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Proximity effect, preferential attachment and path dependence in inter-regional network: a case of China's technology transaction

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Abstract We analyze whether proximity effect, preferential attachment and path dependence or three "P" mechanisms would concur within the evolutionary process of inter-regional network. Using a unique database of China's technology transaction between regions, we show that proximity effect, preferential attachment and path dependence have coexisted in the evolutionary process of China's inter-regional network of technology transactions. In particular, the inter-regional relations positively and significantly correlate with the geographical and economic proximity matrix, all regions' three centrality values in current year positively and significantly correlate with their centrality in the last two years, and the inter-regional relations in current year positively and significantly correlate with own relations in last two years. This paper contributes to the existing literature by identifying three evolutionary mechanisms of inter-regional network. An interpretation is that the evolution process of inter-regional network is a very complex process, and one mechanism such as geographical proximity from the perspective of economic geography or preferential attachment from the perspective of network science only could explain a part of the process.

Keywords Technology transaction · Inter-regional network · Proximity effect · Preferential attachment · Path dependence · Social network analysis · Centrality

Introduction

Innovation has become a key driving force of regional competitiveness (Krätke 2010). Accordingly, several terms such as cluster (Porter 1994, 1998), the learning region (Florida 1995; Hassink and Klaerding 2012) and innovative milieu (Fromhold-Eisebith 2004) all stressed that region as a geography unit is increasingly significance for innovation, and

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regional innovation system has become a central analytical framework of regional innovation and a main policy measure for innovation in emerging countries like China (Lundvall 1992; Cooke et al. 1997). Obviously, these academic terms focus more on interactions between organizations and regional environment, organizations within regions, while over emphasizing inter-organizational relations within regions might even create development barriers of regional innovation, such as the status quo of "path locking" (Belussi et al. 2010; Fitjar and Rodriguez-Pose 2011). Thus, inter-organizational relations across regions, with increasing the knowledge diversity on a local knowledge basis, are crucial for regional innovation (Gertler and Levitte 2005; Boschma and Ter Wal 2007).

Indeed, networks have gained a great deal of attentions in the field of economic geography particularly in regional innovation since the last decade (Grabher and Ibert 2006). Meanwhile, various inter-organizational relations like knowledge spillover, research collaboration and technology transaction have formed the intra-and inter-regional networks (Sun and Cao 2015). Besides intra-regional networks involving to regional innovation system, the study of inter-regional networks has related to evolutionary economics and its application to economic geography (Boschma and Frenken 2006). In particular, social network analysis techniques have been applied in an effort to examine how the structure of inter-regional network looks like and what the evolutionary mechanisms of inter-network are.

Extant studies have examined the inter-regional network based on inter-organizational relations of research collaborations, knowledge spillover, and so on (Wanzenböck et al. 2014; Maggioni and Uberti 2009; Bottazzi and Peri 2003; Ejermo and Karlsson 2006; Morescalchi et al. 2015). In essence, inter-organizational knowledge spillover is an example of positive externality, the sender transferring its knowledge to the receiver is an unconscious, passive and non-marketization process (Cheyre et al. 2015); while inter-organizational research collaboration like co-authorship of patents or co-operation project is an active and mutual process, which involves funding and knowledge exchange but not pure transaction behavior. The features of technology transaction is different with knowledge spillover and research collaboration (Table 1).

Technology transaction is an active process through patent license, patent assignment, know-how transfer, in which a buyer–seller transaction is at market prices between organizations (Liu and Jiang 2001). In this sense, technology transaction is quite closer to market than research collaboration and knowledge spillover. Prior literature seldom refers to inter-organizational relations based on technology transactions (Amesse and Cohendet 2001), although some scholars begin to pay close attention to inter-regional network based on patent license which just is a part of technology transactions (Zhang et al. 2016; Wang et al. 2015). Admittedly, technology transaction could reflect different inter-regional economic relations with collaboration and spillover. Meanwhile, the scope of technology transaction is much wider than patent license. Thus, this paper intends to focus on the technology transaction to map a diverse network of inter-regional relations.

