Technological Forecasting & Social Change 108 (2016) 70–82

Contents lists available at ScienceDirect

Technological Forecasting & Social Change

The structure and dynamics of intra- and inter-regional research collaborative networks: The case of China (1985–2008)

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ARTICLE INFO

Article history:
Received 28 September 2015
Received in revised form 14 March 2016
Accepted 11 April 2016
Available online 29 April 2016

Keywords:
Research collaboration
Intra- and inter-network
Regional innovation
China

ABSTRACT

Intra- and inter-regional research collaboration are two faces of regional innovation relations. This paper develops a multilevel network model of intra- and inter-regional research collaboration using co-patents. It then applies the model and social network analysis (SNA) to the Chinese case by examining collaborative invention patent applications to China's patent office. Over the past two decades, both China's intra- and inter-regional networks have been expanding in size, becoming more cohesive, and reflecting the "core-periphery" structure. In particular, inter-regional networks have begun to reflect characteristics of a triangle in space in which the most active collaborations occur between the Yangtze River Delta, the Pearl River Delta and the Bohai Rim, with many regions from 2000 onwards shifting from the high/low quadrant to the low/low quadrant within the two-dimension quadrant (TDQ) of regional degree/betweenness centrality in the inter-regional network. Intra-regional networks also reflected a "chain-like" structure of inter-organizational collaborations, with the key organizations shifting to universities from both universities and state-owned enterprises (SOEs) in intra-regional networks of Beijing and Shanghai. Our preliminary analysis suggests the possibility of complementary relationships between inter- and intra-regional networks for regional innovation rather than ones based on relevance.

1. Introduction

In an increasingly knowledge-based economy, knowledge has become the most important resource and innovation has become a key driving force of regional competitiveness (Krätke, 2010). In addition to the input of knowledge production, R&D expenditure and researchers, several terms such as cluster (Porter, 1994, 1998), the learning region (Florida, 1995; Hassink and Klaerding, 2012) and innovative milieu (Fromhold-Eisebith, 2004) have all stressed in increasing significance of the region as a geographical unit for innovation. Several factors, including social institutions, the economic environment, public infrastructure, cultural and linguistic homogeny, and physical proximity embedded in a geographical unit or local community, have been identified as influencing not only investment for innovation, but also the interactional relationships of organizations.

Interactions or collaborations between firms as well as between firms and academic institutions are central to research and innovation (Lundvall, 1992; Cooke et al., 1997). Organizational interaction and innovation overlap significantly with spatial organization. Several studies have already examined the relationship between location/place and regional innovation (Ter Wal and Boschma, 2009; Maggioni and Uberti, 2011). However, we know relatively little about organizational collaboration within and across regions. Indeed, inter-organizational research collaboration as an important form of interaction between organizations is central to the flow of technology and knowledge in an innovation system (Chesbrough et al., 2006; OECD, 1997).

The broader literature has provided considerable evidence of the influence of the intra- and inter-regional collaboration in regional innovation, with some studies revealing the regional patterns between intra- and inter-regional collaborative research (Marzucchi et al., 2012; Sun and Cao, 2015). Meanwhile, some scholars have argued that multilevel models of innovation and network help us to understand research collaboration within and across regions (Gupta et al., 2007; Guan et al., 2015). Beyond a general recognition of intra- and inter-regional collaborative research, more important questions are about the network structure and dynamics of inter-organizational collaboration within and across regions. However, we observe that surprisingly little attention has been given to interactions between organizations and regions. To be specific, what are the structures of an intra-regional network at the organizational level and an inter-regional network at the regional level? How is the process of network evolution related to the evolution of inter-regional and intra-regional structures? In this paper, we focus on the structure and dynamics of inter-organizational collaborative networks within and across regions, and attempt to understand the regional boundary-spanning activities through linking inter- and intra-regional collaboration.

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http://dx.doi.org/10.1016/j.techfore.2016.04.017
0040-1625/

In reality, we are concerned with the structure and dynamics of networks in terms of how they evolve, rather than the relationship between network structure and innovation performance. There are several practical reasons. First, previous empirical studies have investigated the relations between the network structure and actors' innovation performance, and emphasized their positive relations (Grewal et al., 2006; Schilling and Phelps, 2007; Phelps, 2010). However, the advantages of the network approach may enable us to overcome this artificial division between structure and performance (DeBresson and Amesse, 1991). After introducing the network approach, we intend to reveal the structure and dynamics of networks and move beyond traditional studies that focus on structures which condition performance. Second, while Guan et al. (2015) have explored the impact of inter-city and inter-county networks on the innovation performance of cities, the likely effects of inter- and intra-regional networks on the region may be diverse, uncertain and long-term. Our approach attempts to draw on and extend research examining the structure and dynamics of intra- and inter-regional networks, and help to understand the boundary-spanning activities of inter-organizational collaboration. Lastly, in the case of China, collaborative research is scarce with only between 1.0% and 1.3% of total patents resulting from the collaborative research of organizations (Sun and Cao, 2015), suggesting a weak relationship between collaboration and regional innovation performance. It would appear that as an emerging country, China's huge investment is the key driving force of innovation performance.

2. Collaborative research networks within and across regions: a literature review

Inter-organizational research collaboration has been widely recognized as being at the heart of regional innovation systems, with differences between regional innovation networks being an important topic of academic and policy debates.

2.1. Intra-regional network of research collaboration

Within regions, formal networks of research collaboration, together with informal networks, are effective means for knowledge creation, sharing and spillovers since geographical proximity constitutes a clear advantage for establishing or maintaining collaborative and interactive relationships between organizations (Fritsch and Schwirten, 1999; Hussler and Rondé, 2007). The innovation network is central to a regional innovation system, and social network analysis also has the potential to contribute further to the analysis of regional innovation systems (Cooke, 2001).

Intra-regional innovation networks are often formed from a heterogeneous group of different actors including firms, universities, technology centers and development organizations (Pekkarinen and Harmaakorpi, 2006). Of them, the role of universities is central to a regional innovation network. Graf and Henning (2009) found that universities and non-university public research institutions are key actors in all regional networks based on the analysis of four East German regional networks of innovation. Based on empirical analysis of eighteen German regional innovation networks, Kauffeld-Monz and Fritsch (2013) showed that public research organizations, especially universities, are profoundly involved in knowledge-exchange processes and possess more central positions within their regional innovation networks than private firms.

It is widely acknowledged that the regional difference of innovative performance seems to be related to difference in the structural properties of networks (Graf and Henning, 2009). Fritsch and Kauffeld-Monz (2010) found that strong ties are more beneficial for the exchange of knowledge and information than weak ties in a sample of 16 German regional innovation networks. Eisingerich et al. (2010) suggested that high performing regional clusters are underpinned by network strength and network openness, but that the effects of these on the performance of a cluster as a whole are moderated by environmental uncertainty. Through a case study of Sophia-Antipolis in France, Ter Wal (2013) revealed that a local network of collective learning emerged only in Information Technology and not in the Life Sciences. Randelli and Lombardi's (2014) empirical study suggested that among all the clusters of Italian small and medium-sized leather enterprises, only the Florence cluster had an asymmetric path in the period 1995–2011, which lead by Gucci, continues to have a positive rate of new firm formation, compared to a general trend of decline in the number of firms.

Meanwhile, the intra-regional network is also determined by talent flow, specialization of technology and innovation intensiveness. Cantner and Graf (2006) described the evolution of the innovator network of Jena, Germany resulting from the job mobility of scientists and the technological overlap between actors in the period from 1995 to 2001, rather than past cooperation. Cantner et al. (2010) has examined the differences across three regional innovator networks in Germany, and as a region that is relatively specialized in a number of broad technologies fields, it exhibits the least fragmented network structure. Using patent data, Óh Uallacháin and Kane (2014) analyzed the association between intraregional collaboration and levels of invention in nine developed countries within the OECD, and show that inventors in highly inventive regions co-patent more with own region partners.

2.2. Inter-regional network of research collaboration

It is possible that overemphasizing intra-regional collaboration could create regional development barriers. For example, a region might be stuck in its current knowledge base and lack knowledge diversity, which is likely to induce local technological trajectories mainly directed towards inferior solutions, thus entering the status quo of "path lock" (Belussi et al., 2010; Fitjar and Rodriguez-Pose, 2011). So, inter-regional collaboration that increases knowledge diversity within the local knowledge base is also crucial for regional innovation (Gertler and Levitte, 2005; Boschma and Ter Wal, 2007).

