How can clusters sustain performance? The role of network strength, network openness, and environmental uncertainty

ABSTRACT

This paper draws on social network theory to develop a model of regional cluster performance. We suggest that high performing regional clusters are underpinned by (1) network strength and (2) network openness, but that the effects of these on the performance of a cluster as a whole are moderated by environmental uncertainty. Specifically, the positive effects of network openness on cluster performance tend to increase as environmental uncertainty increases, while the positive effects of network strength on cluster performance tend to decrease as environmental uncertainty increases. Our findings have theoretical and practical implications for social network research in general, and cluster research in particular.

Keywords: geographical clusters, cluster performance, social networks in clusters, network strength, network openness, environmental uncertainty

1. Introduction

There is increasing recognition that clusters of co-located firms play a key role in supporting innovation and wealth creation. For example, Schmitz and Nadvi (1999: 1503) concluded that clustering helps firms to 'overcome growth constraints and compete in distant markets', while Porter (2000) has argued that the economic performance of regions and ultimately nations is contingent upon the innovativeness of their industrial clusters. The upshot, as St John and Pouder (2006: 142) noted, is that "virtually every state in the US has a cluster development strategy as part of its economic development plan". These strategies are not confined to the US or other developed economies, however; they are also evident in many emerging markets (Bell and Albu, 1999; Bell and Giuliani, 2007; Giuliani and Bell, 2005; Parrilli, 2004).

Consequently, there has been growing academic and policy interest in the factors that underpin high performing clusters, and a substantial body of scholarship has emerged in geography, economics, and more recently strategic management, which considers the social and economic processes that drive processes of agglomeration. Broadly speaking, three sets of partly overlapping arguments within this literature can be identified.

For some scholars, high performing clusters are underpinned by the *economic efficiencies* they confer on constituent firms, including increased specialization, reduced transaction costs and enhanced reputation. From this perspective, spatial proximity allows firms to take advantage of scale and positive externalities such as an abundance of highly skilled labor, specialized subcontractors and rapid flows of information (Ahoaronson, Baum and Feldman, 2007; Hirschman, 1958; Kaldor, 1972; Krugman, 1991; Marshall, 1920; Rosenthal and Strange, 2003). Moreover, proximity is thought to facilitate the profitable de-integration of value chains by allowing greater specialization of inputs and outputs, leading to

improved efficiency and greater speed to market (Feldman, 2000; Herrigel, 1993; Storper, 1997).

A second strand of scholarship focuses upon the distinctive *dynamics of knowledge* transfer among co-located firms as the main determinant of cluster performance (Bathelt, Malmberg, and Maskell, 2004; Tallman, Jenkins, Henry, and Pinch, 2004; Tallman and Phene, 2007). This work posits that the key advantages of clustering are to be found in processes of knowledge creation and learning within geographical regions. Specifically, through shared conditions and experiences, clustering is thought to increase the speed and ease with which members can find, access and transfer valuable knowledge that is difficult to codify - because of its 'stickiness' (Nelson and Winter, 1982) tacit knowledge may be exchanged more effectively through frequent interpersonal contacts that are facilitated by proximity (Lawson and Lorenz, 1999).

A third strand in the literature, and the one with which we are concerned in this paper, considers that cluster performance is rooted in the *social networks* that bind co-located firms. This work draws heavily on ideas from economic sociology, and in particular Granovetter (1985) and Uzzi (1996, 1997). From this standpoint, it is the nature of the relationships that emerge across organizational boundaries, both within and outside a given cluster, which is the key distinguishing feature of clustered economic activity (Aydalot and Keeble, 1988; Cohen and Fields, 1999; Harrison, 1992). The social network perspective has been used to explain the success of many clusters and regions around the world, the most notable of which are the Italian industrial districts (Best, 1990; Goodman, Bamford, and Saynor, 1989; Piore and Sabel, 1984), and American cases such as Orange County (Scott, 1986) and Silicon Valley (Larsen and Rogers, 1984; Saxenian, 1994).

Two network characteristics are thought to be especially important for high performing clusters (Schmitz and Nadvi, 1999; Rugman and D'Cruz, 2002): (1) strong

network ties, which are assumed to facilitate the transfer and assimilation of knowledge within clusters; and (2) openness to new network, which are assumed to provide cluster members with access to new knowledge and ways of operating. More fundamentally, implicit in this scholarship is the assumption that successful clusters exhibit these network characteristics regardless of external circumstances or market-related factors.

Yet previous research suggests that the networks of successful clusters that specialize in different industries and that are located in different regions may vary considerably (Aharonson, Baum, and Plunket 2008; Robinson, Rip, and Mangematin 2007; Stuart and Sorenson 2003). For example, the network processes that underpin the entertainment cluster in Hollywood are clearly far removed from those that underpin Route 128 Boston (cf. Porter, 1998a; Saxenian, 1994). More concretely, Gordon and McCann (2000), Markusen (1996) and St John and Pouder (2006) have identified analytically distinct types of cluster networks, and have argued that network interactions across clusters, both successful and less successful, are far from homogenous. This suggests that the network characteristics of high performing clusters may vary considerably, and that more work is needed to understand the relationship between network configuration and cluster performance.

In this paper we address this ambiguity in the literature by examining the social network properties of industrial clusters and their effects on cluster performance. We follow Gulati, Nohria, and Zaheer (2000) and define an organization's network as its set of relations, both horizontal and vertical, with other actors that are of strategic significance for the exchange partners. More specifically, we study eight clusters in the automotive, information technology, chemical, and biotechnology industries in two different countries in order to explore: (1) the effect of network strength on cluster performance; (2) the effect of network openness on cluster performance; and (3) the effect of environmental uncertainty on the relationships between network strength, network openness and cluster performance.

Consistent with the extant literature, we find that network strength and network openness are both positively correlated with cluster performance. Indeed, these network characteristics arguably constitute the building blocks of competitive advantage in clusters. However, we also find that the relationships between network openness, network strength and cluster performance vary according to environmental uncertainty: as environments become more uncertain, the relative importance of network openness for cluster performance increases, while the relative importance of network strength decreases. By showing that the social network characteristics of successful clusters are more diverse than has been portrayed in much of the literature to date, and that the social network properties required for cluster success are contingent on the environmental uncertainty faced by constituent firms, we offer new insights into the performance of regional clusters.

The remainder of the paper is structured as follows. The next section gives a description of our conceptual framework which connects social network theory to cluster performance, and considers the influence of environmental uncertainty. We then outline the procedures we used to collect and analyze our data and provide background information on the clusters in our sample. This leads to a section in which we present our results. In the final section we discuss how our model adds to the clusters literature, and draws implications for managers and future research.

2. Network strength and openness, environmental uncertainty, and cluster performance

In this section, we formalize our expectations about the impact of network strength and network openness on cluster performance. In summary, both the strength and openness of networks are expected to have a positive effect upon cluster performance. However, we consider that the relative importance of these two network characteristics will vary in their

impact on cluster performance according to different environmental circumstances. We therefore introduce the concept of environmental uncertainty as a potential moderator of the relationships between network strength and network openness on cluster performance. We expect that as environmental circumstances become more uncertain, network openness will have an increased effect on cluster performance, while the positive effect of network strength is expected to be reduced.

We recognize, of course, that the notion of cluster performance is not straightforward, and there is no consistently applied definition or set of measures that has been used to conceptualize the term. This is evidenced by the myriad of ways that the concept has been operationalized in the literature. For example, scholars have considered cluster performance in terms of innovation (Audretsch, 1995), rates of technology transfer (Audretsch and Feldman, 1996), employment growth (Piore and Sabel, 1984), and local wage growth (Porter, 2003). In this paper we conceptualize cluster performance as the growth in new firms, jobs and (financial) output in a given cluster, controlling for the national growth rate of these measures in the relevant industry. We believe that this conceptualization captures the key economic benefits of clustering which underpin the high levels of interest in the concept. It is also a practical approach as it allowed us to draw upon data collated by government statistical services in order to reliably measure and compare cluster performance.

We also recognize that defining and clearly delineating a given cluster is a difficult and ambiguous task. Following Porter (2000: 254), we define a cluster as ‘a geographically proximate group of interconnected companies and associated institutions in a particular field, linked by commonalities and complementarities’. As Porter (2000) noted, the geographic scope of clusters may range from a city or region to neighboring countries. Along the vertical axis of the value chain are customers and suppliers of specialized inputs. Along the horizontal axis are producers of complementary products and specialized infrastructure, including

financial services organizations and firms in related industries. Some clusters may also include other key factors such as universities, public research centers and trade associations. Because of these variations in scope, the boundaries of a cluster are seldom defined by standard industrial classification systems. The automobile industry, for example, relies heavily on specialized suppliers (Dyer, 1996; Dyer and Nobeoka, 2000), which are not necessarily in the automotive parts industry as measured by national statistical services, but may belong to the engineering and machinery, electronic equipment, information technology and steel industries. Indeed, 'equating a cluster with a single industry misses the crucial interconnections with other industries and institutions that strongly affect competitiveness' (Porter, 1998b: 5). In this paper we followed Porter's (1998a) approach to cluster identification which involves (1) looking for a geographic concentration of firms in the same industry, and (2) looking horizontally for industries passing through common channels or producing complementary products. We examined four clusters in Canada (all of which were in the Greater Toronto Area) and four in Austria (two in Vienna and two in the Upper Austria Area). We expand on this process and our rationale for the selection of the eight clusters in our sample in the methods section.