Table 1 A taxonomy of inter-organizational relations for innovation

Taxonomy	Spillover	Collaboration	Transaction
Active/passive	Passive	Active	Active
Directed/undirected	Directed	Undirected	Directed
Marketization/non-marketization	Non-marketization	Semi- marketization	Marketization

Author's research

For inter-regional network, regional innovation studies and network studies have provided different interpretations for network growth. A strong belief accompanied regional innovation studies is "geography matters", not only geographical proximity but also relevant cultural, social, cognitive proximities matters as an approach for knowledge transmission, which is central to regional innovation (Breschi and Lissoni 2001; Morgan 2004; Boschma 2005; Capello 2009; Capello and Caragliu 2012). Besides, the preferential attachment is a primary mechanisms of network evolution, which could explain the emergence of a "core-periphery" structure among regions as a process of network growth (Guimera and Amaral 2004; Barrat et al. 2005). In particular, network evolution is understood as an entry process of new nodes connecting with certain probability to existing nodes depending on the latter connectivity (Barabási and Albert 1999). However, it is worth noting that "path dependence" is a primary mechanisms of system evolution in evolutionary economics (Arthur 1989; Cowan and Gunby 1996). Extant literature seldom involves "path dependence" of inter-regional relations, let alone the concurrence of these three mechanisms.

In sum, the evolutionary mechanisms of inter-regional network based on technology transaction cannot be understood very well yet. We need to know much more about how the inter-regional network of technology transaction evaluation looks like. We attempt to provide a three "P" mechanisms hypothesis. That is, proximity effect, preferential attachment and path dependence would concur within the evolutionary process of inter-regional network rather than exist separately. This article explores theories of network evolution for their use in geography and develops the conceptual framework of geographical network evolution.

This study also yields two other contributions. First, it is (to the best of my knowledge) the first study to attempt to propose economic proximity effect of inter-regional network. Besides geographical proximity, previous studies have examined cultural, social and cognitive proximity effects in the collaboration network while most of them is related to geographical proximity (Wanzenböck et al. 2014; Maggioni and Uberti 2009). Additional, the organizational and technological proximity is also central to create collaborative relations (Boschma 2005). However, seldom literature pays attention to the economic proximity. In terms of our argument in this paper, the economic proximity between two regions is also important for inter-regional relations of technology transaction.

Second, this study has redefined the preferential attachment behavior during the process of network evolution from the perspective of existing nodes. Extant studies defined the preferential attachment from the perspective of new nodes through the number of links (measured by the degree centrality) (Barabási and Albert 1999). However, it is invalid when we expand this concept to other positions of nodes in networks (measured by the close centrality and the betweenness centrality) (Abbasi et al. 2012), because new nodes connecting to existing nodes with high close centrality and betweenness centrality could not strengthen their roles or close centrality and betweenness centrality in networks. That is, this process is not general "cumulative advantage". Thus, it is necessary to redefine the preferential attachment from the perspective of existing nodes, and examine the "cumulative advantage" with regard to positions of nodes in the network.

Three "P" mechanisms of inter-regional network evolution

In this part, first we propose a model of inter-regional network base on technology transaction across organizations, then understand how the proximity effect, preferential attachment and path dependence work in the process of inter-regional network evolution and propose three hypotheses.

The model of inter-regional network

A network is a set of individuals or groups each of which has connections of some kind to some or all of the others. In terms of multilevel network model, inter-regional relations are consisted of inter-organizational relations across regional boundaries (Sun and Cao 2015). The following hypothetical example illustrates the main idea. Suppose there are 15 organizations involving firms, universities, research institutes from three regions A, B and C. B1 buys technologies from C3, and C1 and C4 buy technologies from B4 and B3 respectively. Then, the relations between organizations can be expressed as three pairs of network ties: C3–B1, B3–C4, B4–C1. These pairs of ties constitute the relations of technology transaction between region B and region C. The width of lines reflects the volume of technology transaction. Repeating the same exercise for total cases of technology transaction, we end up with a map representing the inter-regional network of inter-organizational technology transaction (see Fig. 1).

Similar with the collaborative network, the node is region and the tie is the relation of technology transaction between two regions. However, the collaborative network is an undirected network based on the mutual collaborative relations between organizations, which means that the mutual knowledge exchange is contained in collaborative ties; the network of technology transaction is an directed network based on a buyer–seller transaction, which means that the seller transfer the technology/knowledge to the buyer. While regions are nodes of inter-regional network, the transaction behavior between organizations still is the primary cause which condition the evolution of inter-regional network. Thus, focusing on organizational behavior is useful for understanding the inter-regional relations.