Indeed, inter-regional networks of research collaboration are of central concern to European countries. Based on the inter-regional networks of co-inventors in Sweden, Ejermo and Karlsson (2006) found that spatial affinity extends beyond the region if it has less own R&D-related resources (business R&D, university R&D and patenting), and it is relatively small and close to the other region. Maggioni et al. (2011) revealed that within single industries inventors are spread across Italy, but applicants are geographically concentrated in few areas (i.e. industrial districts and metropolitan areas) and "drain" brains from other provinces. Hoekman et al. (2009) found that inter-regional collaboration is more likely to occur between regions of excellence measured by publishing and patenting activities and between regions of political capitals in 29 European countries based on analysis of scientific publications and patents. Sebestyén and Varga (2013) found that quality of inter-regional knowledge networks in Europe is related to the level of knowledge accumulated by partners ('knowledge potential'), the extent of collaboration among partners ('local connectivity') and the position of partners in the entire knowledge network ('global embeddedness'). Wanzenböck et al. (2014) investigated the embeddedness[1] of European regions in different types of inter-regional knowledge networks, namely project-based R&D collaborations within the European framework programs (FPs), co-patent networks and co-publication networks, and the results reveal conspicuous differences between the knowledge networks. European experience shows that while the ongoing process of European integration is removing territorial borders, this does not render collaboration less sensitive to physical distance, knowledge distance and political distance. Recent studies on the geography of knowledge networks have documented a negative impact of physical

[1] Embeddedness refers to the network positioning of regions captured in terms of social network analytic (SNA) centrality measures.

distance and institutional borders upon research collaborations. Morescalchi et al. (2015) found the constraint imposed by country borders and distance decreased until mid-1990s then started to grow, particularly for distance; the intensity of European cross-country inventor collaborations increased at a higher pace than their non-European counterparts until 2004, with no significant relative progress thereafter.

Furthermore, scholars have begun to pay attention to inter-regional networks of research collaboration in emerging countries in Asia. Shapiro et al. (2010) confirmed that the centrality of Seoul as the primary research hub has declined although it is still the research broker for Korea. Having examined the determinants of trans-regional technology transfer within China with patent license data, Zhang et al. (2014) found that most technologies are transferred from provinces with greater R&D input such as Beijing and Shanghai, to economically developed provinces, such as Guangdong, Jiangsu and Zhejiang. Wang et al. (2015) indicated that five distinct technology exchange patterns have recently emerged in China: importers, exporters, self-sustainers, active generalists, and isolationists.

2.3. Intra- and inter-regional network of research collaboration

As both intra- and inter-regional collaborative research are vital for innovation, an appropriate balance between the two seems to be necessary for a region. It is argued that successful clusters should include actors that generate novelty by drawing on local and external knowledge (Graf, 2011). Based on the analysis of Statistics Canada's 1999 Survey of Biotechnology Use and Development, Gertler and Levitte (2005) found that both local and global relational linkages are important for knowledge circulation and successful innovation in firms. Boschma and Ter Wal (2007) demonstrated that local knowledge networking is quite weak and unevenly distributed among local firms in the South of Italy and being connected either locally or non-locally was important. Wilhelmsson (2009) in a study based on patent data for 1994 to 2001 in Sweden found a similar phenomenon in that the spatial distribution of inventor networks was not uniform and inventor networks were more likely to exist in densely populated areas with a diversified industry.

Using Chinese co-patent data in the U.S. Patent and Trademark Office (USPTO), Gao et al. (2011) examined geographic variations in the intra-regional, inter-regional and inter-national knowledge exchanges of China from 1985 to 2007 and the degree centrality reveals that while intra-regional and inter-national collaborations are the main channels of knowledge exchange for the provinces and municipalities of China, inter-regional knowledge exchange is relatively weak. Karna et al. (2013) found that innovation networks formed by subsidiaries of MNCs (including ABB, Alcatel-Lucent, AMD, Cisco, Dell, GE, Google, IBM, Intel, Microsoft, Philips, Siemens and Texas Instruments) in Bangalore, India, first developed as hierarchical networks and then were extended to the local markets.[2] Sun and Cao (2015) investigated the balance pattern, organizational types and evolutionary trend of intra- and inter-regional research collaboration in China using a dataset from the State Intellectual Property Office (SIPO), and the results show that major innovative regions were shifting from collaborative to independent research, from inter-regional collaboration to intra-regional collaboration, and from academic-enterprise to enterprise-enterprise collaboration, particularly in their inter-regional collaboration.

2.4. The literature and study

The above literature provides a strong foundation for this study. It explains how intra-regional networks, inter-regional networks, collaborations spanning regional boundaries and both intra- and inter-regional collaborations have been constructed. Meanwhile, these studies investigated network structure, properties and processes, the relationship between network structure and actors' performance and so on. The findings of these studies provide a rich source for theoretical concepts, empirical methods and data for intra- and inter-regional network.

Obviously, the extant literature has limitations in understating the intra- and inter-regional network. The broader literature on research collaboration has emphasized the influence of intra-regional or inter-regional network on regional innovation and their determinants but overlooks other important questions about the whole picture of intra- and inter-regional networks. Furthermore, it is widely recognized that both of intra- and inter-regional collaboration is central to regional innovation, with most studies investigating the intra-regional and inter-regional relationships of research collaboration. However, less attention has been devoted to the structure and dynamics of both intra- and inter-regional network.

From a regional perspective, the network approach could identify regional collaborative partners and positions in inter-regional collaborative networks through processing complex inter-regional relations, while also revealing the spatial structure and temporal dynamics of the network. Furthermore, the inter-organizational relations create the intra-regional network, which is crucial for regional innovation. Comparing the structure of inter-organizational networks within regions with that across regions is particularly important for understating regional innovation under the national innovation system, which also provides evidence for understanding the relationship between intra- and inter-regional networks.

It is noteworthy that broader empirical studies focusing on intra- and inter-regional networks in Europe seldom refer to an emerging country like China. This is partly explained by the focus on European integration by scholars publishing in European journals. For a vast territory like China, however, using the region is also an important unit of analysis. For a nation with great ambitions in innovation, researching innovation networks within and across regions has considerable potential particularly since Chinese organizations have had little engagement to date in international collaboration in patenting.

In order to expand the existing literature, this study advances a model of intra- and inter-regional networks and attempts to apply it to examine the structure and dynamic of intra- and inter-regional network of research collaboration. Not only are the results useful for understanding the characteristics of China's regional innovation system, but the framework and findings based on it will also have implications for the study of research collaboration in other countries.

3. A model of intra- and inter-regional network

While the literature on regional networks is by now quite extensive, it seldom proposes a model of multilevel networks in regional innovation (Guan et al., 2015). Following the extant studies, we develop a model of multilevel networks based on inter-organizational relationships in research collaboration (Hong, 2008; Motohashi, 2008; Hong and Su, 2013). There are several ways to represent research collaboration, including co-invention, co-authorship, and alliance, and also informal personal relations such as private discussion and random communications. In this paper, we measure the inter-organizational research collaboration by patent co-assigneeship,[3] bearing in mind the many limitations associated with using patents as a proxy for collaborative activities (for more details, please see Sun and Cao, 2015).

The following hypothetical example illustrates the main idea (see Fig. 1). Suppose there are three patents — P1, P2 and P3 whose assignees are five organizations — A3, A4, B3, C5, C4 and from three regions A, B

[2] Within the first part, the networks start with a non-local nature (phase A) and become embedded into local networks (phase B and phase C), while finally developing into non-local (phase D) market ties that enable MNC headquarters to source innovation from the host country.

[3] The present paper only studies collaboration between organizations, and therefore patents filed by individuals are excluded.

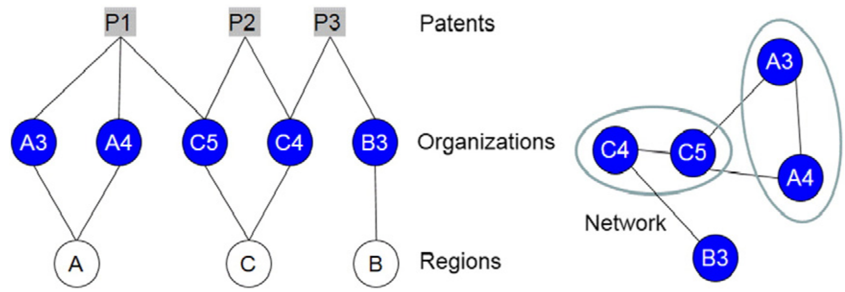


Fig. 1. The construction of regional network based on inter-organizational collaboration in patents.

and C. P1 was collaborated by A3, A4 and C5, P2 was collaborated by C5 and C4, and P3 was collaborated by C4 and B3. The relations between organizations can then be expressed as five pairs of network ties: A3–A4, A3–C5, A4–C5, C4–C5, and B3–C4. A network is shown graphically in Fig. 1. The width of lines reflects the collaborative strength, that is the number of ties between each pair of organizations.