2.1. Network strength and cluster performance

We bring together common elements from the social networks literature to define network strength as a function of the (1) frequency, (2) intensity, (3) stability of interactions, and (4) levels of trust, between cluster members (Antia and Frazier, 2001; Granovetter, 1973; Rindfleisch and Moorman, 2001; Uzzi, 1996, 1997). The apparent benefits of strong networks have been well documented in the management and other social scientific literatures. Most obviously, strong networks may provide access to resources which would otherwise be beyond the scope of a single firm (Portes and Sensenbrenner, 1993). These

resources may be tangible, but it is the transfer of tacit knowledge and other intangible resources, many of which are embedded in processes, that arguably provide the greatest added value to firms that are members of strong networks (Grant, 1996). Another key benefit of strong networks is that, through repeated interactions, constituent firms are able to better assess their partners' resources and capabilities, making complementarities more visible and helping firms to organize transactions in ways that maximize the synergies between them (Bell et al., 2009; Gulati, 1995; Gulati and Gargiulo, 1999; McFayden and Cennalla, 2004). The high levels of confidence in exchange partners' good intent (Mishira, 1996) and reliability (Ring and Van de Ven, 1994) that characterize strong networks also increases trust and reduces the likelihood of malfeasance among network members. Kenis and Knoke (2002), for example, found that strong networks expose actors' mutual dependencies and obligations, leading them to resist opportunistic behavior because of the costly sanctions that are likely to arise. Not only does the increased trust associated with strong networks augment firms' *willingness* to exchange knowledge and other resources, it also improves their *capacity* to do so (Eisingerich et al., 2009; Mesquita, 2007). This is because partners require co-ordination and problem solving skills in order to capitalize upon the benefits of network membership. Indeed Uzzi (1996) argued that "coordinated adaptation" is crucial if the economic advantages of networks are to be realized, and several studies have shown that strong networks created through site-specific investments facilitate information transfer and increase the speed to market by allowing problems to be resolved more effectively. For example, Saxenian (1994: viii) argued that the success of Silicon Valley was rooted in strong regional networks that allowed constituent firms to 'discuss common problems, debate solutions, and define the shared identities that enable an industrial community to transcend the interests of independent firms'. Thus while network membership may offer potential resource advantages for participating firms, 'it is the quality of the relationship between

network members that enables true and full realization of this potential' (Kale, Singh, and Perlmutter, 2000: 233). This line of argument suggests that strong networks are liable to be a key feature of high performing clusters, and leads to our first proposition:

Proposition 1: Increased network strength will be associated with increased overall cluster performance.

2.2. Network openness and cluster performance

We define network openness as a function of (1) network membership diversity, (2) willingness to accept new members, and (3) the extent to which there are ties to organizations outside the cluster (Romanelli and Khessina, 2005; Zaheer and George, 2004). Networks characterized by a diverse and fluid membership have the advantage of being able to access a wider range of information and resources in order to facilitate product development and build market knowledge (Breschi and Malerba, 2001). By contrast, concentrated levels of exchange with only a few partners may inhibit access to key information and new opportunities (Burt, 1992), thereby forming a barrier to innovation (Coleman, 1988; McFadyen and Cennalla, 2004).

There is empirical support for this position. For example, Rodan and Galunic's (2001) findings show a positive relationship between knowledge heterogeneity in networks and the levels of innovation exhibited by network members. Similarly, McEvily and Zaheer (1999) found that firms with access to diverse information were able to acquire more competitive capabilities than firms whose networks were relatively homogeneous with respect to information flows, and Markusen's (1996) examples of successful satellite platforms among US clusters underscore the importance of inter-cluster networks for cluster performance in some sectors. This suggests that clusters are likely to perform better when they comprise members with differing but complementary resources, competencies and information flows.

More generally, international linkages are a prominent characteristic of many successful clusters around the world (Bresnahan, Gambardella, and Saxenian, 2001). Indeed, economic development is often particularly dynamic at the intersections of clusters, 'where insights, skills, and technologies from various fields merge, sparking innovation and new businesses' (Porter, 1998a: 85).

The upshot is that clusters that are unwilling to accept new members risk stagnation (Pouder and St. John, 1996; McFadyen and Cennalla, 2004). For example, Markusen (1985) argued that Pittsburgh in the late nineteenth and Detroit at the beginning of the twentieth century resembled Silicon Valley in terms of its dynamism and success, but that their inward-looking orientations left both vulnerable to the maturation of the steel and automotive industries. By contrast, many of the most successful clusters around the world, which Bresnahan and colleagues (2001) label 'the new Silicon Valleys', are underpinned by their openness to a range of potential partners, both locally and internationally. Accordingly, we propose:

> *Proposition 2: Increased network openness will be associated with increased overall cluster performance.*

We recognize that the relationships between network strength, network openness and cluster performance may be less linear than is suggested by our first two hypotheses. For example, Uzzi's (1997) study of 23 apparel firms located in New York City showed that while strong ties can engender important competitive advantages for network members, they may also constrain firms' ability to respond to changes in their competitive circumstances. Moreover, Markusen (1996) found that while open clusters were often crucial for innovation, some are too open, which can undermine their internal and geographical stability. Nonetheless, we proceed with our hypotheses as outlined given our analytical focus on

clusters (rather than industry-based networks); we are more persuaded by the view that it is very difficult for an entire geographical cluster to become overembedded. Indeed lack of connectedness, not excessive connectedness, is more often the key challenge facing cluster members (Saxenian, 1994).

2.3. Environmental uncertainty and cluster performance

There is considerable support in the clusters literature for our first two hypotheses concerning the relationships between network strength, network openness and cluster performance. For example, Saxenian (2006) offers a fascinating account of the emergence of some of the world's fastest growing clusters, which are characterized both by dense local networks and by links to other innovative regions. Similarly, McKendrick, Doner, and Haggard (2000) point out that while Silicon Valley and other US electronics clusters are well known for their strong intra-regional networks, their relationships with suppliers and manufacturers in Southeast Asia also constitute a key element of their success. These authors further noted that local networks within Silicon Valley are not static, but rather are flexible in order accommodate new partners and sources of knowledge. In addition, Owen-Smith and Powell's (2004) study of the Boston biotechnology industry concluded that as well as strong linkages with a range of local actors such as universities, government laboratories and venture capital firms, links to national and international partners also played a crucial role in development of that cluster. This finding was echoed by Bresnahan and colleagues' (2001) results.

However, despite the evidence connecting network strength and network openness to cluster performance, the relative importance of these network characteristics in different competitive circumstances remains unclear; scholars have tended to assume that network strength and network openness are both key elements of high performing clusters regardless

of the context in which a given cluster operates. Yet, as noted in the introduction, a range of network configurations within successful clusters have been identified in the literature. For example, Markusen's (1996) study of high performing clusters in Brazil, Japan, South Korea and the US, identified four distinct types of cluster networks. She noted that these networks differed both in terms of the extent to which knowledge was shared between cluster members, and the extent to which cluster members engaged in relationships with external actors. Gordon and McCann (2000) and St John and Pouder (2006) also identified the existence of different network structures within clusters. Thus, there is evidence of significant diversity in the social network characteristics of successful clusters.

Drawing on the concept of environmental uncertainty, we argue that the relative importance of network strength and network openness for cluster performance is not homogenous but rather is contingent upon environmental conditions. More specifically, we propose that environmental uncertainty has a moderating effect on the relationships between network strength, network openness and cluster performance. We adopt Kohli and Jaworski's (1990) definition of environmental uncertainty, which comprises: (1) market turbulence or the rate of change in the composition of customers and their preferences; (2) competitive intensity; and (3) technological turbulence or the rate of technological change.

Two important recent studies (Beckman, Haunschild, and Phillips, 2004; Rowley, Behrens, and Krackhardt, 2000), both of which draw on March's (1991) notion of exploration and exploitation in organizational learning[1], have considered the moderating effect of environmental uncertainty on the relationship between network configuration and business performance. Specifically, Rowley and colleagues (2000) examined the relative importance of weak versus strong network ties for organizational performance under conditions of uncertainty through a large-scale study of the semiconductor and steel industries, while Beckman and others (2004) examined the relative importance of new versus existing

alliances for organizational performance under conditions of uncertainty though a study of the networks of the 300 largest US firms from 1988 to 1993. These studies represent key contributions to the networks literature, and we draw in part on this work to inform our predictions about how environmental uncertainty affects the relationships between network strength, network openness, and cluster performance.

We expect that the positive effects of network openness on cluster performance will increase as environmental uncertainty increases. This is because uncertain environments demand that firms continually modify their product lines and capabilities in order to maintain competitive advantage as new market preferences, competitors and technologies emerge. Indeed, environmental uncertainty is likely to place a premium upon innovation as a key dimension of competitive advantage. Network openness is crucial in this respect, because new sources of information are more likely to enter a cluster both if it comprises a diverse range of actors, and if new actors are continually being absorbed.