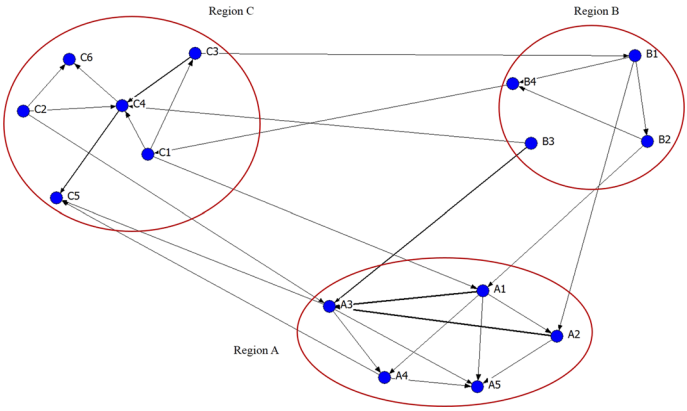

Fig. 1 The inter-regional network model of technology transaction. *Note* The wide of links means the turnover of technology transaction between organizations; the arrows of links means the direction of technology transaction between organizations

The dynamic process of inter-regional networking was determined by the three key mechanisms of proximity effects, preferential attachment and path dependence due to three main reasons. First, the inter-regional network is consist of regions and relations between regions, and the regional (nodal) properties will condition whether the connect each other. Within the economic geography (Katz 1994), regional proximity/similarity is central to make connections each other because of reducing cost and increasing efficiency. Second, the inter-regional network is a kind of network that follows the principle of network evolution. As we all know, preferential attachment is the principal process of network evolution, which can generate power law distributions under suitable circumstances (Barabási and Albert 1999). Third, the dynamic of inter-regional network is an evolutionary process, which means that the current structure of network should be conditioned by the historical structure to a certain degree, or "history matters" (David 1985). Thus, it is necessary to consider the path dependence.

At the early stage of network emerging, focal organization would like to select a buyer with technical demand or seller with knowledge intensive resources in their own region or surrounding region, because geographical proximity could reduce cost and increase efficiency of technology transaction and commercialization, in particular driven by tacit knowledge (Hoekman et al. 2010; Maggioni et al. 2011). Or, focal organization would like to select a buyer or seller in the region with similar development level, because they are likely to have similar technological interests and R&D fields.

Obviously, the distribution of network ties in organizations and regions is uneven, because some organizations or regions with rich resources have more ties. The region already has a number of ties, which would attract more ties proportionally, and this is the preferential attachment. Meanwhile, the previous relations between two organizations or regions would determine their current or future relations due to more trust and less information asymmetry which could reduce cost and increase efficiency of research and innovation activities (Ma et al. 2013). The path dependence effect works.

Over time, too much proximity between organizations or regions might harm their efficiency of technology transaction and reduce the influence for further transaction at the same time (Broekel and Boschma 2012). Accordingly, dominant organizations or regions in a network do not find it easy to overcome organizational inertia associated with trust or information advantage and network inertia-position advantage, and it is also possible that the advantage of preferential attachment increases and the path dependence become a "path locking", which reduce knowledge diversity and external heterogeneous resources.

In sum, in order to sustainable development of inter-regional network, proximity effect, preferential attachment and path dependence in it should be very complementary.

Proximity effect

Geography matters is central to regional innovation studies. Extant studies on the geography of knowledge networks have documented a negative impact of physical distance and territorial borders upon research collaborations (Katz 1994). Similar with the collaboration, farther geographical distance would increase travel and time cost, which are impediments to inter-regional relations' creation and technology transaction, and knowledge spillovers are much localized and exist only within a distance of 300 km (Bottazzi and Peri 2003). With recent advances in information and telecommunication technologies, especially Internet-based applications such as Email, MSN, Skype, Facebook, Twitter and Wechat, the "death of distance" seems to be reality (Ma et al. 2014; Sun and Cao 2015). Nevertheless, the empirical evidences indicated that geographic distance and territorial borders

are still relevant for determining the structure of inter-regional knowledge network (Maggioni and Uberti 2009; Frenken et al. 2009). Meanwhile, it is possible that physical distance proximity effects are much smaller than the territorial border effects and the effect of both physical distance and territorial borders are changing over time across European regions and OECD regions (LeSage et al. 2007; Hoekman et al. 2010; Morescalchi et al. 2015).