Repeating the same exercise for the total patents sample, we end up with a map representing the regional network of inter-organizational collaboration (see Fig. 2). The inter-organizational collaborations span regional boundaries, which forms a multilevel network — intra-regional network (or inter-organizational network) and inter-regional network. A network of the intra- and inter- regional collaboration could be drawn based on either organizational relations or geographic distinctions. In particular, inter-organizational research collaboration within regions forms an *intra-regional collaborative network* in which nodes are organizations and ties are linkages of organizational collaboration. Inter-organizational collaboration across regional boundaries forms an *inter-regional collaborative network* in which nodes are regions and ties are inter-regional linkages through the inter-organizational research collaboration. In sum, a region is a node in an inter-regional network as well as being part of a whole network of intra-regional collaboration.

The structure and dynamic process of regional research collaborative networking was determined by the two key mechanisms of proximity and preferential attachment. At the early stage of network emerging, organizations would like to select a collaborative partner with complementary assets or knowledge intensive resources in their own region, because geographical proximity could reduce cost and increase efficiency of research and innovation activities, in particular driven by tacit knowledge (Hoekman et al., 2010; Maggioni et al., 2011). Organizations within the regional boundary that may also enhance other forms of proximity such as social and culture homogeneity could connect more easily. Obviously, the distribution of network ties in organizations is uneven, because organizations with rich resources have more ties.

Then, the preferential attachment works. Preferential attachment means that the likelihood of a new organization within a region linking to another organization is proportional to the number of ties that organization already has (Barabási and Albert, 1999). In other words, "the rich get richer", or what is referred to as the "Matthew effect". A consequence of preferential attachment is that an inter-organizational network with a "core-periphery" structure seems to gain a great deal of stability (Orsenigo et al., 2001). The "core-periphery" structure in intra-regional networks means that the inter-organizational sub-networks within intra-regional network consist of a dense cohesive core or multiple cores and a sparse, loosely connected periphery. It is possible that an intra-regional network includes several sub-networks with "core-periphery" structure. The core organizations account for most of ties, and the periphery organizations have less ties or only connected to cores. Thus core organizations dominating the network will reap most of the innovation bonuses within the region.

Over time, the advantage of geographical proximity and preferential attachment in a network begins to erode. Besides geographical proximity, it is possible that organizations prefer to connect with partners having technological proximity (similar technological interests and R&D fields) and organizational proximity (similar management system and culture), although they may not be located in the same or nearest region. This indicates that originations attempt to create collaborative relationships spanning the regional boundary. In fact, too much proximity between organizations on any of the dimensions might harm their

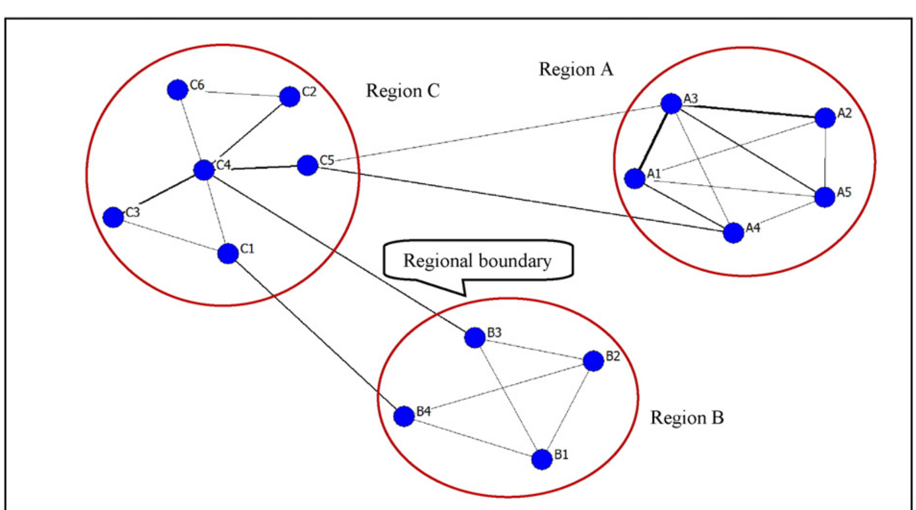


Fig. 2. A network model of intra- and inter-regional research collaboration. Note: The wide of links means the cooperation frequency between organizations.

innovative performance and reduce the influence for further collaboration at the same time (Broekel and Boschma, 2012).

Meanwhile, this phenomenon is not unique. Within the "core-periphery" structure, the core organization may attempt to create boundary spanning ties in order to access external heterogeneous resources. However dominant organizations in a network do not find it easy to overcome organizational inertia associated with knowledge advantage which means that the organization with richer knowledge could attract more partners, and preferential attachment which means that the organization already has many ties receive connections more than those who are not or less. The peripheral actors of a network also attempt to reap more innovation bonuses through improving their network position, and creating inter-regional ties. In sum, when more organizations connect partners from outside a region, and when a region with more inter-regional ties could appeal to more new outside ties, this could shape a new "core-periphery" structure at the regional level. The inter-regional networks with "core-periphery" structure means the network consists of a core or multiple cores regions and other periphery regions. The core regions have most of ties and dominated the network, and the periphery regions are less ties.

4. Methods and data

In order to learn more about China's various regional innovation systems, this article intends to investigate a region's position in the inter-regional network, the structure of its intra-regional network, and the dynamics of two networks. Base on the visualization of a network, the network size, network cohesion and network centrality are measured by the UCINET software package to reflect the network structure.

The size of the network means the number of regions participating in the inter-regional network and the number of organizations participating in the intra-regional network. Network size (NS) is critical for the structure of collaborative relations because of the limited resources and capacities that each organization/region has for building and maintaining ties.

Network cohesion was measured using network density (ND), average path length (PL) and clustering coefficient (CC). For a valued network, ND involves all of the actual ties including collaborative frequency divided by the number of possible ties, and provides insights into such phenomena as the speed with which information diffuses among organizations. An organization's CC is the density of a network consisting of its collaborators. The CC of a network is the mean of all organizations' CC, and when an organization's collaborators are connected to each other, it has a highly clustered or cliquish sub-network which consists of organization's collaborators who are interacting extensively with one another. PL measures the average number of ties between any two organizations in the network along their shortest path, in which the length of a path is the number of organizations it contains and the strength of a path is the strength of its weakest link (Watts and Strogatz, 1998; Uzzi et al., 2007). PL represents the efficiency of information transport across actors in a network.

Centrality measures are widely used in social network analysis, as centrality can identify the power of nodes in a network at the ego network level, and centralization is used to measure the distribution of nodes in a network at the whole network level (Kim and Song, 2013; Borgatti, 2005; Freeman, 1979; Freeman et al., 1989).

From the perspective of inter-regional networks, we focus on the role of a region as a contributor or coordinator in the inter-regional network by centrality. The degree of contribution was measured by the share of the number of a region's direct ties (degree centrality) accounted for by total ties in the network.[4] The degree of coordination was measured by the normalized betweenness centrality which is the betweenness centrality[5] divided by the maximum possible betweenness expressed as a percentage. In our study, a region on the shortest paths with other regions is playing the key role in transferring technology and knowledge through collaboration, or, on the other hand, the region is able to isolate, influence, manipulate or even prevent technology and knowledge from being transferred between other regions.

Obviously, the threshold for distinguishing high and low levels is central to the categorization of regions. The average value is used to distinguish high and low level in the degree/betweenness centrality quadrant because of the universality of two-dimension quadrant (TDQ), which could be applied to other cases of similar characteristics (Kim and Song, 2013). Certainly, such categorization could also be influenced by the distribution of regions' data, in particular the number of regions in each quadrant (Sun and Cao, 2015). Thus, we set up 50% as the cut-off point for measuring high- and low-degree centrality, and 2% as the cut-off point for measuring high- and low-betweenness centrality in terms of the distribution of regions in networks. We then map the positions of regions in TDQ of degree/betweenness centrality. A scatter was divided into four quadrants — high/high, low/low, high/low and low/high. A region at the high/high quadrant indicates that it plays a critical role as both contributor and coordinator, and one at the low/low quadrant is weak in both roles. A region at the high/low or low/high quadrant prefers to contribute or coordinate in inter-regional collaboration.

