes as a group. Individuals represented the research, intermediary, enterprise, and support organizations.

A case study is a desirable research strategy for the exploratory phase of an investigation because it 'investigates a contemporary phenomenon within its real life context, especially when the boundaries between phenomenon and context are not clearly evident' (Yin, 1994). Using this method enables the researcher to investigate the Corridor and the organizational ties in their natural environment.

Survey of organizations

The sampling frame of the accessible population was obtained from official sources. We found the list of organizations on the Animal Health Corridor's website. In each sample organization we targeted an 'informant,' whose daily work activities lend itself to a greater likelihood of inter-organizational interactions. This included chief research scientists, design engineers and communications professionals. Table 3 summarizes the responses and non-responses of the informants by domain.

Network questions

The survey questions were directed toward the 20 publicly traded organizations from the support and enterprise domains and 24 organizations from the intermediary and research organizations. The purpose was to gather data on linkages and connections in the Corridor. The study uses different strategies to construct the network questions. Because of the sensitive nature of some relationships, we employed a variety of question formats, including hypothetical, factual, and direct questions.

Social network format for asking questions

Social network questions were designed to obtain specific information about the relations people have with other

Table 3. Number of organizations responding to survey by domain type.

	Number of organizations sampled	Number of organizations responded	Number of organizations not responding
Support	8	3	5
Intermediary	14	8	6
Research	10	5	5
Enterprise	15	5	10
Total	47	21	26

members of a particular group. In general, well-constructed questions are ones that different respondents will interpret in the same way, be willing to answer, and be able to answer accurately (Dillman, 2000; Wellman and Berkowitz, 1988).

Hypothetical questions are very descriptive and are designed for sensitive questions about trust, for example, or questions that ask what exchange relationships they would explore as opposed to who they have worked with in previous years. Hypothetical questions are answered with a yes/no (0, 1) or on a 5-point scale that indicates strength of agreement or disagreement with a specific statement. Factual questions are explicit and related to the nature of the ties; i.e. the frequency, reciprocity, and the degree of specificity in the exchange relationship. These questions are answered with a yes/no or a 5-point scale. Direct questions are related to formal and informal relations between individuals in the network. These questions assess the degree of the ties' strength (or weakness) in the Corridor. The direction questions are answered in a yes/no format.

Data collection

This study incorporated web-based social network survey data collection software to design social network surveys, to collect social network survey data, and to retrieve and export data pre-formatted for social network analysis. We administered the survey over the Internet using a secure website from Network Genie (Greensboro, North Carolina). It allowed us to design the network survey and survey questions, manage the social network project, collect the social network survey data, and retrieve and export formatted data into a master matrix to conduct an analysis. The master matrix is analyzed in UCINET 6 (Lexington, Kentucky) for all network analyses and was used for the network visualization. The master matrix reflects the responses and the extent of organizational ties, hypothetical relationships, previous collaborative work, and the existence of strong positive or negative past interactions. UCINET is commonly used software in the network sciences. It provides a means to perform the quantitative and qualitative analysis of social networks.

6. Results

The network composition is described according to their ties. Outbound ties are the number of ties to organizations by a focal organization having or likely to have a transaction. Inbound ties refer to the number of ties a focal organization has that have been identified as having or as likely to have a transaction relationship with another organization. Reciprocal ties exist when two organizations have inbound and outbound ties with each other. Inbound and outbound ties are indications of the movement of information or materials between organizations. The equal or unequal distribution of inbound and outbound ties is a signal of reciprocity and the frequency of dyadic relations. Outbound and inbound ties also provide evidence of weak and strong ties, respectively. We begin with an analysis of the ties in the Corridor. Table 4 summarizes the ties in the Corridor by domain.

A next step is to describe how these ties are arranged to explain the interdependent relationships (if any) in terms of the strength of ties according to the hypothesis. With this understanding, we can characterize the ties by the extent to which counterparties in the Corridor rely on trust (personal connection) or a contractual provision (technical connection) to carry out the exchange.