Besides geographical proximity, the empirical evidences clearly showed that cognitive, social, cultural proximity related to geography were crucial for explaining the inter-regional network of collaboration (Agrawal et al. 2008; Broekel and Boschma 2012). Innovation is dependent on combining complementary knowledge of heterogeneous organizations, however it is not easy to incorporate external knowledge/technology into one's own knowledge system, therefore a certain amount of absorptive capacity is needed. The cognitive, social and cultural proximity denotes a common knowledge, experience and custom base which enables organizations to exchange each other (Boschma 2005; Balland et al. 2015). Thus, the geographical proximity may also plays role in technology transaction, given the fact that other dimensions of proximity related to geography can also fulfil this role. It is worth noting that two very closely located organizations may have little technology to transact and that innovative production usually requires the combination of dissimilar, although related, complementary knowledge (Boschma and Frenken 2010; Boschma and Iammarino 2009; Broekel and Boschma 2012).

At the moment, it is possible that the economic proximity can play an efficient role, and most technologies are transferred between regions with similar development level according to the empirical research (Zhang et al. 2016). It is clear that regional level of economic development is related to the structure of R&D-related resources, the level of technological development and the industrial structure, which gradually shape the technological proximity (Ejermo and Karlsson 2006; Hoekman et al. 2009; Maggioni and Uberti 2009). As mentioned above, organizations need to have a sufficient absorptive capacity to identify, to interpret and to exploit technology and knowledge of others, thus the technological proximity is in favor of marching supply and demand of technologies (Cohen and Levinthal 1990). If two organizations' technologies are similar, the cost of an innovative recombination is lower than when dissimilar technologies are merged (Broekel and Boschma 2012). That is, economic proximity play also a relevant role in suggesting that technology transaction easier between similar regions (according to their level of economic development).

Understanding how the proximity effect inter-regional network, I thus test the following hypotheses:

Hypothesis 1a The geographic proximity will have a relevance effect on technology transaction relations across regions.

Hypothesis 1b The economic proximity will have a relevance effect on technology transaction relations across regions.

Preferential attachment

Preferential attachment made its first appearance in 1923 in the celebrated GyörgyPólya' surn model, and it has appeared repeatedly over the past century, particularly in the social sciences (Barabási 2012). Its current usage emerged only in 1999, with the discovery that it accounts for the power-law distributions observed in several real networks.

During the network evolving process, the growth hypothesis suggests that networks tend to expand by the addition of new nodes or new links between the nodes, while the hypothesis of preferential attachment indicates that new nodes attach preferentially to existing nodes that are already well connected (Barabási and Albert 1999). That is, a new node is (or a new link favor) connected to some existing nodes in the network based on its number of links measured by degree centrality. The empirical evidences have proved that preferential attachment effect the evolution of collaboration networks (Wang and Zhu 2014). The quality of inter-regional knowledge networks in European is related to the position of partners in the entire knowledge network, and the preferential attachment shaped the "core-periphery" structures of the inter-regional network (Orsenigo et al. 2001; Gao et al. 2011; Sebestyén and Varga 2013; Guan et al. 2015).

The nature of preferential attachment is the principle of "the rich get richer" or more generally "cumulative advantage". Originally, we could test this hypothesis through calculating the correlations between existing nodes' degree centrality and the numbers of new links in the next stage. Abbasi et al. (2012) extended preferential attachment from degree centrality to closeness centrality and betweenness centrality, and tested hypothesis through calculating the correlations between existing nodes' centrality measures and the numbers of new links in the next stage. The results show that betweenness centrality of an existing node is a significantly better predictor of preferential attachment by new entrants than degree or closeness centrality, and preferential attachment shifts from (local) degree centrality to betweenness centrality as a global measure. In terms of Abbasi et al. (2012)'s work, for nodes' closeness centrality and betweenness centrality, the preferential attachment is similar with degree centrality, and the existing nodes like to close other nodes (with high closeness centrality) or act as a broker or gatekeeper (with high betweenness centrality) could attract more new links from new nodes or existing nodes in the next period. Obviously, more new links couldn't increase nodes' closeness centrality and betweenness centrality, that is, without "cumulative advantage".

Returning to the principle of "the rich get richer", we could redefine the preferential attachment based on nodes' centrality. Previous studies define the preferential attachment from the perspective of new nodes or new links. For the inter-regional network, regions as nodes of network is fixed while it is possible that new organizations participating technology transaction could create new inter-regional relations. Beyond the attachment behavior, the consequence of preferential attachment is increasing the position of nodes in network. That is "cumulative advantage".