From the perspective of an intra-regional network, it is an inter-organizational network within a region. In this sense, network centralization could be used to measure the distribution of organizations in an intra-regional network. The degree of centralization represents the distribution of organizations' degree centrality, with the more centralized or unequal network having a higher degree of centralization. Similarly, betweenness centralization represents the distribution of organizations'betweenness centrality, with higher betweenness centralization reflecting a network divided into several blocs and depending too much on one organizations' transmission.

This research uses the co-assigneeship data from Chinese invention patents applications to China's SIPO to study intra- and inter-regional research collaboration from 1985 to 2008. In order to illustrate the dynamics of the collaborative innovation network, we divided the sample into three periods of roughly equal length — 1985–1992, 1993–2000, and 2001–2008, for two reasons (Sun and Cao, 2015). One is the evolution of China's patent system and IPR protection. China promulgated the *Patent Law of the People's Republic of China* in 1984, which was in force in 1985, and acceded to the *Paris Convention for the Protection of Industrial Property* in 1985. So 1985 is the start year of patenting in China. Second, these years are also coincidently important from the perspective of China's reform and open-door policy, especially with respect to technology and innovation. In 1985, the Chinese state issued the *Decision on the Reforms of the Science and Technology System*; in 1992, Deng Xiaoping's southern tour deepened Chinese economic reforms and heralded China into a new era of S&T and innovation development. Then in 2001, China joined the World Trade Organization (WTO) and became a member of the TRIPS agreement,[6] which indicates that Chinese S&T system began to be integrated into the global innovation network.

[4] The normalized degree centrality is the degree divided by the maximum possible degrees expressed as a percentage, which should only be used for binary data. We do not consider in- and out-degrees of organizations because research collaboration is a two-way interactive process.

[5] The betweenness centrality was the number of times a region acts as a bridge along the shortest path between two other agencies.

[6] The Agreement on Trade Related Aspects of Intellectual Property Rights (TRIPS) is an international agreement administered by the World Trade Organization (WTO) that sets down minimum standards for many forms of intellectual property (IP) regulation as applied to nationals of other WTO members. It was negotiated at the end of the Uruguay Round of the General Agreement on Tariffs and Trade (GATT) in 1994.

Between 1985 and 2008, there are a total of 751,913 patent applications based on direct national count and 766,965 patent applications based on sum of regional counts taking into account inter-regional collaboration. The academic–academic (AA), industry–industry (II) and academic–industry (AI) collaboration accounted for 8.56%, 13.88% and 77.56% of the intra-regional collaboration respectively, and 11.66%, 22.33% and 66.01% of the inter-regional collaboration respectively (Sun and Cao, 2015). The statistics means that AI collaboration dominated research collaboration in China, whereby enterprises, motivated by acquiring knowledge, tended to collaborate with academic institutions instead of enterprises.

5. China's inter-regional network: structural properties and regional positions

After mapping China's inter-regional network of provinces and municipalities, we have calculated several network indicators to reflect the structural properties of the whole network and to identify regional positions in the inter-regional network (see Table 1 and Figs. 3 and 4).

5.1. In the first period 1985–1992

In the first period 1985–1992, the whole network is relatively sparse with 29 regions participating in the network. Tibet and Hainan were the isolated actors, denoting no knowledge exchange happening with others. ND was only 1.2172, indicating almost inactive research collaboration. The clustering coefficient (CC = 3.921) indicates that regions' collaborators did not like to collaborate with each other. The average path length (PL = 1.811) indicates that the efficiency of knowledge exchange across regions was highest in the three time periods. Beijing was the major knowledge exchange center with strong ties to provinces on the east coast and a few central provinces. It indicates that research collaborations extends beyond the region if it has more own R&D-related resources (research institution, university, R&D and patenting), which differs with Sweden's situation (Ejermo and Karlsson, 2006). Thus, it is possible that a region if it has more (or less) own R&D-related resources, will like to inter-regional collaborations. The ties involving most the mid-west provinces were weak. In addition to Beijing, the regions in high/high quadrant included Shaanxi, Shanghai, Liaoning, Hubei and Shandong, as both contributors and coordinators in the network. No region was in the high/low quadrant and two regions — Jiangsu and Hebei were in the low/high quadrants. Apart from Sichuan on the central axis line, all other regions were in the low/low quadrants, and the majority of them played only a small role of coordination in the network.

5.2. Entering the second period 1993–2000

Entering the second period 1993–2000, the network became denser but still not strongly interconnected, evidenced by the fact that its network density was only 1.7355, slightly higher than that in the first period. There was no isolated actor as Tibet and Hainan had also begun to create inter-regional ties which were still weak (Network size = 31). CC increased to 7.824 from 3.921 and regions' collaborators began to collaborate with each other, resulting in several small groups. PL increased to 2.234, which indicates that the length between regions increased and the efficiency of knowledge exchange across regions reduced. Shanghai became the first region to seriously engage in intra-regional collaboration, with its within-region collaborations exceeding that of Beijing and Liaoning. Meanwhile, collaborations within Beijing, Liaoning, and Shanghai were all increasing.

Beijing continued to be the major knowledge exchange center, and the strongest pairs of ties were Beijing–Shanghai, Beijing–Guangdong, and Beijing–Liaoning. It looks like that inter-regional collaboration is more likely to occur between regions with active research and patenting activity, which is similar with Europe (Hoekman et al., 2009). Other ties among regions were relatively weak, specifically those to provinces in the mid-west. Apart from Beijing, Shanghai and Liaoning, Guangdong and Jiangsu as new entrants shifted to the high/high quadrant. As both contributor and coordinator of the network, they were the primary regions not only because of their direct and indirect ties to other regions but also for their being the bridges between other regions. Shandong, Shanxi and Hubei dropped to the low/low quadrant from the high/high quadrant. Shanxi was on the central axis line instead of Sichuan. Similarly, only Hunan was in the low/high quadrant and the high/low quadrant was blank. It is clear, however, that, relative to the first period, the distribution of regions in the TDQ changed a little, with Guangdong and Jiangsu rising together, and changing the domain of China's regional innovation.

5.3. In the third period 2001–2008

In the third period 2001–2008, the network expanded even more (more ties). The density of the network was 14.557, being much higher than the first two periods and suggesting that collaboration did increase in scale. Collaborations in patent production had become more decentralized and more cohesive (more ties between nodes). Beijing became the major knowledge exchange center according to its collaborations within the region, followed by Shanghai, Jiangsu, and Zhejiang who also increased their co-patenting activities a lot. Meanwhile, the intra-regional collaboration in Liaoning was not high compared with the four regions mentioned above and the gap in intra-regional collaborations between the less advanced and more advanced regions had increased. CC increased to 31.427, which indicated great progress relative to 7.824 in the previous period, and the network became a highly cliquish network. PL increased to 2.654, which means the length between regions only increased a little although the network expanded greatly.

Apart from Beijing, Shanghai, Liaoning and Jiangsu were in the network as both contributor and coordinator. Sichuan, Hubei and Hunan shifted to the high/high quadrant, and Guangdong dropped to the high/low quadrant. Beijing and Shanghai took up the same position in the network. Most of the regions concentrated in the high/low quadrant that was blank in the first two periods, and no region was in the low/high quadrant. Only a few regions were still in the low/low quadrant. Obviously, the distribution of regions in the TDQ changed a lot relative to the previous two periods. In essence, Beijing and Shanghai were experiencing a reduction in their coordinating advantage a lot, and other regions increasingly improved their roles in the network through coordination.

In sum, the network between 1985 and 2008 was not much different from that in the third period (2001–2008), because the number of collaborations in the third period accounted for more than 80% of the total number of collaborations between 1985 and 2008. Thus, it is not necessary to analyze the situation of network between 1985 and 2008 again. Meanwhile, comparing the network between 1985 and 2008 to that between 2001 and 2008, could find the development trend of regions' collaborations since 2001. Compared with the third period, fewer regions during the first two periods were in the high/high quadrant and more regions were in the high/low quadrant, indicating that fewer regions wanted to become brokers in the network, and most

Table 1
The structure properties of the inter-regional network as a whole.

Periods	Network size	Network density	Clustering coefficient (CC)	Average path length (PL)
1985–1992	29	1.2172	3.921	1.811
1993–2000	31	1.7355	7.824	2.234
2001–2008	31	14.557	31.427	2.654
1985–2008	31	17.5097	33.646	2.428

Sources: Calculated by authors based on data from SIPO.
Notes: For non-binary data, linkages among actors with values (strengths etc.), network density is usually defined as the sum of the values of all ties divided by the number of possible ties.