Network openness also encourages experimentation and processes of active search, which increase the likelihood that new opportunities will be identified and that the cluster will contain the capabilities to exploit them (March, 1991). This suggests that cluster openness may serve as a coping strategy that accommodates and even embraces environmental change, rather than resisting or ignoring it. Paradoxically, clusters that are open to new firms may experience more stable patterns of exchange than 'closed clusters', which are at risk of becoming obsolete when faced with radical changes in their environment (Scott, 1986).

Some empirical work in the networks literature lends general support to this position. For example, Rowley et al. (2000: 371) found that networks comprising weak ties, which act as 'local bridges' to distant others possessing unique information, led to increased firm performance when firms were required to exploit emerging innovations and respond to other

significant environmental changes. Similarly, Beckman et al. (2004: 271) found that firms which broadened their networks to include new actors in the same industry were able to reduce the market uncertainty that they faced because '[p]ossibilities for collective action are enhanced with these new relationships'[2]. Moreover, in the context of biotechnology start-ups, which operate in highly uncertain environments, Baum, Calabrese, and Silverman (2000) found that new ventures whose networks allowed greater access to a wide range of information and capabilities enjoyed superior early performance. We therefore contend that:

Proposition 3: The positive effects of network openness on cluster performance tend to increase as environmental uncertainty increases.

While we expect the benefits of network openness for cluster performance to increase as environments become more uncertain, by contrast we expect the positive effects of network strength on cluster performance to decrease as environmental uncertainty increases. This is because the advantages of strong relationships, which include predictability and stability of interaction, may not be as applicable or useful in uncertain environments. In particular, strong relationships with existing partners are less likely to provide access to new information about markets, competitors and technologies. Given that, as noted above, access to such information often underpins firms' capacity to innovate and more generally to build competitive advantage, the benefits of strong network ties are liable to be less relevant. More generally, Larson (1992) has shown that strong networks are fundamentally long-term governance mechanisms because of the significant time and resources required to build them. Such strong and established network ties are likely to be ill-suited to respond to new challenges faced by organizations given short term changes in competitive circumstances. While some scholars have suggested that short term relationships may become highly effective in a short period of time through the development of 'swift trust' (Meyerson, Weick,

and Kramer, 1996), we consider that this unlikely in most clusters given the scope and scale of their networks.

There is empirical work in the networks literature that lends general support to this line of argument. Most notably, Rowley et al. (2000) found that strong networks lead to increased firm performance in environments characterized by low levels of uncertainty, but not when firms faced uncertain environments. These authors are careful to point out that strong networks were found not to be detrimental to firm performance in uncertain environments, as has been suggested by some scholars, which is also consistent with our assumptions. Similarly, Beckman et al. (2004: 271) concluded that reinforcing or strengthening existing alliances in uncertain environments does not reduce the levels of market uncertainty faced by firms 'because no new knowledge is obtained and no new possibilities for collective action are created'[3]. Finally, Afuah (2000) found that strong networks of suppliers, customers and 'complementors' were a key source of competitive advantage in the computing industry when environmental conditions were stable, but that these advantages quickly dissipated following periods of technological change. This line of argument leads to our final proposition:

Proposition 4: The positive effects of network strength on cluster performance tend to decrease as environmental uncertainty increases.

Just as we acknowledged above that the relationships between network strength, network openness and cluster performance may be less linear than is suggested by our first two hypotheses, we also need to acknowledge that the way in which environmental uncertainty moderates these relationships may be more nuanced than suggested by our third and fourth hypotheses. Specifically, the effects of particular network structures may differ depending on the focus of partners and the types of uncertainty that they are familiar with (cf. Gulati and Higgins, 2003; Podolny, 2001).

Thus in the context of our study, it could be argued that as environmental uncertainty increases, the positive effects of network openness on cluster performance will only accrue to clusters where firms are used to dealing with uncertainty (e.g. biotech, IT) and that have developed an associated set of competencies to build and manage different kinds of relationships with multiple firms; for clusters characterized by low levels of uncertainty (e.g. automotive, chemicals), increasing network openness might actually undermine the core relationships in a given cluster, thereby weakening cluster performance overall.

Similarly, it could be argued that as environmental uncertainty increases, the positive effects of network strength on cluster performance will only accrue to firms which belong to clusters where strong ties predominate (e.g. automotive, chemicals) and which have developed competencies in building and managing long-term relationships; for those clustered firms which are less used to strong, durable ties with a fixed number of partners (e.g. biotech, IT) and which do not possess the competencies to sustain relationships of this kind, the effect of increased network strength under conditions of increasing uncertainty may actually be to weaken cluster performance overall. While we think it is important to highlight these alternative scenarios, we again proceed with our hypotheses as outlined above; we are sympathetic to Rowley et al. (2000) and Beckman et al. (2004)'s assertions about the power and ubiquity of the effects of environmental uncertainty.

2.4. Network strength, network openness, environmental uncertainty, and cluster performance: Preliminary insights from the interview data

Prior to coding and analyzing our empirical data, as described in the following section, we conducted a preliminary analysis of our interviews with respondents in our eight focal clusters in order to explore whether the particular concepts that we used in our proposition development were evident in our data. This involved looking for common themes among the transcripts rather than developing a formal coding strategy. Interestingly, we found initial support for the core assumptions underpinning all four propositions.

With regard to our first prediction, that increased network strength will lead to increased cluster performance, a number of themes emerged. First, several respondents noted that cluster networks play a monitoring role. Specifically, firms that broke particular cluster norms and conventions were effectively sidelined from the cluster, suggesting that strong networks can help reduce opportunism among cluster members. These respondents highlighted collective monitoring within clusters as a mechanism for building effective inter-firm relationships, potentially leading to improved cluster performance. For example, the manager of a firm in the Greater Toronto Area (GTA) automotive cluster explained:

> *"…most people here play by the rules. Once you have lost integrity in this community, as far as I am concerned, you are finished."*

A number of respondents also made the point that cluster networks have the potential to improve intra-cluster communication, which they felt led to benefits for the innovative capacity of clusters. For example, the manager of a firm in the Upper Austrian chemical cluster emphasized the importance of direct access to other cluster members:

"And because I have an idea of what others are doing, it is far more straightforward and less complicated to find, and talk to, the right person. If you have chronic connectivity, business can be made to work."

Moreover, some respondents noted the resource advantages that accrue to firms within clusters characterized by strong networks. The head of research and development of a biotechnology firm in the Vienna cluster put it this way:

"We share laboratory equipment and know-how with local research institutes. Without the guaranteed access to local research facilities, we would not be able to progress as quickly as we are. The only thing we can afford at the moment is focus."

We also found preliminary evidence to support our second proposition, which is that increased network openness leads to increased cluster performance. Here two key themes emerged. First, a number of respondents argued that clusters that were open to new ideas and partners from outside a given cluster increased the likelihood that firms within the cluster would find suitable partners to develop and commercialize their products, thereby improving cluster performance. For example, the manager of a firm in the GTA automotive cluster underscored the relevance of network openness for identifying and making use of complementary technologies:

"The proper mix of institutions generates the potential for synergies and opportunities… they are more likely to recognize the benefits of bundling technologies that individual research groups may have developed."

Second, a number of respondents argued that clusters that were open to new ideas and partners from outside a given cluster promoted idea generation and opportunity recognition,

leading to increased innovation within the cluster. For example, one respondent in the GTA information technology cluster said that:

> *The more people keep watching and the more diverse their background, the greater the radius of your radar. We need radars with a radius as large as possible."*

We also found evidence in our interviews to support our third and fourth propositions – that the positive effects of network openness on cluster performance tend to increase as environmental uncertainty increases, while the positive effects of network strength on cluster performance tend to decrease as environmental uncertainty increases. With regard to the relationship between network openness, cluster performance and environmental uncertainty, a number of respondents highlighted the challenges posed by market and technological change, and the advantages of network openness in these circumstances. Specifically, respondents highlighted the utility of network openness as a mechanism for obtaining relevant and timely information about consumer preferences, competitors and technological advances under conditions of uncertainty. For example, according to a senior manager of a firm in the Vienna biotech cluster:

> *"Customers don't know what they want in the future, but we have to be the first to give it to them. Our strategy is to be open as much as possible. Open to new ideas, open to new approaches and, most importantly, open to people who come to us with new research findings."*

A respondent from the bio-tech cluster in the Greater Toronto area made a similar point:

> *"Sustainable performance is all about expanding the realm of the possible. Whether you are an entrepreneur or not, you have to keep your radar switched on to receive*

signals. Often we do not have the time to analyze the general terrain and have to keep going instead. To be successful in such an environment, one needs to think and act global."

With regard to the relationship between network strength, cluster performance and environmental uncertainty, several respondents told us that strong network ties within their cluster impeded innovation by stifling creative thinking and problem solving. For example, a manager in the Upper Austrian automotive cluster told us:

"If we do not do a very good job at thinking outside the box, we will never do a very good job at turning those fantastic ideas into fantastic products. People have to be able to operate outside their geographical comfort zone in order to really get something out of their visions."