Thus, we define the preferential attachment from the perspective of existing nodes. The nodes occupy central position of network (with high degree centrality) would attract more new links, the nodes like to close other nodes (with high closeness centrality) would prefer to close other nodes and the nodes like to act as a broker or gatekeeper (high betweenness centrality) would prefer to act as a broker in the next period.

Understanding the preferential attachment of inter-regional network, I thus test the following hypotheses:

Hypothesis 2a A region's degree centrality will have a relevance effect on its degree centrality in the next periods.

Hypothesis 2b A region's closeness centrality will have a relevance effect on its closeness centrality in the next periods.

Hypothesis 2c A region's betweenness centrality will have a relevance effect on its betweenness centrality in the next periods.

Path dependence

Path dependence means first of all that "history matters" (David 1985). Generally, a path dependence process is one whose outcome evolves as a consequence of the process's own history. For example, an organization's current and future decisions capabilities are imprinted by past decisions and their underlying patterns (Arthur 1989; Cowan and Gunby 1996). A lot of economic evidences on path dependence have actually been exemplified in the context of geographic economies (see Martin and Sunley 2006 for illustrations of the argument). That is, path dependence is related to regional development. Path dependence could be due to technological trajectory, institutional solid, organizations routine, competences rigidity and other aspects.

The role of knowledge creation, transfer, share and application in the development of regional innovation systems, in particular, has been a major spur to the importation of path dependence ideas into innovation geography over the past decade. It is well known that "path dependence" is an actual barrier of innovation development within regions. The interactive processes of intra-and inter-organizational knowledge exchanges which are localized due to path dependence effects are growing in importance for the innovation competitiveness of firms and for the development of regions (Herstad et al. 2014). Thus, it is necessary that the locus of innovation is shifting away from individual region towards inter-regional relations.

Accordingly, our concern is that if path dependence is shifting away from a large extent "place dependent" towards "relation dependent". Obviously, it is possible that innovation development in a region may be influenced by those in other regions, though inter-organizations interactions and resource exchange, and innovation and regulatory policies in other regions and at national level (Martin and Sunley 2006). Furthermore, the relation of technology transaction between supply regions and demand regions is likely to form mutual dependences during a long period, which could due to technological matching, collaboration institutionalization, transaction cost reduction and so on. Thus, the amount of technology transaction between two regions at the current period would condition that in the next period. That is, inter-regional relations of technology transaction evolves as a consequence of their historical or past relations (Cantner and Graf 2006).

Understanding the path dependence of inter-regional network, I thus test the following hypothesis:

Hypothesis 3 Technology transaction relations between regions at current period will determinate their relations in the next periods.

Methods

Sample

This research focuses on inter-regional network of technology transaction in China. In the context of China, the technology transaction involved four kinds of forms of the contracts-technology development (kaifa), technology service, technology assignment and technology consulting between organizations. All inter-organizational technology transactions across regions form the inter-regional relations.

According to *Annual Report on Statistics of China Technology Market 2014,* China's turnover of business contract concerning technology transaction was RMB 746.913 billion.

Of them, the amount of technology transaction related to intellectual property was RMB 379.339 billion, accounted for 50.79 %, including the amount of patent transaction (assignment and licenses) was RMB 56.963 billion (7.63 %). That is, the scope of technology transaction is very bigger than that of patent licenses. Obviously, our study has extended the inter-regional relations based on patent licenses (Zhang et al. 2016; Wang et al. 2015), could reflect China's inter-regional technology flow more fully.

According to the amount of inter-organizational technology transaction across regions, we calculated the total amount of technology transactions between two regions, in particular, the amount of technology sales and that of technology purchases respectively. Then, we could create an inter-regional network of technology transactions, in which regions are nodes, the seller-buyer transaction is ties, the arrow direction is from seller to buyer of technology, the width of ties is the amount of technology transaction between regions.

Measures

In order to verify these hypothesizes we need to measure various variables. At first, the inter-regional relations of technology transaction is measured by inter-regional matrices. Originally, the inter-regional matrices have valued relations measured by the amount of technology transaction between two regions, called valued matrices, which are used in Hypothesis 2 for centrality measures and Hypothesis 3.

Additional, the technology transaction relation is also used in Hypothesis 1. Since the proximity matrices are binary relations and the correlation analysis should relational matching, we transformed the valued relations to the binary relations further. Median of the bilateral amount between regions as a cut-off point is used to divide all regional bilateral relations into two groups (strong and weak). If bilateral relations between two regions are strong, their relation in matrix is 1; if not, their relation is 0. The new matrices are binary, called binary matrices.