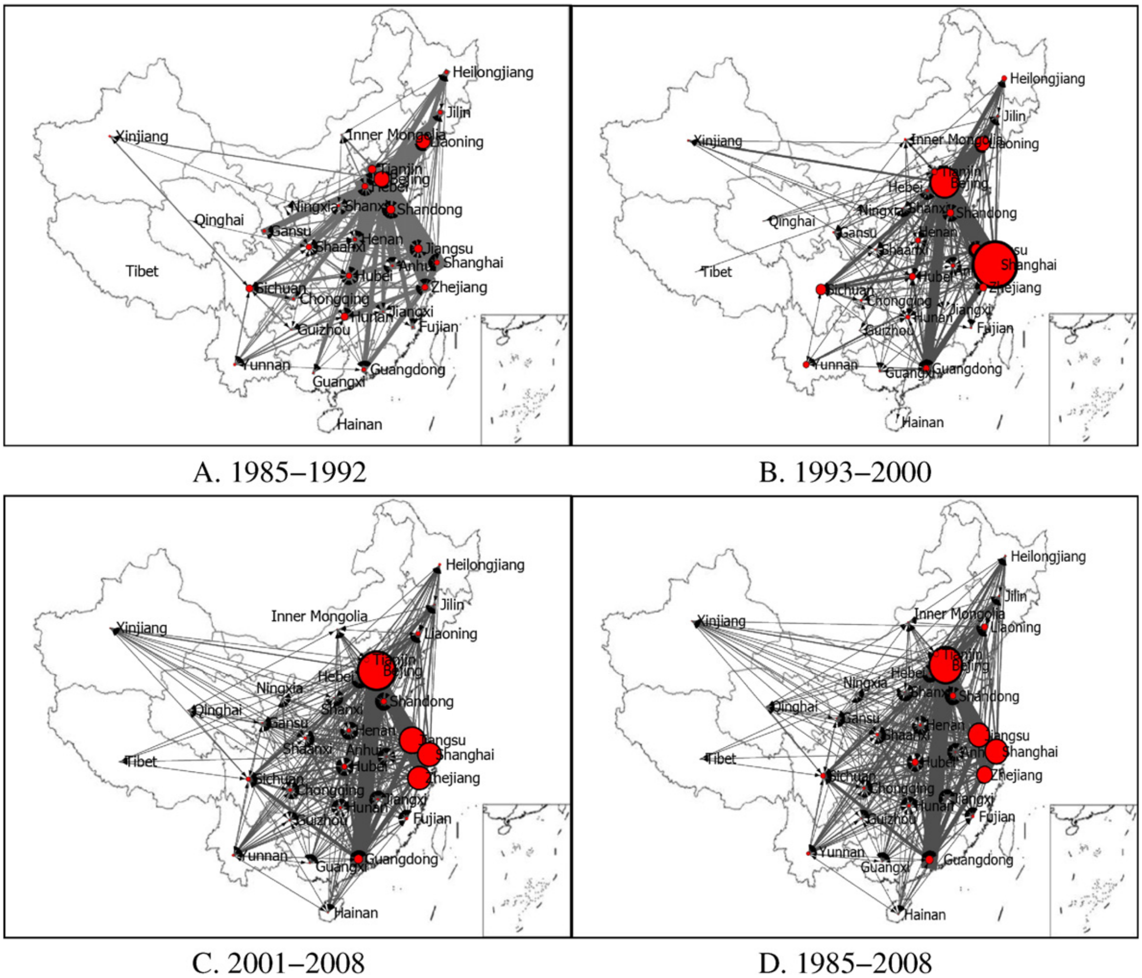


Fig. 3. The inter-regional network of research collaboration in China. Source: Calculated by authors based on data from SIPO. Notes: a) Provinces are the nodes of networks whose size represents the number of intra-regional collaboration. b) The lines are the collaborative linkages between provinces whose thickness represents the number of inter-regional collaboration.

regions just connected to knowledge-intensive regions like Beijing and Shanghai directly to access new technologies (Zhang et al., 2014).

6. China's selected intra-regional networks: structural properties and organizational positions

When focusing on the intra-regional network, only a number of regions could be selected as a sample, because most regions have a very small number of collaborative patent applications. Seven major regions – Beijing, Shanghai, Zhejiang, Jiangsu, Guangdong, Tianjin, and Liaoning – produced 64.57% of the invention patent applications, and 70.23% of the intra-regional collaborative patents. Thus, we measured the structural properties of the intra-regional network in these seven regions firstly, and then investigated two visual networks of Beijing and Shanghai because of their significant role as contributor and coordinator in inter-regional networks (see Tables 2 and 3, Figs. 5 and 6).

6.1. In the first period 1985–1992

In the first period 1985–1992, there was a significant difference in the structural properties of intra-regional networks in selected regions. There were 124 organizations participating in Liaoning's intra-regional network, the biggest network size of the selected regions, and Beijing was another region whose number of participating organizations (network size) was more than 100. Overall, the number of organizations participating in collaboration was small. Guangdong's intra network only included 37 organizations, and was ranked first place in network density (ND = 0.0308). However, its CC was zero, which indicates organizations' collaborators did not connect to each other in the network, and weak network connectivity made it difficult to form a cluster of organizations. Guangdong's centralization degree was 7.83%, the most unequal network in the selected regions, with a few organizations contributing most ties in the network.

While Shanghai had the biggest clustering coefficient (CC = 0.909) and the shortest path length (PL = 1.001), its network connectivity was poor according to the visual network, and while there were a lot of collaborative pairs it was not a connectivity network. Beijing's betweenness centralization was 6.93%, and several organizations such as Central Iron & Steel Research Institute, Ministry of Metallurgical Industry[7] (A5859) and Institute of Mechanics, the Chinese Academy of Sciences (A6497) were major brokers in the network. Relative to Shanghai, Beijing had formed a big cluster although other collaborative pairs also did not connect with each other. Within the cluster, Tsinghua University (A3648) and China Petroleum & Chemical Corporation[8] (A6743) were the core actors.

[7] Ministry of Metallurgical Industry was a department of the State Council in China, revoked in the 1998 administration reform. In 2006, Central Iron & Steel Research Institute and Automation Research coupled with Design Institute of Metallurgical Industry formed the China Iron & Steel Research Institute Group, a central state-owned enterprise (SOE).

[8] China Petroleum & Chemical Corporation is a large scale integrated energy and chemical company with upstream, midstream and downstream operations, and China's largest manufacturer and supplier of petroleum products and major petrochemical products. It is the second largest oil and gas producer in China.