The manager of an information technology firm from the Greater Toronto area further underscored the relationship between environmental uncertainty and network strength:

"Strong relationships are an asset. But when things get uncertain, one has to venture out and explore new ideas and different opportunities. Otherwise there is always a danger of pretending that business goes on as usual – when we all know that sometimes it doesn't."

In sum, we found initial descriptive evidence for all four propositions. Note, however, that the purpose of this section was not to test our propositions but simply to present a preliminary discussion of our data in order to explore whether there is support for the development of our propositions, and to illustrate some of dynamics which may lead to the success or failure of a given cluster. Additional representative data which offer further

evidence for our propositions are presented in Table 1 (cf. Nag, Corley and Gioia, 2007). In the following section we outline the methods that we adopted to analyze the relationships between network strength, network openness, environmental uncertainty and cluster performance, before examining our propositions through a highly structured 'pattern matching' (Yin 1994) process.

Insert Table 1 about here

3. Methods

Studying cluster performance is complicated by a number of factors. For example, clusters do not have clear-cut boundaries, which makes it difficult to reliably establish cluster membership and to develop a sampling frame (Martin and Sunley, 2003). Moreover, the sheer size of many clusters, the number of constituent firms, and the diverse range of other actors involved (e.g., universities, VC firms, MNCs, defense plants) renders the study of multiple clusters a very resource-intensive endeavor. Finally, the fact that clusters exist in relatively small numbers makes it difficult to design quantitative studies incorporating a large numbers of clusters.

As a consequence of these complicating factors, most scholars have adopted a case study method where observations are limited to in-depth analyses of one cluster (e.g., Piore and Sabel, 1984), or comparisons made between two clusters (e.g., Saxenian, 1994). There have been preliminary attempts to draw from a larger sample of clusters (e.g., Markusen, 1996) although these are rare. Indeed, in casting the net to a broader selection of clusters and relying on secondary data, these studies have necessarily traded off the empirical richness of the case study method.

Our study attempts to navigate between these two approaches. In line with earlier research we rely on the case-study method (Eisenhardt, 1989, 1991; Yin, 2002), but we

extend our research design so that it incorporates a sample of eight clusters. The use of case-studies allowed us to build an accurate picture of social network characteristics—something that cannot be gleaned easily from secondary data sources. Studying eight clusters allowed us to capture some variance in environmental uncertainty such that we could begin to identify themes and patterns across the sample. Our coverage of four different industries also allowed us to respond to the call 'to accommodate the diverse array of industrial sectors and geographical locales in which clusters are found' (Wolfe and Gertler, 2004: 1072).

We are keenly aware that our sample of eight clusters is unlikely to be representative of the global population of clusters, nor will our (non-probabilistic) sample of respondents in each cluster be representative of the population of firms. Further, with a sample of 8 clusters we are unable to submit cluster-level results to tests of significance. Accordingly, we need to be cautious about generalizing our findings to other clusters. We believe, however, that extending the case-study approach beyond one or two clusters, combined with our analytical framework (outlined below), allows us to gain important insights into the relationships specified in our proposed model. Thus, our research design represents an important contribution of our study.

3.1. The setting: Eight industrial clusters

An important criterion for selecting the clusters for this study was that they demonstrated sufficient variation in environmental uncertainty and overall performance. Hence, we selected clusters from a wide range of industries (biotechnology, chemicals, information technology, and automotive) and from two different countries in North America (Canada) and Europe (Austria). We used Kohli and Jaworski's (1990) definition of environmental uncertainty to make a preliminary assessment of the environmental conditions

faced by each cluster. We validated this assessment using the coefficient of variation on sales in each industry and region (Lant, Milliken, and Batra, 1992).

From our pre-study interviews it became apparent that it was more difficult for biotechnology firms to gauge future sales levels for existing products and markets than firms in the chemicals sector. Similarly, companies in the information technology and biotechnology sectors had to cope with more frequent changes in the environment, such as technological change, product obsolescence and the development of new markets, than chemical and automotive companies. With regard to research and development efforts, information technology and biotechnology firms focused to a large extent on exploring new applications of their current capabilities, while chemical and automotive companies focused most of their resources on maximizing the efficiency of extant processes. Interview respondents from the information technology and biotechnology sectors underscored the importance of timely results.

In extending our sampling of clusters beyond one country, we were conscious of the need to control for variation in national context and, thus, selected clusters that shared similar structures in addition to their geo-economic context. Specifically, clusters in both Canada (Greater Toronto Area) and Austria (Life Sciences & IT Cluster Vienna, Automotive & Chemicals Cluster Upper Austria) are strongly linked to the economic, research and cultural capitals of their economic regions. In addition, clusters in both countries are focused to a considerable extent upon public research facilities, and medical research plays an equally important role in both regions. Further, clusters in both countries have relatively poorly developed venture capital communities. At the same time public organizations in both regions played a broadly equivalent role in the funding and dissemination of research activities. Also, we were able to identify clusters in Canada (Greater Toronto Area) and Austria (Vienna and Upper Austria Area) that are similar in age and stages of development.

For example, automotive and chemical clusters are equally well-established, whereas biotechnology and information technology clusters are still in nascent stages in both countries. Finally, the two countries share a number of other crucial factors such as proximity to economic powerhouses (e.g., United States, European Union members, respectively), welfare policies and a highly-skilled labor force. These basic similarities enabled us to control for a range of critical factors which allowed comparison of clusters across international borders.

3.2. Background: Clusters in the Greater Toronto Area (Canada), Vienna and Upper Austria Region (Austria)

The Greater Toronto Area (hereafter, GTA), encompassing the regions of Halton, Peel, York, Durham as well as the City of Toronto, hosts more than 90 per cent of all biotech activities in Ontario (BioCourse Directory, 2004). Similarly, the Life Science Vienna Cluster accounts for a large proportion of biotech activity in Austria. More specifically, over half of Austria's and Canada's pharmaceutical and biotech industries are located in the Vienna and GTA, respectively, and more than 80 per cent of Canada's generic drug manufacturers are located in the Toronto area (Life Science Austria, 2006; Research Report, 2004). The Greater Toronto Area and Vienna Region both represent the most concentrated biomedical and information technology (IT) research clusters in their respective countries (Canada and Austria) and one of the biggest cluster of biotech activity in their wider geographic location (North America and Central Europe). For instance, with more than 50 hospitals, 40 internationally acclaimed medical institutions, and over 55,000 professionals, the GTA has one of the largest medical and biotechnology cluster of any metropolitan area in North America (MaRS Report, 2004). The chemical and automotive cluster in the Upper Austria Region represents the largest clusters in these industries in Austria.

In total, multinational companies invested over $1.1 billion in research and development in the Greater Toronto Area over the past ten years (Toronto Biotechnology Initiative Report, 2004). In addition to this, the GTA receives over $800 million annually in R&D funding from regional and federal governmental departments (ibid., 2004). The University of Toronto's Faculty of Medicine alone, for instance, has an annual research budget of over $200 million (BioCourse Directory, 2004). Government tax concessions play an equally important role in both the GTA and the two Austrian regions in stimulating research and development activity. Another important source of competitive advantage for the Greater Toronto Area, Vienna, and Upper Austria region are their diversified economies. According to recent working papers, "Toronto has the most diversified economies of any city in North America" (Institute for Competitiveness and Prosperity, 2004: 20). From previous research (Porter, 1998a, b), we know that clusters may be most successful at intersections of various industries. Accordingly, economic diversity can create new opportunities for enterprises in various sectors. Toronto and Vienna's strengths in medical research, for example, also have positive spillover effects for their biotechnology activities. Natural synergies between manufacturing and biotechnology in areas such as medical devices should help Toronto and Vienna sustain their strong position in this specific field. Indeed, in both the Greater Toronto Area and Vienna, the scientific excellence of public research centres anchors an entire network of businesses, linking the bio-pharmaceutical communities with other supporting industries. This may increase the efficiency in accessing specialized inputs such as services, human resources and information (Bell et al., 2009). The presence of multiple suppliers and diverse institutions, on the other hand, can enhance actors' ability to perceive innovation opportunities and facilitate commercialization of ideas.

The size and depth of Toronto, Vienna, and Upper Austria region's talent pool in areas such as research, technical occupations and management constitute another significant

strength of these clusters' competitiveness. As a venture capitalist once remarked during a conversation, "firms can be built by mixing ideas, people and money". During the fieldwork of study, we observed that the Greater Toronto Area, Vienna, and Upper Austria region certainly all have an abundance of talented, innovative people, but what they often lack are competitive financing opportunities. In all three regions, the venture capital community is underdeveloped compared to other clusters such as Boston or Munich. This was noted by cluster members as one of the major weaknesses of the GTA and the two Austrian clusters as it means a smaller pot of money available for new business ventures.

The Greater Toronto Area, Vienna, and Upper Austria region excel on several key location factors, offering relatively cheap land, electricity, transport and an educated labor force. Commercial/office space, for example, costs up to 68 per cent more in U.S. cities (Toronto Discovery District, 2004). Similarly, the cost for land or rent is considerably cheaper in Vienna and the Upper Austria region compared to Munich in Germany. Consequently, total operating costs in Toronto can be cheaper than in Boston, Los Angeles, New York, and San Francisco by more than 27 per cent, 32 per cent, 33 per cent, and 44 per cent, respectively (ibid., 2004). Due to their well-established infrastructure and highly skilled labor force, the Greater Toronto Area, Vienna, and Upper Austria region have, thus far, managed to compete against low-cost alternatives, such as neighboring provinces in Canada or Eastern Europe.