Strong ties

One of the most common measurements of a strong tie is the density of the network. Network density (D), for example, measures the number of nodes that are actually tied to other nodes in the network and is expressed as a proportion of all the possible ties in a network, so that:

Table 4. Network composition by the number of inbound and outbound ties.

Domain and number of organizations in the corridor	Number of outbound ties	Number of inbound ties	Total number of ties
Enterprise (36)	88	132	220
Intermediary (18)	110	101	211
Research (10)	89	72	161
Support (110)	71	150	221

$$D = \frac{\lambda}{N(N-\lambda)/2} \quad (1)$$

where λ denotes the total number of lines (ties) present and N is the number of organizations in the network. Since n=174 organizations and λ=498, the density for the Corridor is calculated as 0.02, suggesting this network is not dense at all, but rather is very loose. Most network studies regard density levels above 60% as dense networks. Based on this calculation, the Corridor can be described as a sparse network of organizations with a relatively low number of connections among them.

The tests for equivalence or similarities reveal whether the inbound ties from one organization are from the same organization that has outbound ties to another. This suggests the organizations are interacting with the same firms. The extent of the interdependent relationship might prevent opportunistic behavior or influence how one firm could adopt innovations similar to another.

The measure of similarity is particularly useful when the data on ties are 'valued,' that is, tell us about the strength and direction of association rather than simple presence or absence. Pearson correlations range from -1.00 (meaning that the two actors have exactly the opposite ties to each other actor), through zero (meaning that knowing one actor's tie to a third party doesn't help us at all to guess what the other actor's tie to the third party might be), to +1.00 (meaning that the two actors always have exactly the same tie to other actors – perfect structural equivalence). Based on responses to survey questions related to long-term relationships, 12 organizations have strong ties. Table 5 shows the similarities and dissimilarities of the structures. Most organizations in the Corridor have patterns of greater than 0.5, indicating the organizational pairs have similar ties with other organizations. Organizations with correlations less than 0.5 indicate that organizational pairs have dissimilar ties.

In Table 5, organizations 11 and 13 (intermediary and support organizations) have identical ties, meaning the

Table 5. Equivalent relationships based on survey responses.

Organization	11	13	51	65	82	94	106	158	163	165	166	169
11-Intermediary	1											
13-Support	1	1										
51-Intermediary	0	0	1									
65-Enterprise	0	0	-0.02	1								
82-Enterprise	0	0	0.71	-0.02	1							
94-Intermediary	0	0	-0.02	0.81	-0.01	1						
106-Enterprise	0	0	0.27	0.81	-0.02	0.70	1					
158-Research	0	0	0.40	0.27	0.70	0.34	0.27	1				
163-Intermediary	0	0	-0.01	0	-0.01	-0.01	0.57	-0.01	1			
165-Support	0	0	-0.01	0.57	-0.01	0.71	0.50	-0.01	0	1		
166-Enterprise	0	0	0.81	-0.02	0.81	-0.02	0.27	0.81	-0.01	-0.01	1	
169-Intermediary	0	1	0.57	-0.01	0.71	-0.01	-0.01	0.50	-0.01	-0.01	0.57	1

pair have exactly the same ties to other organizations. That is, they are structurally equivalent to one another. Likewise, organizations 13 and 169 have the same organizational pairs. While there are several organizations with negatives values, this is an indication the pairs have opposite ties in the Corridor.

The network tests of density and similarities did not give conclusive evidence of prevalent strong ties throughout the network. The Corridor, as a network form, shows more signs of strong ties seen in industrial districts compared to the ties found in craft industries and partnerships. The hypothesis on strong ties suggested the lack of strong ties would lead to lower numbers of asset specific relationships in the Corridor. Based on the answers from a factual question, less than 10% of the respondents had specifically designed tools, equipment or machinery or accumulated specific knowledge regarding animal health and nutrition. Thus, asset specificity does not appear to be high for relationships among firms, which further supports the observation that there are not a significant number of strong ties among firms within the Corridor.

