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Emergence of biotechnology clusters: How prior structure affects formation of technology connections in Boston and San Diego from 1979 to 2006☆,☆☆

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ABSTRACT

We explore the network structure of technology in biotechnology industrial clusters and how prior structure affects formation of ties among technologies from a network perspective. We select Boston and San Diego as cases. Based on visualization techniques of networks, we find both clusters have a separate components structure pattern. We also observe a phenomenon of boom and decline of technologies during the evolution process. We use network degree and Pagerank algorithm to measure the importance of patents (technologies as sources), betweenness centrality, and structural holes to measure the ability of technology diffusion (technologies as conduits) in prior structure. Networks of technology connections are indicated by medical patent citations in Boston and San Diego from 1976 to 2006. We find that core position of global network has a positive relation with formation of ties. Effects of bridge position are different in two clusters.

1. Introduction

Industry clusters are agglomerations of organizations at different stages of industrial chains and all of them are in the same industry and district (Porter, 1998, 2003). Geographic proximity influences on knowledge flowing (Bell & Zaheer, 2007), which also determines agglomerations occur in specific area and form the industrial clusters.

It is always a key issue why industrial clusters occur. The mechanism can be explained from varied theory perspectives, such as Krugman (1991)'s new economic geography theory and Porter (1998)'s competitive advantages perspective. Extant literature also stress on cost advantage and important of knowledge spillover (Owen-Smith & Powell, 2004). Yet few studies explicitly considered how a cluster developed from a network perspective (Giuliani, 2013; Ter Wal & Boschma, 2011).

Industrial clusters can be seen as networks of different organizations with different relationships (Siu & Bao, 2008). Thus, network evolution is a key part of cluster evolution. Organizations can get many benefits from the networks which they embedded in (Uzzi & Gillespie, 2002). On the other hand, networks also bring some constraints to organizations (Moody & White, 2003). To understand the evolution of clusters, we should focus on how the network structure emerges (Kogut, 2000). There are three levels of network in a cluster: individual networks, organizational networks, and institutional networks. Different network structures

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have different effect on knowledge flowing in the cluster (Bell & Zaheer, 2007). Evolution of clusters is actually an emerging process of different networks in the cluster. This helps us to transfer the question of evolution of clusters to the question of network dynamic.

Network dynamic is an interesting topic because it is about "how," and most prior research is only about "what" (Koka, Madhavan, et al., 2006). Some scholars have discussed the evolution of different networks, such as ownership networks of business enterprises (Corrado & Zollo, 2006). From graph theory view, network evolution means increase or decrease of nodes and ties, which results in a change of network structure. So starting point of research on geography network trajectory should focus on formation of ties (Walker, Kogut, and Shan, 1997; Gulati and Gargiulo, 1999), which can help us to simplify the question and make the analysis beyond dyadic level (Glückler, 2007). Giuliani's research, which used small sample of low-tech industry, indicated that reciprocity, cohesion, and knowledge base played critical roles in formation of ties in a Chile wine cluster (Giuliani, 2013). But there are other factors which affect formation of ties worth exploring. In fact, most of current studies focus on the networks of inter-organization. We know little about other kinds of network, such as technology flowing network in clusters. This paper intends to fill this gap via depicting the structure of technology flowing network and exploring the question how prior network structure affects formation of connections in pharmaceutical and biotechnology clusters.

To do so, we refine our research topics to the following questions. First, what does the structure of technology network of the biotechnology cluster look like? Second, how does prior structure affect formation of technology connections in the future? To answer these two questions, we compare networks of two biotechnology clusters: Boston and San Diego.

The rest of this study is organized as follows: we review literature about clusters, network evolution, and network structure in Section 2. Research hypotheses are developed in Section 3. Section 4 introduces the data, sample, and method. In Section 5, we draw the graphs of network structures of two clusters and present the empirical results. Section 6 concludes the paper.

2. Theory

2.1. Industrial clusters

In past studies, scholars always paid attention on why organizations in the same industry aggregated in the same district. The answer is different in different contexts. In economics, Marshall's theory (Becattini, 1990; Marshall, 2004) and Krugman's new economic geography theory (Krugman, 1991, 1994) are mostly used by scholars. Marshall's theory which was re-developed by Becattini mainly considers external benefits caused by organizations agglomerations (Becattini, 1990). Theory of new economic geography analyzes clusters based on the logic of increasing returns to scale (Krugman, 1991). In management field, Porter tried to explain why clusters appear from the perspective that clusters enhancing firm's competitiveness (Porter, 1998).

In addition to those pioneering works, many other studies try to answer the question that why firms aggregate in specific areas from different perspectives and contexts (Audretsch, 2001; Casper, 2007; Orsenigo, 2001; Swann & Prevezer, 1996; Ter Wal & Boschma, 2011). We summarize four reasons why clusters formed from past research: (1) the spillover effects of public research organizations (PROs), hospitals, and leading firms; (2) well financial supports from financial institutions; (3) knowledge and technology flowing caused by laboring pool in the cluster; (4) supports from excellent institution and entrepreneurial culture.

In the last two decades, with the improvement of network analysis methodology and computer processing capabilities, there are new trends of cluster theory which try to answer how questions except why questions. It is an exploring question about how do industrial clusters evolve and emerge. To answer this question, cluster scholars used some concepts and methods from network theory (Cantner, Meder, et al., 2010; Cassi, Morrison, et al., 2012; Gluckler, 2007; Ter Wal & Boschma, 2011). For example, Powell, White, et al. (2005) contribute by analyzing the dynamic mechanism of industrial clusters at the micro level. They used four logics – accumulative advantage, homophily, follow-the-trend, and multi-connectivity – to explain the collaboration structure between biotechnology firms in Boston cluster. Combination of cluster theory and network theory can help us to depict the evolution process from a distinct view.

2.2. Network theory

A network is a series of nodes and ties connecting them. Clusters are multilevel networks composed of many organizations. A single organization may be embedded in different kinds of network. For example, a firm is embedded not only in the supplied network but also in a cooperation network or a financial network. Furthermore, employees of the organization are also embedded in the social network. The network of technologies is another kind of network, in which actors are abstract technologies and ties are citations from one technology to another. These networks provide critical resources and also constrains to the organization. So structures of these networks have a huge influence on organizations' performance (Andersson, Hohn, et al., 2007).

Structure defines payoffs of actors in networks. On the level of individual's networks, structure has an influence on individuals' willingness of sharing or transferring knowledge with each other (Reagans & McEvily, 2003). Kossinets and Watts (2009) discussed how structure has constraints on formation of individual's networks. They found that structure affected ties formation via cumulative advantage process. When new actors who are willing to acquire or possess more resources to entry the network, they will certainly be affected by the existing structures.

On the organizational level, Granovetter (1985) held that organizations are embedded in certain economic and social structures, which affect allocation of resources between organizations. These kinds of relationship of embeddedness include social relations, exchange of resources, and combination of resources. Gulati and Gargiulo (1999) suggested that the structural differentiation in