The Greater Toronto Area, Vienna, and Upper Austria region have been investing in its extensive fibre-optic networks and have the largest utilization of fibre-ring technology in Canada and Austria, respectively. Major telecommunications suppliers such as AT&T, Bell, Mobilkom, and Telus, amongst others, have major networks throughout the Greater Toronto Area, Vienna, and Upper Austria region. In addition to providing technologically advanced networks, these companies also offer competitive alternatives to customers. Numerous

telecommunications providers foster a competitive market ensuring high quality and low prices for customers in these economic regions. Past literature convincingly argues that market access can play a crucial role for the competitiveness of a region (Feldman, 2000; Herrigel, 1993; Krugman, 1991; Marshall, 1920; Storper 1997). The Greater Toronto Area, Vienna, and Upper Austria region all offer optimal accessibility to major markets such as the United States and European Union markets, respectively. For instance, from Toronto and within a 400-mile radius (one hour by air flight, approximately one day by truck), firms can access more than 90 million consumers, as compared to 70 million for New York, 65 million for Detroit, and 35 million for Los Angeles at the same distance (BioCourse Directory, 2004).

3.2. Data collection procedure

The study was conducted over a number of stages. In the pre-study stage, we reviewed the extant literature on social network theory and industrial clusters in order to develop our conceptual framework. At the same time, we conducted five pilot face-to-face interviews, involving open-ended, moderately directive interview questions. Interviewees in our pilot study held general managerial positions in firms within the four industries identified earlier. As we collected and analyzed interview data, we integrated new findings to clarify particular issues and revised our conceptual framework accordingly.

In order to identify the constituent parts of the clusters in our sample, we followed Porter's (1998a) approach and began by looking for a geographic concentration of firms in the same industry. The second step was to look horizontally for industries passing through common channels or producing complementary products. Based on the literature review and our preliminary findings from pilot interviews, we used a stratified sampling plan to ensure that the sample included a similar representation of firms and organizations across all eight clusters. The approach we employed to qualify organizations cluster members was to analyze

company web-sites, looking for commercial links with other established cluster members. Organizations that had links with at least two other actors (e.g., firms, universities, financial institutions and support agencies) within the same geographic cluster were classified as belonging to the cluster.

As result of this we identified 268 organizations evenly distributed across the eight different clusters. The sample of firms ranged from five employees to several tens of thousands. Sampled firms also varied in terms of, 1) strategies and scope (e.g., universities, trade associations, venture capital companies), 2) age, and 3) country of origin. A key informant methodology was employed requiring one respondent from each organization. The use of single informants is common in organizational research and is particularly appropriate when only a limited number of employees in a firm can reasonably be expected to have complete and detailed knowledge about the phenomena under investigation (Kumar, Stern, and Anderson, 1993). Key informants were not expected to be statistically representative of members of the organization but, due to their specialized knowledge, they were assumed to be able to generalize about patterns of behavior after summarizing observed and/or expected organizational relationships (Seidler, 1974).

Letters were then sent to each company to introduce the research team and seek involvement in the study. We were able to arrange 134 in-depth interviews with organizations that were at the core of individual clusters, including private businesses, public research institutes, cluster incubators, trade associations, venture capitalists, consultants, and academics. Our intention was to speak with a sample of firms who had *experience* of operating within the cluster in which they were located; in effect we were seeking to talk with *multiple key-informants* (Phillips 1981). Table 2 and 3 provide the number and average length of interviews conducted in individual clusters in Canada and Austria. We recorded all of the interviews. At the end of each interview we asked respondents to complete a brief

questionnaire gauging their perceptions of cluster network strength and openness, the measures for which are discussed in the next section. These data were collected to validate our findings from the analysis of the qualitative interviews. Interviews were then transcribed and formally coded using NVivo.

"Insert Tables 2 and 3 about here"

3.3. Measures

Network Strength measures the frequency, intensity, trust, and stability of interactions among network partners. These dimensions of network strength were the most frequently occurring within the literature (e.g., Antia and Frazier, 2001; Granovetter, 1973; Rindfleisch and Moorman, 2001; Uzzi, 1996, 1997). Together they form what is effectively a 'composite factor' of network strength (Jarvis et al., 2003). We explored the interview transcripts for the incidence of key words relating to the frequency, intensity and stability of relationship ties within the cluster. Table 4 provides mean values of interviewee responses when describing network characteristics of individual clusters. These means were derived by adding up the total number of times each concept was mentioned across all interviews and then divided by the number of interviews conducted in this particular cluster. The level of network strength was then rated as either 'high', 'moderate', or 'low'. These ratings were then validated using the responses to a four-item scale of network strength developed for this study. Scale items were designed to match these key dimensions of network strength. The scale was found to be reliable ($\alpha = .89$). The full wording of scale items can be found in the Appendix.

Network Openness is defined as the extent of network membership diversity, willingness to accept new cluster members, and the extent of external linkages to organizations outside the cluster. As with network strength, these dimensions were derived from a survey of the literature (e.g., Romanelli and Khessina, 2005; Zaheer and George, 2004). Interview transcripts were, again, explored for the incidence of words and phrases that

were indicative of network openness. Each cluster was then rated as either ‘high’, ‘moderate’, or ‘low’. A four-item scale gauging network openness (see Appendix), developed for the purpose of this study, was used to validate our findings from the qualitative data. We adapted the measure for network openness on the basis of discussions in the literature on lock-in effects, ‘inertia’ and ‘overembeddedness’ (Noteboom, 2000; Pouder and St. John, 1996; Uzzi, 1997) and the suggested importance of interaction among different actors (Granovetter, 1973; Nelson and Winter, 1982; Noteboom, 2000; Smith and Van de Ven, 1994). The scale was reliable ($\alpha = .87$).

Environmental Uncertainty is defined as the extent of market turbulence, competitive intensity, and technological turbulence (Kohli and Jaworski, 1990). We rated the environmental uncertainty within each cluster as ‘high’ or ‘low’ by to the prevalence key words that related to the three key dimensions of environmental uncertainty (i.e., market turbulence, competitive intensity, technological turbulence) identified by Kohli and Jaworski (1990).

“Insert Table 4 about here”

Cluster performance, we measure as growth in the creation of new firms, jobs and output in each cluster, controlling for industry growth in each country. Cluster performance was therefore computed as:

$$CP_c = \Sigma(F_{cj}\text{-}f_{Cj} + J_{cj}\text{-}j_{Cj} + O_{cj}\text{-}o_{Cj})$$

where CP_c = weighted composite performance score for industrial cluster c

F_{cj} = percentage growth in new firms of industrial cluster c in country j

f_{Cj} = overall percentage growth in new firms of industry C in country j

J_{cj} = percentage growth in new jobs of industrial cluster c in country j

j_{Cj} = overall percentage growth in new jobs of industry C in country j

O_{cj} = percentage growth in output of industrial cluster c in country j

o_{Cj} = percentage growth in output of industry C in country j

The data to measure respective growth rates was gathered from industry reports and Statistics Canada as well as Statistics Austria. We then categorized the performance of individual clusters as 'very high', 'high', 'moderate', 'low', or 'very low'.

The intention of our composite measure of performance was to build a robust performance construct that reflected important areas of economic and policy interest. Jobs growth, new business growth, and the overall increase in economic output are key metrics for most regional and national policy makers and tend to be highly correlated. These measures are also highly relevant to the performance of clusters (Porter, 2003). It is plausible however that each of these dimensions of cluster performance could respond differently to the interactions between cluster network characteristics and environmental uncertainty.[4] For example, employment levels may drop with increases in environmental turbulence irrespective of the mix of cluster network properties. Accordingly, we checked to see if our results were robust using each of the sub-dimensions as a separate performance measure. We found that our results were consistent for each performance metric and so in the interests of clarity we limit our reporting of results to our composite performance measure.

4. Data analysis

In order to compare our empirical results with the a priori hypotheses derived from our model, we followed Yin's (1994) 'pattern matching' approach.[5] This involved assessing predicted levels of cluster performance that were based on our initial set of propositions, and comparing these with actual outcome levels based on our composite measure of cluster performance. In order to test propositions 1 and 2 we considered simple bivariate relationships between network characteristics (strength and openness) and cluster

performance in which network strength and openness for each cluster (‘low’, ‘moderate’ or ‘high’) was mapped against cluster performance (‘very low’, ‘low’, ‘moderate’, ‘high’, or ‘very high’). The relationships are presented in Figures 1 and 2.

To test the moderating effect of environmental uncertainty on the relationships between strength/openness and cluster performance (hypotheses 3 and 4) and to arrive at our predictions of performance we used the following rationale. First, we measured cluster performance on a scale of 1 to 5 where; 1=‘very low’, 2=‘low’, 3=‘moderate’, 4=‘high’, and 5=‘very high’. We then looked to the level of environmental uncertainty (high/low) and the relevant network characteristic (openness/strength). If we observed high network openness (strength) in the context of high (low) environmental uncertainty then cluster performance was, at this stage, predicted to be ‘very high’ and assigned a score of 5. If we observed moderate openness (strength) given high (low) uncertainty, cluster performance was predicted to be ‘moderate’ and assigned a score of 3. Finally, if we observed low openness (strength) given high (low) uncertainty then expected ‘cluster performance’ was predicted to be ‘very low’ and assigned a score of 1.