Within Hypothesis 1, the geographic proximity is measured by spatial proximity matrices. The territorial border effects is much bigger than physical distance proximity effects (LeSage et al. 2007), thus we create spatial proximity matrix through contiguity strategy rather than distance strategy, in particular, if a region is near to other ones with shared borders, they are proximity and their relation in matrix is 1; if not, their relation is 0. The economic proximity is measured by economic proximity matrices. The gross regional product (GRP) is one of the primary indicators measuring regions' economic performance, thus the development level of regional economic is measured by GRP per capita (Wennekers et al. 2005; Zhang et al. 2016). Further, all regions' median of GRP per capita as a cut-off point is used to divide regions into two groups (high and low) in China. If GRP per capita of two regions belong to one group either high or low group, they are economic proximity and their relation in matrix is 1; if not, their relation is 0.

Within Hypothesis 2, node centrality concepts and measures help determine the position of a region in the inter-regional network. Freeman argued that centrality is an important structural factor influencing leadership, satisfaction, and efficiency (Freeman 1979). To quantify the importance of an actor in a social network, various centrality measures have been proposed over the years (Scott 1991). Extant literature has provided a specific statement of three kinds of centrality-degree, closeness and betweenness (see Abbasi et al. 2012). UCINET, a software tool, is used to calculate degree centrality, closeness centrality and betweenness centrality of inter-regional network.

Calculation

We tested Hypotheses 1 and 3 by conducting a Quadratic Assignment Procedure (QAP) correlation analysis using the UCINET, since QAP correlation could measure convergence between two matrices (Mathieu et al. 2000). QAP correlations are essentially zero-order correlations between two matrices and therefore range from −1 to 1. Within QAP correlations, observed matrix is similar with dependent variable and structure matrix is similar with independent variable.

In particular, simple matching and the Jaccard coefficient are reasonable measures when both relations are binary, which is used to test Hypotheses 1, in which proximity matrix is observed matrix, and the inter-regional binary matrices is structure matrix. The Pearson correlation is a standard measure when both matrices have valued relations measured at the interval level, which is used to test Hypothesis 3, in which inter-regional valued matrix at the current period is observed matrix, and the inter-regional valued matrix at the next periods is structure matrix.

In addition to QAP correlation, Spearman correlation is used to test Hypotheses 2. Following Abbasi et al. (2012), using Spearman rank correlations, we measure the correlations between regional centrality measures in the current year and in the following year between 2006 and 2010.

Data

Our unique data of technology transaction between 2006 and 2010 was from China Technology Market Management and Promotion Centre, a unit under the Torch High Technology Industry Development Center, Ministry of Science and Technology, China. The data of GRP per capita was from *Chinese Statistics Yearbook (2006–2011)*. As mentioned above, the inter-regional network of technology transaction is a directed network or a nonsymmetric matrix, however QAP correlation could only calculate the relations of symmetric matrix. So, we transformed the directed relations of the seller-buyer transaction to the mutual relations ignoring the direction, which changes the nonsymmetric matrix to symmetric matrix.

Results

In order to test our Hypotheses about the evolution of inter-regional network, first we need to present the evolutionary process of inter-regional network; second, we correlate the proximity matrix with the inter-regional binary matrix using QAP correlation; then, we calculate centrality measures (i.e., degree, closeness and betweenness for each year) for all regions, and measure the correlations between these values in different years using Spearman rank correlations; Finally, we measure the correlations between the inter-regional valued matrix in different years.

Mapping the network

Before testing Hypotheses, we present the evolutionary process of inter-regional network of technology transaction though visualization (Fig. 2).

