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# Spatial and temporal evolution of urban innovation network in China

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ABSTRACT

Scientific and technological knowledge are increasingly becoming predominant in developing regional competitiveness and shaping the role of innovation in development. This paper focuses on the topological and spatial features of urban innovation networks in China. Using published papers and applied patents in biotechnology field from 2000 to 2012, we analyze the evolution of scientific knowledge networks (SKNs) and technological knowledge networks (TKNs). Four major findings are derived: (1) SKNs are much more complicated than TKNs in terms of size, ties, average degree and other indicators; (2) the two networks meet the scale-free networks, and the correlation analysis confirms the preferential attachment and dis-assortative traits in SKNs and TKNs; (3) spatial and temporal evolution of central nodes and networks structure show the hierarchical diffusion and contagious diffusion in both the networks; (4) multi-dimensional proximity (social, organizational, cognitive, geographical) well explains the knowledge spillover and innovation in SKNs, but it fails to explain them in TKNs. Moreover, social and organizational proximity weigh higher than the other two. The central nodes analysis helps cities better understand their position in networks. We find that comparative analysis of SKNs and TKNs contribute to recognizing the gaps of each city in innovation, which could assist in determining urban innovation policy.

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## 1. Introduction

With the rise of knowledge-based economy after 1980s, knowledge capital has replaced land and labor as a major factor in promoting economic development (Laperche, 2013; Toivanen & Ponomariov, 2011) and urban governance (Hjorth, 2003; Hordijk & Baud, 2006). Innovation in technology, production, market, management, input and other forms has become a key to maintain regional competitiveness and sustainable development (Laperche, 2013). Due to the complexity and uncertainty of innovation process, modern enterprises are showing increasing interest into the global and local knowledge networks (Carayannis & Von Zedtwitz, 2005; Qadeer, 1996). The relationships between innovation and regional development, and factors influencing knowledge spillovers, or innovation networks have also aroused the attention of scholars.

Owing to the spillover effect of foreign direct investment (FDI), and research and development (R&D) investment (Sengupta, 2013), Asia's economic growth miracle (China, South Korea, Singapore and other newly industrialized countries) has been a shock to the world for the past thirty years. Though knowledge and technology have become key factors in influencing the urban competitiveness and innovation in China (Shen & Yang, 2014), the relationships between innovation and economic growth are not fully answered, and how to improve regional innovation capability still challenges the governments at all levels. Furthermore, even after 30 years of rapid growth, China's economic development still faces many problems, such as overcapacity, weak indigenous innovation capacity, decline of investment returns, deteriorating environmental carrying capacity, and so on. Although the central government has been attempting to involve global production networks by attracting human capital and R&D activities with the help of FDI (Liefner, Wei,

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& Zeng, 2013; Wei & Liao, 2013), the mismatches in technology, structure, space, and institution have been hindering knowledge exchange between global pipelines and local buzz (Liao & Wei, 2013; Wei, Liefner, & Miao, 2011). Hence, it is essential to discuss scientific and technical knowledge, and innovation in China. This article studies innovation networks at China's urban scale. We will not only focus on topological and spatial structure of urban innovation networks, but also the differential status of cities and mechanisms that have been affecting the innovation network evolution.

## 2. Literature review and analytical framework

### 2.1. Knowledge spillovers and innovation networks

Although Krugman (1991) argues that knowledge spillovers can't be measured due to its invisible features, many scholars have traced knowledge spillovers (Jaffe, Trajtenberg, & Henderson, 1993; Newman, 2004) with the help of social network analysis method (Ter Wal & Boschma, 2009). The works have also resulted into various scientific papers (Hennemann, Wang, & Liefner, 2011; Hullmann & Meyer, 2003) and patents (Jaffe & Trajtenberg, 2002; Xiang et al., 2013).

Knowledge spillovers are common in cooperation, which shelters new products, new ideas, new process to rivals, and achieves a win–win (Toivanen & Ponomariov, 2011). There are many reasons to promote the cooperation of academic research and patents. For co-authored published papers, collaboration can realize the complementary advantages of different authors, such as theoretical analysis and data processing. Collaboration is also in demand for interdisciplinary development. When it comes to co-applied patents, there are at least three reasons for cooperation. First, as R&D possess the characteristics of high investment (expensive laboratory equipment), high risk and uncertainty (changing markets), and long payback period (Laperche, 2013), cooperation is one better way to minimize the risks. Second, it is not only important for access to new technologies and knowledge, but also a key strategy to prevent lock-in effect of local knowledge (Kim & Von Tunzelmann, 1998). Last, it is an effective way to protect intellectual property from competitors.

