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The effects of network characteristics on performance of innovation clusters

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ABSTRACT

Industry clusters provide not only economic benefits but also technological innovation through networking within a cluster. In this study, we analyze network-specific structural and behavioral characteristics of innovation clusters with the intention of delving into differences in learning performance in clusters. Based on three representative networks of real world, scale-free, broad-scale, and single-scale networks, the learning performance of entire organizations in a cluster is examined by the simulation method. We find out that the network structure of clusters is important for the learning performance of clusters. Among the three networks, the scale-free network having the most hub organizations shows the best learning performance. In addition, the appropriate level of openness that maintains long-lasting diversity leads to the highest organizational learning performance. This study confirms the roles of innovation clusters and implies how each organization as a member of a cluster should run their organization.

1. Introduction

"Industry cluster," also known as "business cluster," or "innovation cluster," refers to geographically close groups of interconnected companies and associated institutions in a particular field, linked by common technologies and skills across horizontal or vertical supply networks (Porter, 2003; Wixted, 2009).

Increased collaboration between organizations in a cluster leads to an economy in which networking becomes the most characteristic feature of a business organization (Deman, 2008). In particular, as the world is moving toward a knowledge-based economy and levels of information are advancing, industry clusters provide not only economic benefits but also individual firms' technological innovation through networking within the various organizations in a cluster. It also enhances the firms' overall competitiveness in related industry. Numerous studies on the network effects between diverse firms have been conducted, focusing on the way in which innovation clusters are continuously achieving competitiveness. (Asheim & Isaksen, 2002; Boschma, 1999; Feldman, Francis & Bercovitz, 2005; Giuliania and Bella, 2005; Gilbert, Ahrweiler, & Pyka, 2007; Oakey 2007).

Geographical advantages of being located in a certain region vary depending on how to capitalize on local resources including knowledge. From the perspective of innovation, sources of effects within a cluster must be clearly analyzed. However, dynamic mechanism in business habitats like innovation clusters is not easy to identify. According to a study on social networks by Granovetter (1973), case analysis cannot fully clarify how certain characteristics of knowledge networks specifically contribute to the performance of the networks. Nor can they identify the dynamic processes. Also, the difficulties of getting information on business network between organizations prevent researchers from field research. Therefore, the aim of this research is to analyze the interconnections between the factors taking effect in the innovation cluster through simulation. We analyze network structures and topological characteristics of innovation clusters with the intention of delving into differences in organizational performance resulting from such network-specific structural and behavioral characteristics.

For the purpose of our study, we used the network types suggested by Amaral, Scala, Barthelemy, and Stanely (2000); scale free, broad scale, and single scale networks. These three networks are considered to best represent the Small World (Watts & Strogatz, 1998), the equivalence to the real world. Amaral's three types of network are adopted to represent the diverse inter-organizational learning relationships within an innovation cluster. Based on those three innovation cluster types, structural and behavioral factors influencing performance of innovation clusters are systematically analyzed, focusing on the research questions below:

- How does learning performance of innovation clusters differ depending on network structures of clusters?
- How does learning performance of innovation clusters vary depending on the learning rate of organizations within clusters?

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- What factor leads to organizational diversity that affects the learning performance of organizations?

In order to address these questions, this paper is organized as follows. In Section 2, we review the previous studies on innovation cluster, network structure, and learning performance. In Section 3, we propose our research method including the simulation algorithm. In Section 4, we compare and analyze the learning performance of an innovation cluster in the diverse situations derived from network structures and openness. Finally, the implications and further research issues are discussed in Section 5.

2. A review of related research

2.1. Innovation cluster

Research on the innovation cluster originates from the phenomenon that globally renowned industries were generally formed in specific areas. Silicon Valley in the USA (IT), Hsinchu in Taiwan (high-tech), Bangalore in India (software), and Silicon Wadi in Israel are well-known examples of successful innovation clusters. Within a cluster, information is shared, while competition and cooperation occur during technology development or swift production. Thus, firms within a clustered region have higher R&D productivity and performance (Yang, Motohashi, & Chen, 2009; Lofsten & Lindelof, 2002). In the case of Silicon Valley, enterprises startup through spin-offs, and by this, they form a network with firms such as HP or Intel at the center. The necessary ambience or space that allows founders to establish networks exists. Also job shifting is encouraged rather than hindered, and enterprise startup and personnel exchange for innovation are active. So the characteristics of a regional network are crucial to have higher aggregated performance as well. The network itself is multidimensional, a variety of channels exists such as the network of the founder or director, and there are too many firms to cover. The process of concurrent network formation or innovation taking place has not been dynamically observed.