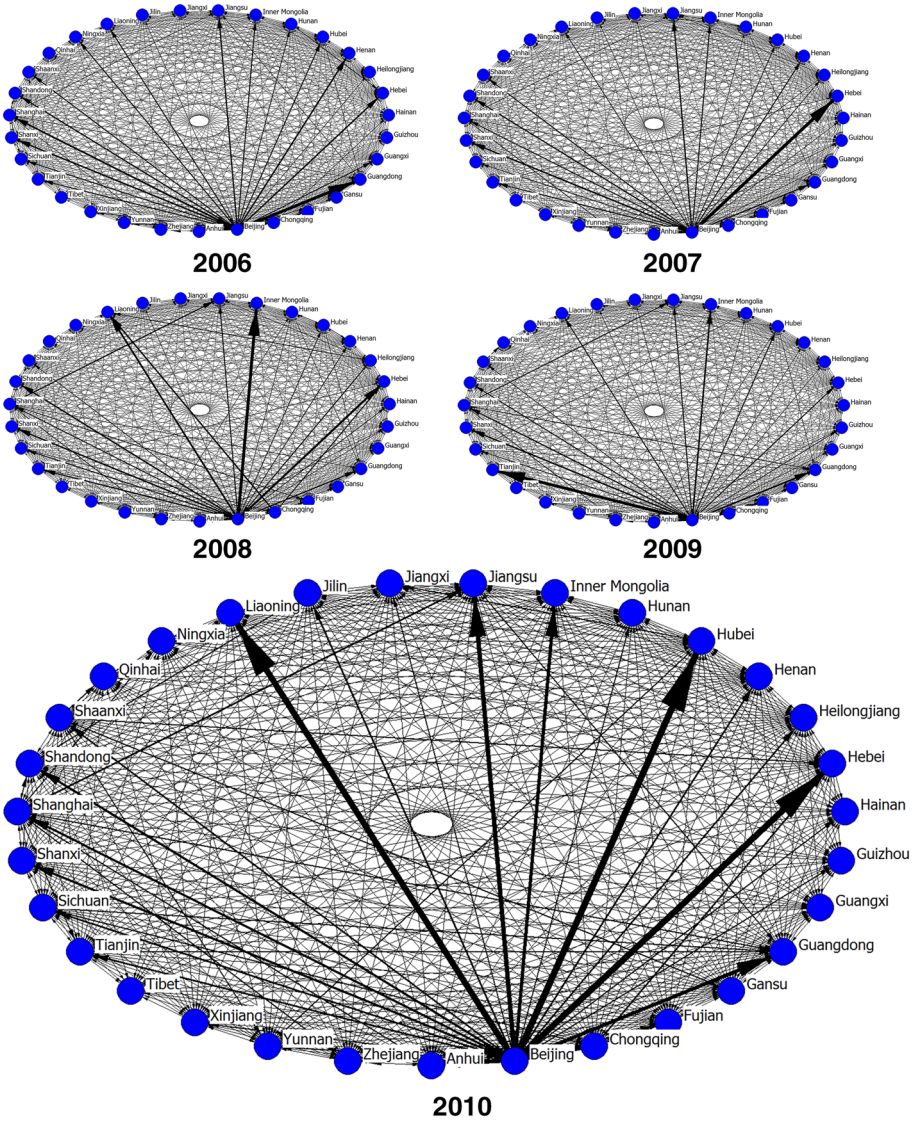

Fig. 2 The inter-regional network of technology transaction in China. *Note* The wide of links means the amount of technology transaction between regions; the arrows of links means the direction of technology transaction between regions

In 2006, the strong ties occurred in Beijing and many other regions. That is, Beijing transferred lot of technologies to other regions. Of them, Beijing sold most of technologies to Guangdong, followed by Shanghai. These structural relations are similar with that of inter-regional research collaborations. The relations between Jiangsu–Shanghai, Shandong–Hebei, Jiangsu–Guangdong, Shanghai–Guangdong, Tibet and Gansu is stronger than others, although these relations is weaker than that between Beijing and others. Meanwhile, Jiangsu, Shanghai and Guangdong shaped a triangle structure. To a great degree, these

relations reflect the economic proximity effect existing in the network. The inter-regional network in 2007 is similar with that in 2006, just Beijing sold most of technologies to Hebei, which indicates the geographical proximity effect works in network.

Enter in 2008, the relations between Beijing and other regions are still strong. Of them, Beijing sold most of technologies to Inner Mongolia, followed by Hebei. It seems like that the geographical proximity effect works in network. Besides, Shanghai sold more technologies to Jiangsu, and the relations between Liaoning–Heilongjiang, Fujian–Shanghai, Liaoning–Chongqing were stronger than that in the last period. The inter-regional network in 2009 is similar with that in 2008, just Beijing sold most of technologies to Tianjin. Meanwhile, the amount of technology transaction across regions reduced a lot. Partly, this could due to international financial crisis occurred in 2008 which decreased the market demand of enterprises' product and technology. Obviously, the inter-regional network in 2010 is different with that in 2009, Beijing sold lots of technologies to Liaoning, Hubei and Hebei simultaneously, followed by Guangdong, Jiangsu and Inner Mongolia. Meanwhile, Jiangsu, Shanghai and Guangdong shaped a triangle structure again.