Given that both network characteristics can affect cluster performance (i.e., propositions 1 and 2), the predicted performance score could be affected by the degree to which the other network characteristic was present. If the other network characteristic was ‘low’, we deducted one point from the ‘predicted performance’ score, and if it was ‘high’ one point was added. The score remained the same if the other network characteristic was ‘moderate’. The results of this analysis are reported in Table 5.

Finally, in order to add qualitative support and some empirical richness to our findings, we provided a series of representative quotations from respondents based across our sample of clusters. The following section reports our findings.

“Insert Tables 4 and 5 about here”

5. Results

Our first proposition predicted that clusters comprising strong ties would exhibit strong performance. A visual inspection of the relationship between network strength and cluster performance in Figure 1 shows partial support for proposition 1. Austrian biotech and Canadian automotive, both high in network strength, demonstrated high performance as expected. Equally, Austrian automotive and Canadian chemicals, both low in network strength, were low performing clusters as proposition 1 predicted. Three clusters (Austrian IT, Canadian IT, and Austrian Chemicals) were somewhat close to predictions and one cluster—Canadian biotech ('low' network strength and 'very high' cluster performance)—was a significant departure from the relationship predicted by proposition 1.

"Insert Figures 1 and 2 about here"

Our second proposition predicted that open clusters were liable to exhibit strong performance. A visual inspection of the relationship between network openness and cluster performance in Figure 2 shows partial support for proposition 2. Austrian biotech and Canadian biotech, both high in network openness, demonstrated high performance as expected. Equally, Austrian IT and Canadian chemicals, both low in network openness, were low performing clusters as proposition 2 predicts. As with proposition 1, three clusters (Canadian automotive, Austrian Chemicals, and Canadian IT) were somewhat close to the predicted relationship. Finally, one cluster—Austrian automotive ('high' network openness and 'very low' cluster performance)—was a significant departure from the relationship predicted by proposition 2.

Our third proposition was that the positive effects of network openness on cluster performance tend to increase as environmental uncertainty increases, while our fourth

proposition was that the positive effects of network strength on cluster performance tend to decrease as environmental uncertainty increases. From Figure 3 it can be seen that our model correctly predicted five out of eight outcomes of cluster performance: the two clusters operating in highly uncertain environments and which were characterized by high levels of network openness exhibited very high performance; the cluster with low network openness in an environment of high uncertainty exhibited very low performance; and the two clusters characterized by low network strength in environments of low uncertainty experienced very low performance.

In three cases predicted and actual cluster performance outcomes differed. In two of these three cases, however, (Austrian automotive, Canadian biotech) the difference between predicted and actual cluster performance was moderate. In the Canadian biotechnology cluster, low levels of network strength combined with high network openness in a highly uncertain environment did not result in high performance as predicted, but very high performance. In the Austrian automotive cluster low network strength and high network openness in an environment characterized by low levels of uncertainty exhibited very low performance when our model predicted low performance.

In only one case (Canadian IT) the difference between predicted and actual cluster performance was quite large. In the Canadian IT cluster moderate network strength and moderate network openness in a highly uncertain environment did not lead to moderate cluster performance; instead we observed very low performance.

This suggests that propositions three and four are reasonably robust, but that adjustments are needed to account for the instances where the predicted and actual outcomes differed. In the next section, we discuss the findings of our model in more detail and consider potential adjustments that might explain the discrepancies we observed.

"Insert Figure 3 about here"

6. Discussion and implications

The objective of this paper was to use social network theory to develop a more comprehensive understanding of cluster performance; one that is sensitive to external contingencies. Conceptually, we began by proposing that both network strength and network openness are crucial determinants of cluster performance. We extended our arguments by suggesting that, (1) the positive impact of network strength on performance diminishes as environmental uncertainty increases; and (2) network openness may become more important for sustaining the success of clustered-firms as environments become more uncertain. Our results broadly supported these expectations.

Our first and second propositions predicted that cluster networks characterized by strong ties and a high degree of openness would be positively associated with overall cluster performance. These were generally supported by the data with two exceptions; the Canadian biotech cluster was very high-performing yet characterized by low network strength, while the Austrian automotive cluster, rated as high in network openness, showed very low overall performance. Baum, Calabrese and Silverman (2000) provide a potential explanation for these findings. Their study of (coincidentally) Canadian biotech firms showed that better performance was realized by startups that formed alliances with a diverse array of organizations—and even rival firms—in order to attain access to new information and learning opportunities. The nature of the biotechnology industry (i.e., an emergent industry, characterized by many small startup ventures) places a premium on network openness. A corollary of this might be that for established, mature industries, such as automotive, network strength is disproportionately important.

For another potential explanation for our finding in the Austrian automotive cluster, we return to our earlier discussion of potential curvilinearities in the network

strength/openness – cluster performance relationships. Markusen (1996) was concerned that networks within clusters that were too open could destabilize the cluster as a whole. This mechanism might be at work in the Austrian automotive cluster.

Our third and fourth propositions, respectively, predicted that when environmental uncertainty was high, the positive relationship between network openness and cluster performance would strengthen, while the positive relationship between network strength and cluster performance would weaken. Our findings supported this expectation with one significant exception. The Canadian IT cluster, characterized by moderate network strength and moderate network openness showed very low performance in highly uncertain environments instead of moderate performance as predicted. One explanation is that only highly open network linkages can infuse sufficient flexibility and dynamism within a cluster to avoid ossification and reduced performance when technologies, competition and consumer tastes are rapidly changing. In other words, being moderately open to new exchange partners and opportunities may not be sufficient to generate even moderate levels of performance when economic environments are highly turbulent. This rationale is perhaps emphasized by our findings in the Canadian Biotech cluster for which high network openness together with low network strength led to very high cluster performance when environmental uncertainty is high. In building our model we have assumed that both openness and strength in networks are equally important, however these findings might suggest that network openness is disproportionately relevant in an uncertain climate.

Overall, our findings illustrate that levels of network strength combined with openness to new members may help explain why certain clusters decline while others adapt to environmental changes. In highly uncertain environments, openness to new ideas, technologies and ways of doing business become key drivers of sustainable performance for clustered firms. The speed and ease with which innovations can be detected within clusters is

likely to depend on the diversity of actors, openness to new members and extent of linkages to organizations operating outside the cluster. The degree to which networks are trusting and cohesive will enable organizations to leverage such innovations. Accordingly, strong networks in uncertain environments will provide a supportive and complementary role. It is in stable markets, however, where strong network ties are likely to be most valuable; strong networks provide the ideal context to exploit existing innovations and pursue economic efficiencies.

Our findings complement and extend existing cluster research in the following ways. First, we show that cluster performance is dependent on the ability of clustered firms to adapt their network structures to their environmental context. In other words, sustained cluster performance will be contingent upon the capacity of members to reconfigure relationships to meet the emerging demands of the market and to incorporate changes in technology. The integration of environmental contingencies into our analysis of clusters provides a unique perspective that complements our current understanding of the relationship between network characteristics and cluster performance. Our sample of eight clusters across four industries has permitted the inclusion of the environmental uncertainty variable, which is a significant advance on the single case studies that characterize most of the extant research on clusters. Second, we have developed, validated, and tested measurement instruments and research methods that help us to distinguish between key network characteristics (i.e., strength and openness) of clustered firms. These have, in turn, provided a foundation for the development of a model of inter-firm networks and cluster performance.

6.1. Implications for research and public policy

Our findings also have direct implications for both policy makers and research. Our findings indicate the extent to which network characteristics affect cluster performance as

environments become more uncertain. Both network strength and openness can be beneficial to clusters, but under different environmental conditions. Moreover, we suggest that clusters are not necessarily destined to decline. Specifically, we argue that firms' capacity to manage the balance between strength and open network linkages is a key source of sustainable cluster performance. This is likely to represent an enormous challenge for clustered firms, not least because the forces of path dependence and inertia are likely to be particularly strong among co-located firms. Indeed, the inherent difficulty of adapting to changed environmental circumstances for co-located firms is likely to be the reason why we observe relatively few instances of clusters that are able to transform relative to those which decline as consequence of environmental jolts (Pouder and St John, 1996).

Trade associations and public research institutions can play a vital role in facilitating trusting relationships (Mesquita, 2007) and diffusing information among network members that serve as resources to one another. First, social interactions among spatially proximate actors in trade associations can motivate the deepening of existing relationships or formation of new linkages. As partners' trust increases, continued exchange creates new opportunities for cooperation and the effective employment of a greater variety of complementary, strategic resources. Public research institutions might also help members to sidestep dysfunctional forces of collective inertia and reduced competitive vigilance. Universities, for example, provide more 'open' channels, spilling new knowledge across proximate actors much more readily than commercial organizations (Jaffe, Trajtenberg, and Henderson, 1993; Owen-Smith and Powell, 2004). Public research institutions, therefore, can play an important role in facilitating the openness needed to develop new knowledge and innovation. In short, policy makers, trade associations, and public research centers can influence the configuration of networks of clustered firms.