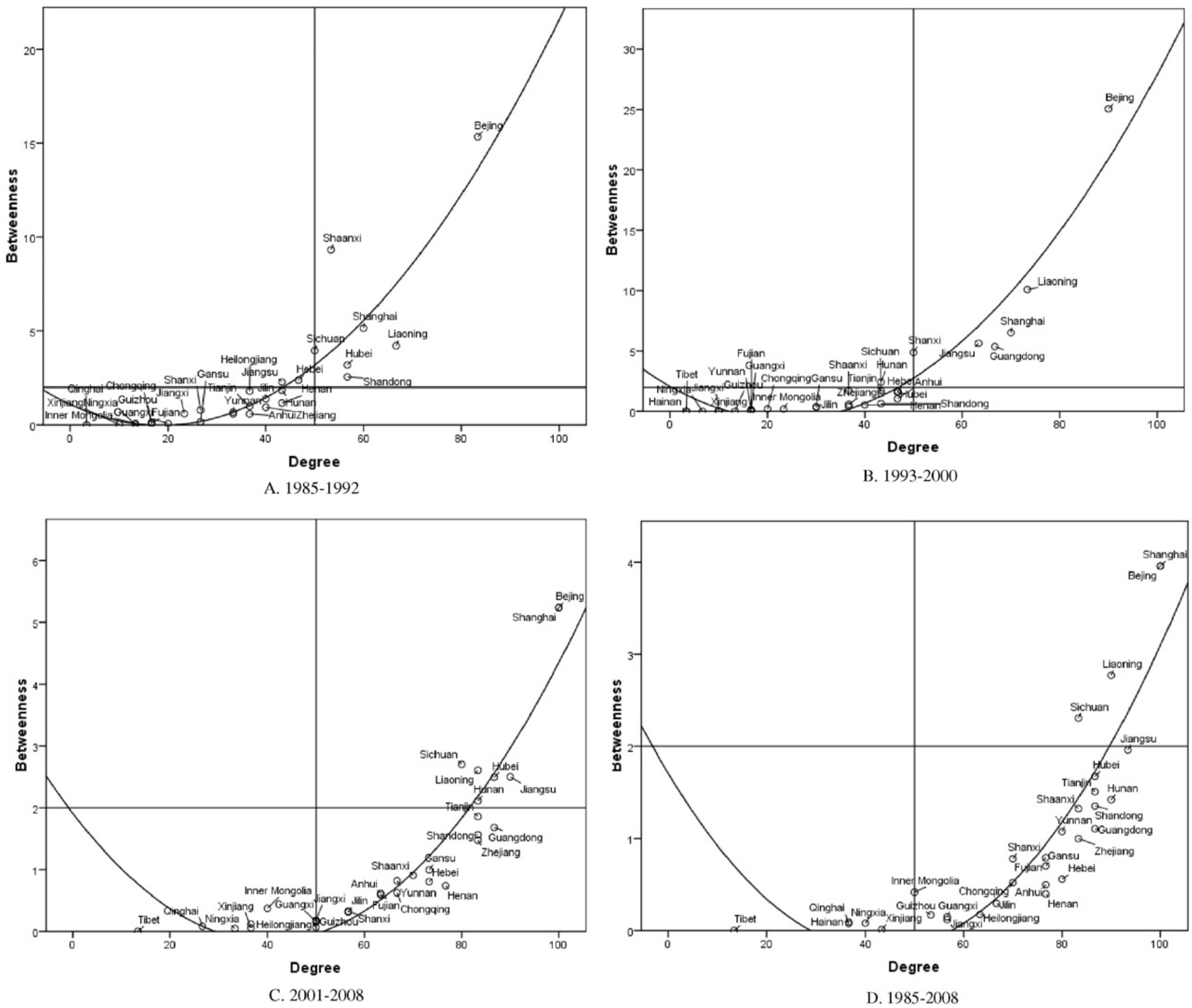


Fig. 4. The regions' position-contributor or coordinator in the inter-regional network. Source: Calculated by authors based on data from SIPO.

6.2. In the second period 1993–2000

In the second period 1993–2000, the intra-regional network in selected regions had no significant change relative to the previous period. More organizations participated in the network of Jiangsu, Guangdong, Shanghai and Beijing, while the network size in Liaoning, Zhejiang and Tianjin reduced a little. Beijing became the biggest network in scale instead of Liaoning whose network size was still 124. Relative to the previous period, ND increased a lot although the network size changed a little in this period.

Except for Guangdong, all selected regions increased their network density, and Shanghai took first place (ND = 0.0629). Beijing had the biggest clustering coefficient (CC = 1.783) and Jiangsu had the shortest path length (PL = 1.005). Selected regions' CC and PL remained stable. Shanghai's clustering coefficient is zero. Apart from Zhejiang and Tianjin, all selected regions' degree centralization declined. Zhejiang, Tianjin and Shanghai's betweenness centralization increased a lot, and that of others declined. Zhejiang took first place in both degree centralization (6.07%) and betweenness centralization (11.06%). This indicates that contribution and coordination were relatively concentrated in several organizations in Zhejiang and Tianjin, while a contrary trend was evident on other regions.

In particular, Shanghai also formed two small clusters, one with a "core-periphery" structure dominated by East China University of Science and Technology (A2399), and the other was a "chain-like" structure with two key organizations — Fudan University (A1288) and Baosteel Group Corporation[9] (A160). In Beijing, the big cluster added a new core organization — China Petrochemical Group (A6740) established in 1998 based on China Petroleum & Chemical Corporation (A6743), as well as forming a spin off cluster centered by Central Iron & Steel Research Institute, Ministry of Metallurgical Industry (A5859). This presents that petrochemical and steel two clear clusters in intra-regional networks, which is similar with Florence cluster of leather enterprises (Randelli and Lombardi, 2014).

6.3. Entering the period 2001–2008

Entering the period 2001–2008, the significant changes happened in the intra-regional networks of selected regions. At first, network size had a great increase and the number of organizations participating in the networks of all selected region ranged from 195 to 711. The smallest

[9] Shanghai Baosteel Group Corporation is a large iron and steel conglomerate set up on Nov. 17, 1998, with the former Baoshan Iron and Steel (Group) Corporation as the core, and absorbing the former Shanghai Metallurgical Holding Group Corporation and the former Shanghai Meishan Group Co., Ltd. Baosteel is one of the most profitable steel enterprises in the world enjoying international competence, and its annual production capacity is about 20 million tons. Baosteel produces high demand products in the domestic and international market.

Table 2
The structure properties of the intra-regional network in selected regions.

Periods	Regions	Network size	Network density	CC	PL	Degree centralization	Betweenness centralization
1985–1992	Liaoning	124	0.0122	0.452	1.063	2.664%	4.33%
	Zhejiang	61	0.0217	0.788	1.006	3.11%	0.32%
	Jiangsu	82	0.0139	0.672	1.008	2.3%	0.27%
	Guangdong	37	0.0308	0	1.031	7.83%	2.82%
	Tianjin	69	0.0205	0.502	1.1	4.62%	2.19%
	Shanghai	51	0.0238	0.909	1.001	1.71%	0.07%
	Beijing	115	0.0118	0.568	1.084	3.94%	6.93%
1993–2000	Liaoning	104	0.0168	0.426	1.021	2.02%	0.85%
	Zhejiang	52	0.0356	0.273	1.136	6.07%	11.06%
	Jiangsu	98	0.0146	0.41	1.005	1.19%	0.14%
	Guangdong	54	0.0256	0.542	1.011	2.96%	0.69%
	Tianjin	38	0.0526	0.83	1.12	5.09%	8.73%
	Shanghai	91	0.0629	0	1.056	1.11%	3.35%
	Beijing	124	0.0224	1.783	1.11	1.65%	6.92%
2001–2008	Liaoning	195	0.0117	0.565	1.071	1.47%	5.2%
	Zhejiang	544	0.0065	1.476	1.317	1.74%	29.83%
	Jiangsu	711	0.0056	4.398	1.206	0.24%	11.54%
	Guangdong	303	0.0093	1.23	1.153	2.33%	11.62%
	Tianjin	195	0.0115	0.793	1.111	3.85%	9.23%
	Shanghai	590	0.0072	0.933	1.545	0.46%	23.18%
	Beijing	617	0.0125	10.8	1.245	0.46%	16.1%
1985–2008	Liaoning	391	0.0053	0.531	1.14	1.01%	8.62%
	Zhejiang	642	0.0051	1.401	1.277	1.54%	26.15%
	Jiangsu	863	0.0041	3.909	1.166	0.2%	9.79%
	Guangdong	377	0.0068	1.081	1.126	2.02%	9.44%
	Tianjin	289	0.0073	0.793	1.1	3.29%	7.61%
	Shanghai	702	0.0063	0.86	1.45	0.27%	18.61%
	Beijing	806	0.008	9.185	1.225	0.38%	15.11%

Sources: Same as Table 1.

network of Liaoning included 195 participants which was more than the biggest network in the first two periods. However, ND dropped a lot, and inter-organizational connections did not form accordingly. The region with the highest network density (ND = 0.0125) was Beijing, which was close the smallest one in the first two periods.

Four regions' CC was more than 1, of them Beijing's CC reached 10.8. In contrast to this Beijing was the only region with a CC higher than 1 in the previous period. Apart from Tianjin, PL of all regions increased a little, indicating a reduction in the efficiency of knowledge exchange based on collaboration. Meanwhile, degree centralization of all selected regions declined while the betweenness centralization has increased. Organizations increasingly participated in the network, which reduced the concentration of degree distribution as well as forming several clusters or blocs, as more organizations became brokers between different clusters.

Shanghai's network, in particular, consisted of seven clusters with the "core-periphery" structure, while these clusters also connected each other. Apart from East China University of Science and Technology (A2399) and Fudan University (A1288), these core organizations also included Shanghai University (A3972), Shanghai Jiao Tong University (A4137), Tongji University (A5299), East China Normal University (A2403) and Donghua University (A1134).