In the process of cooperation, innovation networks are shaped. The factors affecting the structure and evolution of innovation networks can be classified into the following categories. The first is R&D input and coupling of global and local knowledge (Bathelt, Malmberg, & Maskell, 2004; Carayannis & Von Zedtwitz, 2005). The number of R&D personnel and the amount of R&D investment are the foundations of innovation (Sirmon, Hitt, & Ireland, 2007). Though Foreign-investment enterprises are key for local buzz and global pipelines, the linkages between local and foreign companies are often questioned (Wei, 2015). Existing research has also confirmed the weak local embeddedness of foreign firms (Wei et al., 2012).

The second one is proximity. Due to focus of much of the research on FDI, R&D input etc., the complexity of innovation is often ignored (Audretsch & Feldman, 2004). However, proximity matters since it is related to spatial agglomeration, and trust between organizations (Doloreux, 2002). Boschma (2005) has proposed five types of proximities: geographical, cognitive, organizational, social and institutional proximity. Among them, geographical proximity is the most discussed one (Bentivegna, 2013; Feldman, 1994), because tacit knowledge concentrates in a certain region and cannot migrate to long distance (Feldman & Kogler, 2010; Sengupta, 2013). However, the role of geographical proximity is declining as a result of improvement of transport and telecommunication facilities, and some scholars have even proposed the 'death of distance' (Cairncross, 2001).

Inversely, social relationships, institution, culture and other innovation milieu play increasing roles in knowledge spillovers and innovation, which emphasize cognitive, social, institutional, and organizational proximities. In addition to geographical proximity, Boschma (2005) maintains that cognitive proximity makes people share common knowledge and ensures efficient knowledge learning. Organizational proximity lowers the uncertainty of knowledge production in organizational arrangement. While social proximity highlights the embedding of social relations at micro-scales (local conventions, family relations, etc.), institutional proximity emphasizes legal framework at macro scales. Though proximity among organizations exerts positive impacts on knowledge spillovers and innovation, over-proximity may get into a locked-in and fossilized innovation networks (Bentivegna, 2013; Rallet & Torre, 1999). In summary, the five-dimensional proximity has different roles in shaping innovation networks.

Many empirical studies have been devoted to unveil relationships between innovation and knowledge spillovers based on published papers and patents. Studies in automotive industry have observed that knowledge networks depend on synthetic knowledge, and biotechnology knowledge networks rely more on analytical knowledge. Besides, heterogeneity knowledge is expected when a firm builds knowledge networks (Plum & Hassink, 2011). Investigating the gatekeepers of Canadian biotechnology, Schiffauerova and Beaudry (2012) have conducted a comparative analysis on cluster-based sub-networks and component-based sub-networks. In their research, Schiffauerova and Beaudry (2012) finds that foreign inventors are critical for the knowledge transfer among Canadian inventors. Through the analysis of 23 German innovation networks, Kauffeld-Monz (2005) argues that universities are the fountainhead of information and knowledge, public research plays a role of gatekeeper in the process of innovation, and manufacturing companies are the biggest winners during the knowledge exchange.

From the perspective of network structure, several researchers consider that network structure is affected by geographical distance, institution, language, R&D investment, human capital, etc. (Audretsch & Feldman, 2004; Feldman & Kogler, 2010; Sengupta, 2013). Spencer (2003) and Takeda, Kajikawa, Sakata, and et al (2008) holds a view that knowledge networks can enhance the competitiveness of countries' firms and industries, which are in turn influenced by national systems and company properties. The collaboration networks of Latin American countries indicate that the size of country is associated with the collaboration rate, and that larger countries have a relatively high rate than the smaller ones (Gómez, Fernández, & Sebastián, 1999). Yim, Lee, and Kim (2010), by taking the example of Gyeonggi province in Korea, argues that the position of universities, research institutes and industry in the network sturcture have been exaggerated.

In addition to that, the mechanisms of knowledge spillovers and innovation are also explored. Unlike the "death of distance" (Cairncross, 2001), Maggioni and Uberti (2009), through the research on co-patenting, students exchange, fifth framework programme in European regions, maintains that geographic distance is still essential in inter-regional knowledge flows, so are the functional and sectoral distances. The results are in line with Autant-Bernard and Massard (2000), Takeda et al. (2008) and MacLeod (2000), who emphasizes that geographical proximity in the knowledge diffusion, regional learning and innovation either, and the location of hubs firms has a positive influence on the siting of enterprises. According to the findings of Frenken, Van Oort, and Ponds (2007), geographical proximity is more important than institutional proximity in life sciences and physical sciences in EU, USA and at international level. All in all, innovation network structure and mechanisms are still a worth thinking issue.

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