While we consider that our work makes an important contribution, there are, however, some potential limitations to this study. First, in analyzing the role of network strength and openness, we limited our analysis to formal network structures. Clearly, informal interactions between social actors are likely to complement, and contribute to, formal relationships within clusters (Bell, 2005). Informal networking, for example, may facilitate the development of "cognitive capital", thereby enhancing the effective and timely exchange of resources between network members (Carroll and Teo, 1996; Oh, Chung, and Labianca, 2004; Tracey and Phillips 2007). A fruitful avenue for future research, therefore, would be to address the dynamics between formal and informal networks, and their combined effect on cluster performance. Another limitation of our analysis is the limited number of cases under investigation (Lieberson, 1992; Mahoney, 1999; Ragin and Becker, 1992) and the key-informant approach to respondent selection. While our study of eight different clusters across four industries in two countries is a unique contribution, we nonetheless acknowledge generalizing from our sample to other clusters is potentially problematic. Future research is needed to test our propositions with a larger sample of clusters across broader range of industries.

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Footnotes

[1] Exploration is defined as "experimenting with new alternatives" and involves high levels of uncertainty, while exploitation is defined as "refining and extending existing knowledge" and involves low levels of uncertainty (Beckman, Haunschild, Phillips, 2004: 259).

[2] Beckman et al.'s (2004) definition of market uncertainty is broadly comparable to our definition of environmental uncertainty. These authors also found that network broadening reduced firm-specific uncertainty, i.e. uncertainty that is unique and internal to the firm, but this type of uncertainty is beyond the scope of our arguments.

[3]Beckman et al. (2004) conducted a supplementary analysis which found that strengthening/reinforcing existing alliances actually increases market uncertainty. However, as noted above, this is not our position in this paper.

[4] We thank our anonymous reviewers for this point.

[5]Yin (2002) notes that one of the central challenges facing case study researchers is the development of a rigorous strategy for analyzing the large amounts of data that are generated, particularly with multiple case study designs. The advantage of pattern matching is that it provides a structured and systematic method of data analysis (Eisenhardt, 1989; Eisenhardt and Graebner, 2007). Moreover, the comparison of empirically based patterns with predicted ones facilitates theory development: pattern matching is based on the logic of replication, with each case serving as a 'discrete experiment'. Where the predicted pattern is replicated across multiple cases, researchers are in a position to argue that the same processes are evident in each of the cases (see Yin, 2002). Because pattern matching requires the development of specific propositions prior to data collection, it is not suitable for exploratory research on phenomena about which little is known. In these circumstances, a grounded theory approach (Glaser and Strauss, 1967) to data analysis is appropriate.

Appendix

Construct	Measures
Network Strength	This organization has long-lasting relationships with actors in this cluster. We frequently meet with our exchange partners in this cluster to share resources and new ideas. The contact with our exchange partners in this cluster is not very strong. *(reverse coded)*
Network Openness	We are connected to a range of firms, differing in size, age, capabilities, and industry. This organization readily accepts new members to its network of exchange partners in the cluster. We are well-connected with actors outside this cluster. Linkages with actors in this cluster are very difficult to reconfigure. (*reverse coded)*

Table 1

Measures, propositions, and representative quotations

Measures and Propositions	Representative Quotations
Network Strength *P1: Increased network strength will be associated with increased overall cluster performance.*	*Automotive Cluster GTA:* Trust between partners is important. And strong relationships provide this kind of trust. Because we know each other we do not want to let the other side down. We know our strong partners here feel the same. *Automotive Cluster Upper Austria*: Competition in this industry is cut throat with razor thin margins. The only way we can compete is with products that excel in quality. To succeed we hire the best people and build strong links with our exchange partners. Frequent exchange ensures we know we are on the right track. *Biotech Cluster Vienna:* At a very early stage of this business we realized that the only way to make this a success is to co-operate with partners from both the academic world and industry. We have expert teams that meet on a regular basis. Our industry business partners have very close contact with us. We continuously inform them about our work, our progress, and our most recent findings. But I have to emphasize that it is two-way communication that makes a difference. It is not only us taking to our business partners. We also receive valuable input and very stimulating feedback from them. Only the largest biotechnology firms in the world can afford to produce everything in-house. But even they do buy in services or products from others. It does not make sense to waste time and resources on non-core activities. There are other firms that can offer the same service or product much faster, at a higher quality and at a lower cost. In the past we always got what we wanted. *Biotech Cluster GTA:* Our collaborations with the university and research institutes work so well, because we work with, and next to, each other every single day. There is a great amount of information that is being exchanged through this close personal contact. With regards to commercialization of innovations, people often describe technology

transfer as a contact sport. It requires intense contact with the scientists we work with, our colleagues and industry. So again, while in principal you could do everything anywhere in the world by using the internet, it still does not replace the person-to-person, face-to-face direct contact. In part because e-mail is efficient at conveying specific facts but not at transferring content. In projects you need to share content and that is where you need person-to-person interaction and relationship building. That is where geographical proximity among people becomes important.

Chemical Cluster Upper Austria: If you can talk to people directly, the problem will be resolved immediately. And because I have an idea of what others are doing, it is far more straightforward and less complicated to find, and talk to, the right person. If you have chronic connectivity, business can be made to work.

Chemical Cluster GTA: Strong, reliable relationships are the basis for our success and everything we are doing. We would not be able to manage as effectively without these ties. Things could get very complicated. In business we rely on strong relationships with our partners.

Information Technology Cluster Vienna: It is a very unique partnership here. Our exchange partners and contacts with various university research institutes create real benefits. Together we are able to exploit powerful synergies. As you can imagine, there needs to be intensive communication in order to take advantage of the individual strengths of participating partners; research institutes and companies alike.

Information Technology Cluster GTA: Because of our strong relationships, we all trust each other. This is a really small community and we all pretty much know each other. This ensures we are all working together when collaborating and not trying to take advantage of each other.

Network Openness
P2: Increased network openness will be associated with increased overall cluster performance.

Automotive Cluster GTA: The proper mix of institutions generates the potential for synergies and opportunities. When colleagues from different institutions meet more regularly, they are more likely to recognize the benefits of bundling technologies that individual research groups may have developed.

Automotive Cluster Upper Austria: Technologies have become increasingly complex in this industry. It would be impossible for us to achieve everything by ourselves and we rely on partners with different expertise and different backgrounds. As a business we are open to work with new, younger firms that can help us create value.

Information Technology Cluster GTA:. The more interactions that exist, the more people will become comfortable that one can deal with multiple collaborations without short-handing any of the individual ones. You know, if you only do one or two collaborations over a five-year period, you are not going to build up either the experience or reputation that you can manage or juggle multiple collaborations simultaneously. It is a bit of a self-fulfilling prophecy that the more you do the easier it becomes to do more. And being open to new business collaborations is a key determinant not just of success but of survival in this industry.

Information Technology Cluster Vienna: We are very interested in sharing our research findings, because we also want to receive feedback from various sources. We work on completely new solutions and feedback from business partners and other specialists is of tremendous value to us.

Biotech Cluster GTA: Through open exchange with various partners we manage to be faster and more efficient with our work that would be possible otherwise. And speed to market matters.

Biotech Cluster Vienna: We know we cannot be successful if we limit ourselves to close partners in this region only. We also have ongoing collaborations with partners in the UK, Germany and overseas. Especially in fields were we do not have enough expertise; we try to seek the best partners to work and collaborate with – regardless of where they might be located. We definitely plan to grow and want to expand the ring of close partners in the coming years.

Chemical Cluster GTA: A lot of our projects are shared with different firms. Initially I thought it would make things more complicated but these collaborations also help us tap into a new pool of ideas.

Chemical Cluster Upper Austria: Networks are key and our business operates in such a network of different institutions. Openness to work with different businesses and academic institutions has allowed us to develop a series of breakthrough products in the last couple of years and we do not intend to stop being open.

Environmental Uncertainty
P3: The positive effects of network openness on cluster performance tend to increase as environmental uncertainty increases.

Biotech Cluster GTA: Sustainable performance is all about expanding the realm of the possible. Whether you are an entrepreneur or not, you have to keep your radar switched on to receive signals. Often we do not have the time to analyze the general terrain and have to keep going instead. To be successful in such an environment, one needs to think and act global.

Biotech Cluster Vienna: Even if we wanted to plan more, we cannot. Nobody can tell us which road to take. Customers don't know what they want in the future, but we have to be the first to give it to them. Our strategy is to be open as much as possible. Open to new ideas, open to new approaches and, most importantly, open to people who come to us with new research findings.

Automotive Cluster GTA: Sometimes we don't know what the next big solution will be. Of course we are working on a series of issues but any honest firm will tell you that they are trying to drive change but at the same time don't know the future. And in this environment of uncertainty it becomes even more important to work with different partners and to be open to new ideas.

Automotive Cluster Upper Austria: The success of this company is based on the fact that we are not dogmatic in how we view and define things. If we do not a very good job at thinking outside the box, we will never do a very good job at turning those fantastic ideas into fantastic products. People have to be able to operate outside their geographical comfort zone in order to really get something out of their visions.