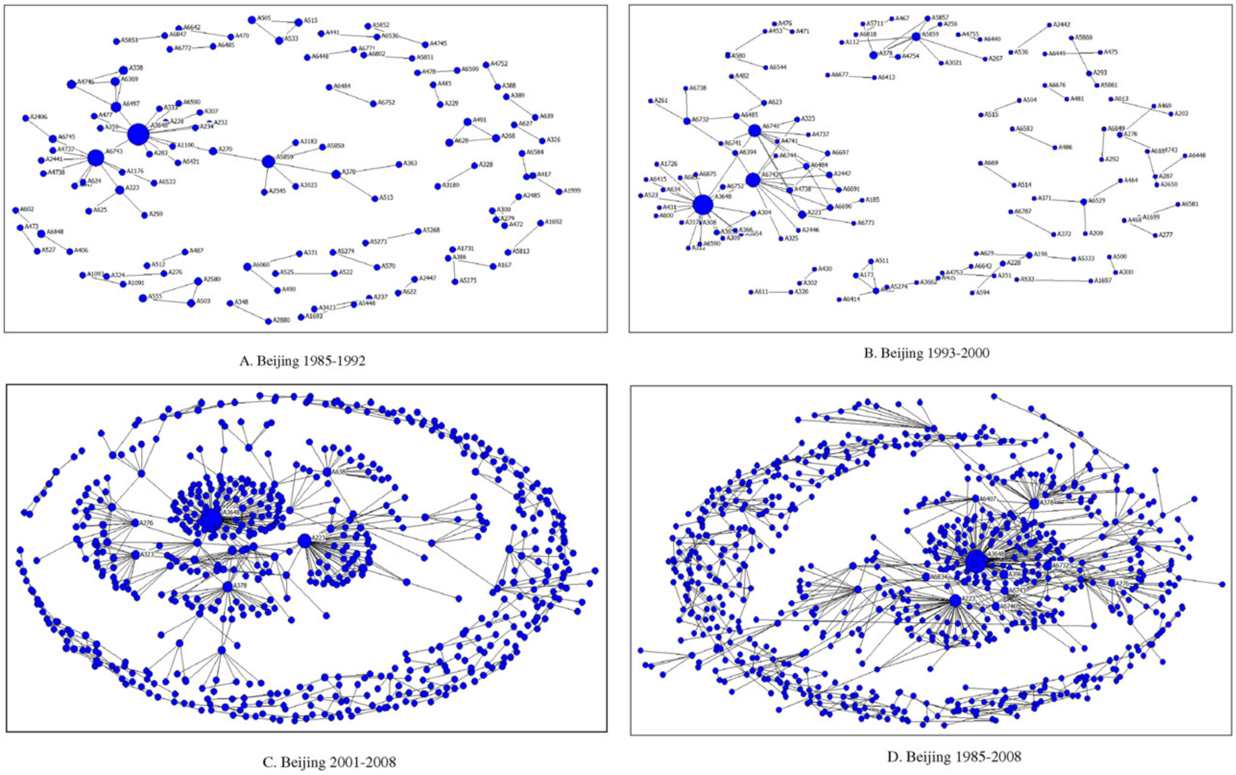
Beijing's network also consisted of several clusters. The biggest cluster was dominated by Tsinghua University (A3648), the second cluster was dominated by Peking University (A 223), and the other clusters were relatively small ones centered on Beijing University of Chemical Technology (A323), Beijing University of Technology (A276), University of Science and Technology Beijing (A378), and Beijing University of Posts and Telecommunications (A638). It is not surprising that famous universities such as Tsinghua, Peking, Fudan, Jiao Tong and Tongji sponsored by Project 985[10] played significant role in the intra-regional network. This is similar with the German regional innovation networks, and universities are profoundly involved in knowledge-exchange processes and occupy more central positions within intra-regional

Table 3
The main organizations in Beijing and Shanghai's intra-regional network.

Codes	Name of organizations
Beijing's network	
A223	Peking University
A276	Beijing University of Technology
A323	Beijing University of Chemical Technology
A3648	Tsinghua University
A378	University of Science and Technology Beijing
A396	Beijing Institute of Technology
A455	Beijing Normal University
A5859	Central Iron & Steel Research Institute, Ministry of Metallurgical Industry
A638	Beijing University of Posts and Telecommunications
A6407	China National Offshore Oil Corporation
A6497	Institute of Mechanics, Chinese Academy of Sciences (CAS)
A6732	Sinopec Corporation
A6740	China Petrochemical (Sinopec) Group
A6743	China Petroleum & Chemical (Petrochemical) Corporation
A6834	China Mobile Communications Corporation
Shanghai's network	
A1134	Donghua University
A1288	Fudan University
A160	Baosteel Group Corporation
A2399	East China University of Science and Technology
A2403	East China Normal University
A3972	Shanghai University
A4073	Shanghai Research Institute of Synthetic Resins
A4107	Shanghai Chemical Industry Designing Institute
A4137	Shanghai Jiao Tong University
A4258	Shanghai Dyestuff Chemical Second Plant
A4331	Shanghai Research Institute of Building Sciences
A4360	Shanghai Resin Factory
A5299	Tongji University
A6510	Shanghai Institutes for Biological Sciences, CAS
A6516	Institute of Cell Biology, CAS

Sources: Same as Table 1.

[10] Project 985 was first announced by Chinese President Jiang Zemin at the 100th anniversary of Peking University on May 4, 1998 to promote the development and reputation of the Chinese higher education system by founding world-class universities in the 21st century and eponymous after the date of the announcement, May 1998, or 98/5, according to the Chinese date format. Up to 2011, 39 universities were sponsored by Project 985.



A. Beijing 1985-1992

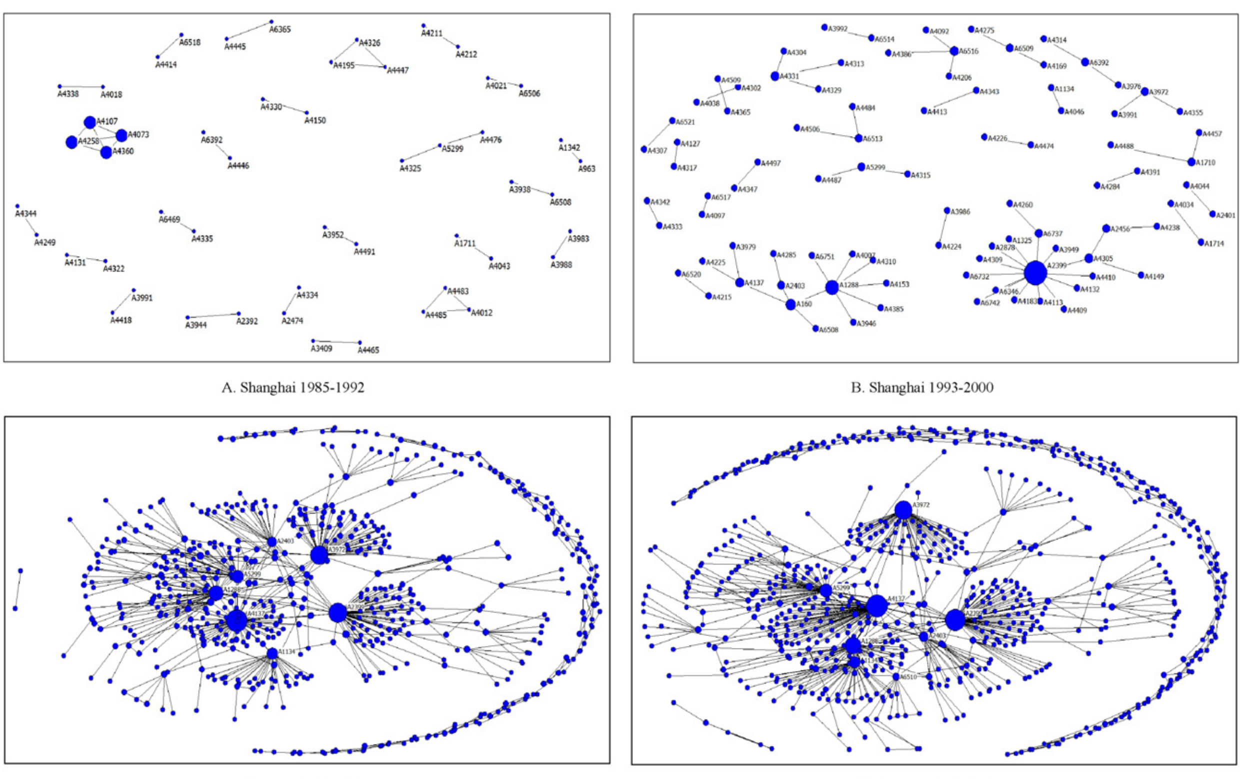
B. Beijing 1993-2000

C. Beijing 2001-2008

D. Beijing 1985-2008

Fig. 5. Beijing's intra-regional network (1985–2008). Source: Calculated by authors based on data from SIPO.

networks than firms (Graf and Henning, 2009; Kauffeld-Monz and Fritsch, 2013). However, China is still lack of contribution of the public research institution to research collaboration, and the contributions of major universities in Shanghai network were relatively equal, the role of both Tsinghua and Peking was significantly more important in Beijing's network.