Reciprocal ties

In all network forms – industrial districts, craft industries, and partnerships – we expect to find medium to high degrees of reciprocity. Table 4 shows the possibility of reciprocal relationships in the Corridor, i.e. firms with uneven numbers of inbound and outbound ties to one another illustrate a very small degree of reciprocity. The firms in the research and intermediary domain showed some evidence of reciprocity. These domains show nearly the same number of inbound and outbound ties, while firms in the support and enterprise domain had a disproportionate number of inbound and outbound ties. Thus, there appears to be a low to moderate number of reciprocal ties within the Corridor.

A more precise reciprocity test reveals that a small number of reciprocal relationships exist. According to traditional models, ties between two organizations are usually asymmetric in information. Overall the relationship is asymmetric and there is rarely an even flow of information between two trading parties (Cook, 1977; Emerson, 1962,). While ties are not symmetric, they are reciprocated. For instance, organizations in the intermediary domain typically work to increase the welfare of the Corridor by garnering legislative support or attracting other enterprises into the region. In turn, firms in the enterprise domain support startup or relocating firms to the area, which might support the intermediary firms' goals for the region. Also by design, firms might avoid too much interdependency in order to maintain autonomy.

A traditional way to measure reciprocity in the network is to quantify 'r' as the ratio of the number of links pointing in both directions $L\leftrightarrow$ to the total number of links L:

$$r = \frac{L\leftrightarrow}{L} \qquad (2)$$

For a purely bidirectional network r=1, while r=0 for a purely unidirectional network. In general, the value of r represents the average probability that a link is reciprocated (Wasserman, 1994). The results from a factual survey question, regarding reciprocal relationships, revealed that 26% organizations have an r=1 or purely bidirectional relationships, 52% have an r=0, and the remaining 12% of organizations have r values less than 0.25. For hypothetical questions related to reciprocity, 30% were r=1 and 38% and 32% were r=0.25 or less.

Menard (2004) suggests the lack of reciprocal relations is due to the nature of coordination in highly decentralized systems. That is, organizational arrangements in less dense networks rely on reciprocity. However, the relatively low degree of reciprocity in the Corridor accounts for a divergent pattern not found in stable and secure networks. Each network form needs to acquire or have access to resources. The inability to receive these may lead to interim arrangements that constantly require contract renegotiations and higher transaction costs.

Frequency of ties

On questions related to frequency, participants were asked how often they communicate with other organizations or hypothetical questions about whether they would consider organizational arrangements like contracts or joint agreements in the Corridor. Nearly 60% of the organizations were identified as having never been in contact with other firms. This is an indication of a high number of isolates, that is, completely unconnected firms. The remaining 40% of the respondents acknowledge their organization had daily or weekly contact with other organizations in the Corridor. Table 6 shows the frequency of such connections within the Corridor. We should expect to find frequency levels of interactions above 0.50 for the entire network or across domains. The higher the frequency value, the greater the chance for formalized agreements and other benefits from interaction.

Hypothesis 3 posits a correlation between frequency and interdependency. Based on the results of Table 6, there

Table 6. Variations in the frequency of interaction across relationships.

	Interactions across intra-domain relationships	Interactions across inter-domain relationships	Combined
Number	20	152	174
Frequency of interaction	0.61	0.25	0.40
Formalization of agreements	0.63	0.36	0.49
Benefits from interaction	0.78	0.55	0.61

appears to be moderate frequency of ties among firms within domains but relative infrequency across domains, suggesting a lack of interdependency among firms across the domains. Thus, overall we conclude that there is a moderate level of frequency within the Corridor.