Information Technology Cluster GTA: Yes, we are seeing a lot of change in this industry. I have to tell you that we are used to uncertainty to some degree. Still it is scary and we must be open to whatever is out there; ideas, new business ventures, regulation, customers, and competitors. The worst thing we could do is to close our doors and stop seeking collaborations with different partners and just focus on what we already know.

Information Technology Cluster Vienna: A lot of discoveries are up in the air. And in order to survive, you have to be fast. We have hundreds of teams competing with each other on a global level. Nobody can afford not to be aware of, and learn from, other approaches. Wise management believes in the abilities of others.

Environmental Uncertainty
P4: The positive effects of network strength on cluster performance tend to decrease as environmental uncertainty increases.

Biotech Cluster GTA: In an uncertain environment things are different. It would be dangerous to rely on existing strong links. They would be less efficient. Work would be less value-added. These are the disadvantages of strong relationships when things are less certain. All this interaction in strong relationships also takes up a lot of time and energy. They do come at a cost.

Biotech Cluster Vienna: When faced with increased uncertainty there is always a tendency to get back to basics. More often than not this is a risky strategy. One needs to be less rigid and

more open in uncertain times. Strong relationships can hinder this kind of openness in times of uncertainty.

Information Technology Cluster GTA: Earlier I said strong relationships are absolutely vital but I also experienced they may hinder businesses from growing and taking advantage of opportunities offered by uncertainty.

Information Technology Cluster Vienna: When things are uncertain it is even more important to seek new advice. Strong relationships may sometimes be a barrier to out of the box thinking, not always, but I have seen it happen a number of times.

Chemical Cluster GTA: There are tradeoffs when it comes to managing strong relationships. They are of extreme value to us for a number of reasons. On the other hand they may convey a sense of certainty when really there is no certainty. And I am not sure whether this is always a good thing.

Chemical Cluster Upper Austria: Strong relationships are catalysts but they can also block exchange. And when faced with uncertainty the latter is more likely than the former. Business needs to be aware of this and plan accordingly.

Table 2

Summary statistics of interviews in Austrian clusters.

Clusters	Number of Interviews	Average Interview Length (h/min)	Total Interview Length (h/min)
Biotechnology	21	1h 32min	~32h
Automotive	16	1h 12min	~21h
Chemicals	11	1h 6min	~12h
Information Technology	10	1h 7min	~11h
Total	*58*	*1h 14min*	*~76h*

Table 3

Summary statistics of interviews in Canadian clusters

Clusters	Number of Interviews	Average Interview Length (h/min)	Total Interview Length (h/min)
Biotechnology	28	1h 26min	~41h
Automotive	17	1h 4min	~19h
Chemicals	9	1h 4min	~10h
Information Technology	22	1h 6min	~24h
Total	*76*	*1h 10min*	*~94h*

Table 4

Summary of cross-cluster evidence of network strength and network openness

	Network Strength				Network Openness			
Clusters	Durability	Frequency	Intensity	Trust	Diversity	New Members	Inter-Cluster	Lock-In[a]
All Clusters	*4.60*	*4.18*	*3.83*	*4.08*	*3.65*	*2.58*	*7.43*	*2.48*
Canadian Biotech	2.81	4.17	1.45	3.25	7.10	4.06	9.18	1.34
Canadian Chemicals	3.74	1.06	2.01	2.98	1.50	1.03	3.02	5.12
Canadian IT	4.09	4.32	5.04	3.24	6.36	1.17	4.07	1.13
Canadian Automotive	5.67	6.98	4.78	6.10	2.01	2.15	8.50	4.09
Austrian Biotech	4.59	8.12	9.01	5.27	5.76	5.20	11.27	1.31
Austrian Chemicals	6.43	2.89	3.61	4.12	2.41	2.81	8.92	2.24
Austrian IT	5.54	3.72	1.64	3.99	1.29	1.10	4.32	1.75
Austrian Automotive	3.91	2.18	3.09	3.65	2.78	3.08	10.12	2.83

[a]Reverse coded

Table 5

Results of proposed model

Clusters	Network Strength	Openness	Environmental Uncertainty	Expected Performance	Actual Performance
Canadian Biotech	low	high	high	*high (4)*	*very high (5)*
Canadian Chemicals	low	low	low	very low (1)	very low (1)
Canadian IT	moderate	moderate	high	*moderate (3)*	*very low (1)*
Canadian Automotive	high	moderate	low	very high (5)	very high (5)
Austrian Biotech	high	high	high	very high (5)	very high (5)
Austrian Chemicals	moderate	high	low	high (4)	high (4)
Austrian IT	moderate	low	high	very low (1)	very low (1)
Austrian Automotive	low	high	low	*low (2)*	*very low (1)*

Figure 1

Relationship between network strength and cluster performance

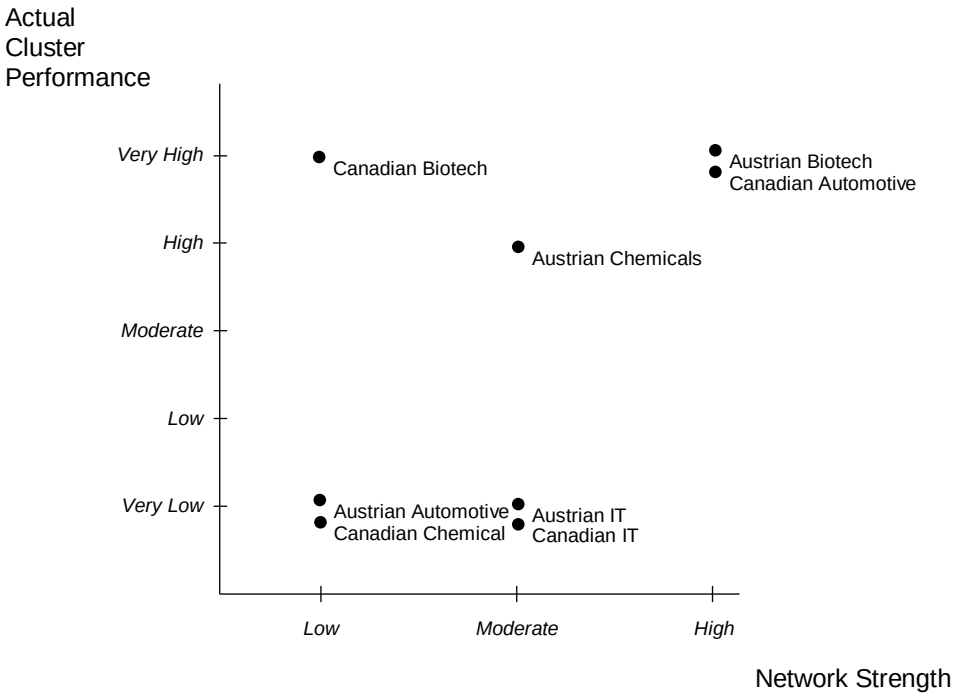

Figure 2

Relationship between network openness and cluster performance

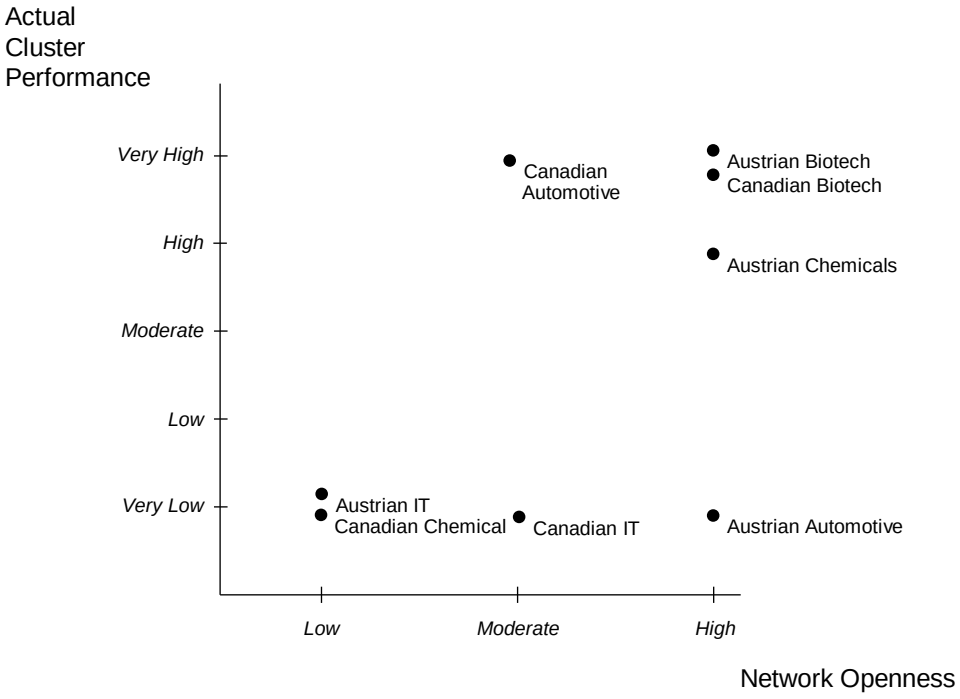

Figure 3

Assessment of the robustness of the model