A. Shanghai 1985-1992

B. Shanghai 1993-2000

C.Shanghai2001-2008

D. Shanghai 1985-2008

Fig. 6. Shanghai's intra-regional network (1985–2008). Source: Calculated by authors based on data from SIPO.

The situation of the network between 1985 and 2008 was not much different from that in the third period apart from more organizations participating in regional networks. Liaoning's NS between 1985 and 2008 was double what it was between 2001 and 2008, which indicates that around half of the organizations left the collaborative network since 2001. Liaoning was the primary collaborative region, even the largest one in term of NS, before 2000, but as a Northeast province it was losing its competitive advantage in research collaboration compared to other major innovative regions from the Yangtze River Delta (Shanghai, Jiangsu and Zhejiang), Pearl River Delta (Guangdong) and Bohai Rim (Beijing, Tianjin), due to China's strategic adjustment of regional development. To a great extent, the collaborative size reflects the active degree of innovation, and although China has decided to implement a strategy to revitalize the old industrial bases in China's northeast since 2003, the region had entered recession.

7. Conclusions and discussions

In this paper we systematically analyze the structure and dynamic of intra- and inter-regional networks based on inter-organizational research collaborations. We developed a multilevel network model of inter-organizational collaboration based on co-patents. Within the network model, one layer is the inter-organizational network within a region, the other layer is the inter-regional network across regions and the number of inter-regional ties is the sum of the inter-organizational ties between regions.

7.1. Conclusions

In fact, intra- and inter-regional research collaboration are two faces of regional innovation relations. Intra- and inter-collaborative networks presented different structures and dynamics, and their roles in a regional innovation are different.

7.1.1. Inter-regional network

Over the past two decades, the inter-regional network has been expanding the number of provinces, becoming more cohesive (more ties) and more decentralized (increasing the degree of regions' contribution). At first, this result is consistent with the existing literature findings for the "core-periphery" structure of China's inter-regional collaborative network, although these studies used different databases (Gao et al., 2011; Zhang et al., 2014; Wang et al., 2015). Besides, the "core-periphery" structure of China's inter-regional collaborative network was dynamic. The core provinces have expanded from Beijing to Beijing and Shanghai according to the degree centrality and the betweenness centrality, and the network begins to show characteristics of a triangle in space in which most active research collaborations occur among the most developed regions of economy and innovation in the Yangtze River Delta, Pearl River Delta and Bohai Rim. Although many less-developed provinces have begun participating in inter-regional networks, the strength of collaboration between these provinces is weaker. Secondly, the role of regions in the network reflects a decentralized process, with most regions increasing contributions to the network through creating ties and being more responsible for coordination as brokers. Meanwhile, after 2000, many regions moved from the left to right, from the bottom to the top within the TDQ of degree/betweenness centrality, with most of regions shifting to high/low quadrant from low/low quadrant within the TDQ.

7.1.2. Intra-regional network

Similar to the inter-regional network, the intra-regional networks have also been expanding the number of organizations in the past two decades, becoming more cohesive (more ties) in seven selected regions. In all selected regions, while NS was increasing gradually, ND was under 0.1 in all cases, which indicates that the potential for creating ties between organizations was great. PL was under 2 in all cases, which means that the average number of ties between any two organizations in the network was short. However, it doesn't mean that the efficiency of knowledge exchange across organizations in a network was higher, because CC is an important precondition for this. When CC was small, network connectivity was weak and the knowledge exchange is confined to a limited number of organizations. Beijing's network connectivity was the best in all selected regions. Furthermore, focusing on Beijing and Shanghai's network, the "core-periphery" structure and the "chain-like" structure are two typical structures of the intra-regional network. In the first two periods, universities and SOEs were central organizations within intra-regional networks, and after that universities became dominant organizations within the networks. Universities have become the key organizations in their intra-regional networks, which is consistent with the findings of the existing literature (Graf and Henning, 2009; Kauffeld-Monz and Fritsch, 2013). These universities were profoundly involved in knowledge-exchange processes and possess many broker positions within their collaborative networks. Additionally, some central SOEs, such as Baosteel Group Corporation, China Petrochemical Group and China Petroleum & Chemical Corporation are also central to collaboration networks, while private firms are seldom involved in collaborative networks.

7.1.3. Intra- and inter-regional networks

For a region, intra- and inter-regional networks are two faces of collaborative behavior, and the relations between intra- and inter-regional networks were determined by organizations' choice of collaborative partners. According to our analysis, there is no significant relationship between a region's position in an inter-regional network and its structural properties of intra-regional network. For example, while Beijing was profoundly involved in inter-regional collaborative processes and occupied most important broker positions within inter-regional collaborative networks, the structural properties of its intra-regional network were without an obvious advantage. In this sense, rather than having relevant relationships between inter- and intra-regional ties, the relationships were complementary. Both the position in inter-regional networks and the structural properties of intra-regional networks are important for regional innovation. For selected regions, universities and SOEs were central to both inter- and intra- connections. For example, Tsinghua and Peking Universities contributed to a large number of Beijing's inter- and intra-regional ties, and Fudan University contributed to many of Shanghai's.

7.2. Theoretical implications

This paper contributes to the existing literature by identifying the structure and dynamics of a multilevel network, specifically in relation to intra- and inter-regional collaborative networks. First, the existing literature has revealed the balance between intra- and inter-regional collaborative research (Marzucchi et al., 2012; Sun and Cao, 2015), and social network analysis provides an invaluable toolbox for a thorough analysis of the relational properties of regional innovation (Guan et al., 2015). This paper developed an empirical method to investigate intra- and inter-regional network, which establishes a bridge of intra- and inter-regional ties and integrates the intra- and inter-regional network.

Secondly, while it is consistent with the findings of the existing literature in terms of the "core-periphery" structure existing in both intra- and inter-regional networks, our new findings are that the inter-regional network begins to show characteristics of a triangle in space and the intra-regional network includes the "chain-like" structure of inter-organizational collaborations. Besides, Beijing and Shanghai being the two primary contributors and coordinators in the inter-regional network, and the role of universities and SOEs as central organizations within intra-regional networks in the early stage, over time universities were becoming more dominant organizations within the networks.

Thirdly, there was a complementary relationship between inter- and intra-regional networks that was determined by organizations' choice of collaborative partners. The structure and dynamics of regional collaborative network in China are useful both for domestic S&T and innovation policy and for decision makers elsewhere. Indeed, the state needs to come up with specific responses to research collaboration according to regional positions in inter-regional networks, rather than uniform regional policy. Local governments should make efforts to improve intra-regional research collaboration with their own respective characteristics of intra-regional networks. In addition to enhancing the role of innovation originating in particular universities, local governments also need to pay attention to deliberately cultivating a collaborative culture and environment.

For organizations, pursuing inter-regional or intra-regional collaboration is critical from the perspectives of the aim and cost of collaboration. Geographical proximity could reduce collaboration costs, but it is not easy to generate heterogeneous knowledge. Collaboration across regional boundaries could gain newer and more appropriate knowledge, but it also incurs additional costs to organizations that may face uncertainty. Therefore, maintaining complementary relations between intra- and inter-regional collaboration is a delicate balancing act for technologically innovative organizations.

7.3. Limitations

Our methodology for analyzing the intra- and inter-regional network has several limitations that should be considered. First, in using co-patent data we employ a rather narrow definition of research collaboration. Obviously, the outcome of research is not only patents, but also know-how, technological achievements and so on. Meanwhile, it must be admitted that the tendency to patent is different across sectors and across type of organizations, which will influence the pattern of regional network ties. Thus, we should investigate regional network through integrating co-patents with technology licensing, and project cooperation.

Secondly, we focus only on organizations of intra-regional networks in Beijing and Shanghai, and partially capture information on organizations with intra-regional ties. This is common to all studies of regional networks that use selected regions. It is not clear how, if at all, this might affect our conclusions. Furthermore, it is significant that our focus is on organizations' inter- and intra-regional ties for selected regions.

Lastly, our study has disregarded the role of China's context. China is a vast country where significant differences exist between regions. With this national context in mind, applying our approach to other countries requires consideration in relation to their territory size, administrative divisions, and S&T institutions (Sun and Cao, 2015).

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Acknowledgement

The authors thank Cong Cao and Seamus Grimes for comments and Liang Liu, Rongkang Ma and Yao Fu for data collection. This work has been supported by the National Natural Science Foundation of China (71203020), the EU 7th Framework Program—Marie Curie International Incoming Fellowship (302303/911303), and the Fundamental Research Funds for the Central Universities (DUT15ZD111).

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