Weak ties

We use structural hole and weak spot tests to measure the Corridor's ability to share new information. The structural hole test (Burt, 1995) measures the effective size of the Corridor or the number of redundant ties in the Corridor, and the weak spot test determines the points in which structure would become divided into unconnected parts. Thus, weak spots represent the organizations that connect others in the network (Hanneman and Riddle, 2005). The organizations identified as weak spots are important because they influence the flow of information and resources in the network. See Figure 3 for an illustration of a weak spot.

The number of weak spots in the network suggests a likelihood that the specific knowledge created will result in opportunistic behavior. However, weak spots in the network are mostly within organizations in the intermediary domain.

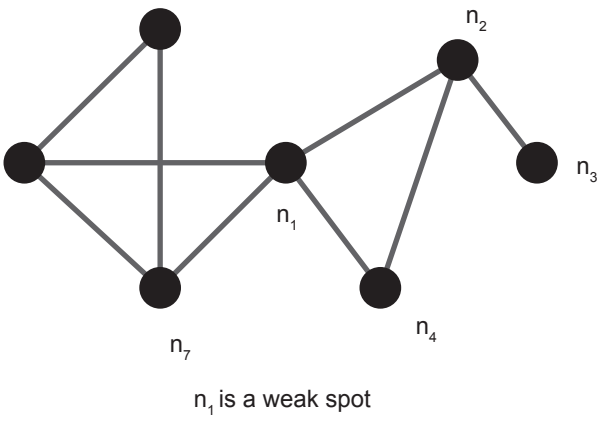

Figure 3. Network illustration of a weak spot.

The primary functions for intermediary organizations are to promote the Corridor. Therefore, they have no or little incentive to 'hold up' other firms in the network to garner better trading terms. There are 10 organizations that fulfill a weak spot. That is, if they were removed from the Corridor, 70 other organizations would become disconnected. The intermediary domain has 40% of the organizations representing a weak spot and accounts for 47% of the organizations that could become disconnected from the network. The proportion of non-redundant ties in the Corridor totals 76%. That is, 76% of the ties in the Corridor are between two organizations and those organizations have a chance to act as a broker between two unconnected organizations. Table 7 identifies each organization that represents weak spots and the domains across the Corridor.

Within the Corridor there are relatively more weak ties than strong, reciprocal or frequent ties in the Corridor. The reason for this can be found in the evidence above indicating that a significant number of Corridor firms have the potential to become disconnected if one of the 10 firms were removed. Additionally, the frequency levels are low across domains, and the density and correlation results do not show significant signs of strong ties throughout, and there are relatively few reciprocal ties in the network.

Table 7. Number of weak spots by domain and organization identification number.

Domain	Intermediary	Support	Intermediary	Enterprise	Research	Research	Enterprise	Support	Intermediary	Intermediary
Org. ID #	11	13	51	82	92	96	106	145	163	169
# of weak spots	15	13	2	8	2	3	4	6	4	12

Animal health corridor versus network forms

Overall, the animal health and nutrition Corridor appears to have a high number of weak ties, a relatively low number of strong and reciprocal ties, and a moderate number of frequent ties. In view of Table 2, the Corridor appears to be most closely related to industrial districts, with an exception in the number of reciprocal ties. Industrial districts are expected to have a high number, whereas the Corridor contains a low number. While reciprocity is prevalent in all network forms stylized by Powell, it is fundamentally lacking within the Corridor.

7. Discussion and conclusion

Our analysis of interdependency within the Corridor bridges two established theoretical frameworks – TCA and SNA. In this approach, neither theoretical framework should be given priority over the other. Our analysis calls for an integration of two frameworks, since together they postulate the types of linkages that are favorable for the flow of materials and theorize the linkages for information sharing in a diverse network. The interdisciplinary approach is particularly useful if there are challenges to the stability of a network. Instability often occurs when joint efforts and competing goals collide. These obstacles continuously create tension among partners, who aim to maintain a fruitful cooperation while ensuring their own organization's objective is being met. A network in which the transfer of knowledge and material do not require reciprocity will be expected to transfer knowledge and material in an unbalanced way (Bouty, 2000; Giuliani and Bell, 2005).