2.2. Network structure and learning performance

A network consists of nodes and links, where nodes are organizations that possess knowledge, and links are the knowledge exchange relationships between them. Among the properties of a cluster, centrality can be regarded as the presence of hubs transferring knowledge. Hubs in the network have a high degree of centrality due to their network characteristics within the region, and thus, they represent the nodes that play a central role in knowledge exchange and connect to other organizations with low centrality. An innovation cluster is made up of networks for knowledge exchange. Within innovation clusters, technological innovations and transference among elements are more efficient and more business ventures are generated (Hsu, Shyu, Yu, You, & Lo, 2003). Within a cluster, there are some organizations with a relatively high number of collaborative links. When a sufficient number of hubs that have an extremely high degree of centrality exist in the network, the corresponding network becomes a scale-free network. In reality, however, because of the cost of establishing a connection, the presence of hubs may be limited.

The analysis related to network structure, i.e., network anatomy, is important because structure always influences function (Strogatz, 2001). For example, computer viruses can spread widely due to the structural characteristics of the Internet. Moreover, the fact that network structure influences the functioning of the system is a strong reason why network related research is necessary. The connectivity distribution of random graphs follows the symmetrical form of Poisson's distribution while small world networks are also symmetrical. Unlike the bell-shaped Poisson distribution of random graphs, the degree distribution of many real-world networks has been documented to have power-law degree distribution (Amaral et al., 2000; Barabasi, Albert & Jeong, 1999; Barabasi, 2003). This phenomenon can be found in a variety of diverse real-world social, informational, biological and technological networks – e.g. the World-Wide Web (Albert and Barabási, 2002), power grids (Watts & Strogatz, 1998), metabolic and protein networks (Jeong, Mason, Barabasi, & Oltvai, 2001), food webs (Huang, 2009), scientific collaboration networks (Nerur, Rasheed & Natarajan, 2007), citation networks (Ord, Martins, Thakur, Mane, & Börner, 2005; Wakefield, 2008), human language (Cancho & Sole, 2001), electronic circuits (Ferrer, Janssen, & Sole, 2001), and software architecture (Valverde, Ferrer Cancho, & Sole, 2002).

In order to explore this area, our research uses the three representative networks proposed by Amaral et al. (2000); (1) scale-free networks characterized by power law distribution; (2) broad-scale, or truncated scale-free networks, characterized by power law distribution followed by a sharp cut-off, like an exponential or Gaussian decay of the tail; and (3) single-scale networks characterized by fast decaying tail, such as exponential or Gaussian networks. The concept of Amaral networks starts from the scale-free network. It is formed when the probability factor (β) of a hub's inactive situation is 0. This network has a sufficient number of hubs because the hubs do not enter an inactive situation. And so diffusion of knowledge happens rapidly. As mentioned earlier, empirical research proved that the structure of most networks that exist in reality follows the scale-free network.

However, among actual known cases of scale-free networks, there were networks with a decreasing number of hubs due to the "aging of vertices" and "cost inducing phenomenon." In the network of Hollywood celebrities known to be scale-free, the death of a famous celebrity who acted as a hub will lead to the disappearance of links and ultimately the end of the hub. Not only that, the flight operation network in an airport being given an absolute time of a day, the maximum number of links a hub can hold is limited and therefore it can be observed that a hub cannot have more than a certain number of links. The former is the phenomenon of "aging of vertices," and the latter is the "cost inducing phenomenon". In order to show this, this research will use the network proposed by Amaral et al (2000). In this network, by setting the probability of hub disappearance, the ascertained characteristics in the examples above are demonstrated through modeling. In accordance with the disappearing number of hubs, the names "broad-scale network" and "single-scale network" are given. Within an innovative cluster, cost is induced when inter-organizational links are formed so a limit can follow the formation of a hub. Above all, inter-organizational learning in several network situations will be examined.

2.3. Diversity and learning performance

The process of sharing, comparing, interpreting, and updating knowledge helps individuals, communities, or companies to develop a shared understanding (Argote, 1999; Brown & Duguid, 199; Larson & Christensen, 19931; Deman, 2008). From the learning perspective, such fast learning is very effective in improving knowledge, and thereby increases the efficiency of organizational learning. However, fast learning also tends to lead to premature convergence around a homogeneous set of ideas or routines, thwarting long-run learning and leading the organization to a suboptimal equilibrium. (Fang, Jeho, Melissa, & Schilling, 2009). Thus, in order to maintain high performance in the organization's learning, the ability to maintain diversity is essential. Additionally, one can observe that the slow diffusion of knowledge can be very effective in maintaining the diversity of that knowledge. However, knowledge that is diffused too slowly might reach a limit in spreading within the entire organization before reaching equilib-