While the triangulation of methods and independent data sources provides more robust inferences than a single source of data, by combining insights from transaction cost theory and SNA and by analyzing the nature of the ties among firms, we come to the following specific conclusion about the Corridor. The Corridor exhibits characteristics of an industrial system built on mostly unilateral relationships where information and resources flow from one organization to another and little information and resources are given in return. These findings have implications for knowledge creation and transfer within a network generally and within the Corridor specifically.

Mutual dependence becomes valuable if it safeguards transactions and influences the flow of resources and information. In *The Competitive Advantage of Nations* (1990), Michael Porter introduced the importance of hybrids and networks for competitiveness. Porter defined the network as 'geographic concentrations of interconnected companies, specialized suppliers, service providers, firms in related industries, and associated institutions (for example, universities, standards agencies and trade associations) in particular fields that compete but also cooperate' (Porter, 1998: 197-198). Thus, a clear condition for the existence of a network is the presence of linkages between companies and institutions. In particular, these linkages are considered important for productivity growth.

Where there is no interdependency, a network will be unstructured and stochastic in nature. The lack of reciprocal ties will prevent the establishment of other organizational forms that require reciprocity and cooperation among members, such as franchising, joint ventures, consortia, and strategic alliances. These forms grow out of interdependent relationships in order to resolve problems through discussion and to develop rules and norms of reciprocity to ensure cooperation (Podolny and Page, 1998; Powell, 1990; Uzzi, 1997). There are two general approaches for understanding how information sharing and material flows create interdependence. The weak-tie approach suggests a large, non-redundant network is most advantageous. In contrast, the strong tie approach suggests that a closed, tightly knit network of ties is most advantageous.

Cantner *et al*. (2011) suggest that weak ties induce interdependency in terms of the innovations created. The Corridor represents an example of a network that has a strong knowledge base and is a local system that is not dense and tends to be open to a high degree of interdependence with other organizations. The evidence presented in Table 7 is consistent with other research findings regarding weak ties. Weak ties enhance relationships by facilitating greater interdependent behavior in the network (Gulati, 1999). Intermediaries particularly contain more links, combining arm's-length and embedded ties that increase the possibility of new information transferred within the network. Those tie combinations provide an optimal network structure, because each type of relation serves different functions: 'Embedded ties enrich the network, while arm's-length ties prevent the complete insulation of the network from market demands and new possibilities' (Uzzi, 1997: 59). To this end, we propose the industrial system collectively as the unit of analysis. The industrial system construct builds on ideas advocated by the theoretical frameworks of SNA and TCA. This study is consistent with how networks cooperate with other firms and leads to a higher innovative capacity up to a certain number of ties (Cantner *et al.*, 2010); cooperating with public research institutes show a significantly higher innovative capacity (Cantner *et al.*, 2010); and intermediaries (Cantner *et al.*, 2011) induce cooperation success in terms of innovations generated. Moreover, TCA deserves priority

consideration when explaining the industrial system. The idea is that formal arrangements provide opportunities to view the nature of interdependent transactions (Menard, 2010).

The key substantive conclusion we draw is that the pattern of interdependence follows a functional logic. Weak ties are more predominant in a network where access to knowledge and resources is important, while the lack of strong ties prevents access to relationship specific assets. In a network where there are more weak ties, power can be relatively evenly distributed. A network structure like this offers many opportunities for future development that will eventually lead to new organizations, which are interdependent and influence knowledge creation.

Industrial systems exist to create products and services. As a result, the industry structure will continue to adapt and evolve. One emerging change is the importance of interdependent relations for furthering information exchange and access to resources. Future research should continue to consider not just the existence or non-existence of a tie but the strength of content of the organizational relationship. The potential future impacts of the bioscience industry are quite significant, and therefore it is important to note that the business models driving bioscience innovation are being constantly reshaped.

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