Generally speaking, besides the proximity effect, we also could find the evidences of the preferential attachment effect. For example, Beijing was the primary region who transacted technologies to most of other regions all the time, although parts of them are major purchasers and the major purchasers were changing. To a degree, the preferential attachment shaped the core position of Beijing in the inter-regional network partly, certainly the rich research resource is also an important factor for that. The inter-regional network in the last period is similar with that in the current period, although it also change over time more or less. That indicates that the path dependence effect also works more or less in the network.

In sum, China's inter-regional network presents two unique characteristics. First, the inter-regional network is emerging the "core-periphery" structures (Gao et al. 2011), and a few technology sources provided most of technologies for purchasers. Beijing is the core node who transacted technologies to others, the role of Shanghai was still weak. Second, most technologies are transferred from provinces with rich research and development resources, e.g., Beijing, to economically developed provinces, e.g., Guangdong and Jiangsu, although many less-developed provinces have begun participating in regional technology exchange networks. This is consistent with existing literature (Zhang et al. 2016; Wang et al.2015).

Proximity effect

The results of the correlation between the proximity matrix and the inter-regional binary matrix are in Tables 2 and 3.

Table 2 shows that the inter-regional relations positively and significantly correlate with the geographical proximity matrix. That is, if a region is near to other ones with shared borders, their relations of technology transaction is strong; if not, their relations is weak. Meanwhile, we all know that the diagonal of matrix mean the technology transaction within regions, and the correlation coefficient with diagonal valid (including intra-regional relations) is bigger than that with diagonal invalid (excluding intra-regional relations). It indicates that the geographical proximity effect within regions was bigger than that across regional borders. Results of the correlation test not only support the *Hypothesis 1a*—the geographical proximity effect existing in the inter-regional network, in particular organizations prefer to transact technology with partners within own regions, but also asserts that

Table 2 QAP correlation between the geographical proximity matrix and the inter-regional networks

Index	Observed matrix	The geographical proximity matrix				
	Structure matrix	2006	2007	2008	2009	2010
Simple matching	Diagonal invalid	.564***	.574***	.561***	.557**	.580***
	Diagonal valid	.582***	.590***	.573***	.575**	.595***
Jaccard coefficient	Diagonal invalid	.202***	.207***	.181***	.191***	.212***
	Diagonal valid	.262***	.265***	.225***	.252***	.268***

* Correlation is significant at the 0.10 level (2-tailed)

** Correlation is significant at the 0.05 level (2-tailed)

*** Correlation is significant at the 0.01 level (2-tailed)

Table 3 QAP correlation between the economic proximity matrix (observed matrix) and the inter-regional networks

Index	Current year					
	Observed matrix Structure matrix	2006 2006	2007 2007	2008 2008	2009 2009	2010 2010
Simple matching	Diagonal invalid	.531	.532*	.561***	.582***	.574***
	Diagonal valid	.550	.549*	.573***	.599***	.589***
Jaccard coefficient	Diagonal invalid	.357**	.353*	.376***	.400***	.390***
	Diagonal valid	.393**	.388**	.401***	.435***	.423***
Index	One year lag					
	Observed matrix Structure matrix	2005 2006	2006 2007	2007 2008	2008 2009	2009 2010
Simple matching	Diagonal invalid	.531*	.520	.548***	.573***	.574***
	Diagonal valid	.550*	.538	.561***	.590***	.589***
Jaccard coefficient	Diagonal invalid	.357**	.347*	.364***	.395***	.390***
	Diagonal valid	.393**	.382*	.389***	.430***	.423***

* Correlation is significant at the 0.10 level (2-tailed)

** Correlation is significant at the 0.05 level (2-tailed)

*** Correlation is significant at the 0.01 level (2-tailed)

organizations prefer to sell or buy technology with partners from neighbor regions with shared borders.

Obviously, our results confirm the geographical proximity effect existing in the inter-regional network of technology transaction, which agrees with that in the inter-regional network of research collaboration (Katz 1994; Maggioni and Uberti 2009; Frenken et al. 2009). The "death of distance" seems not to be reality and regional borders still matter for technology transaction.

Table 3 shows that the inter-regional relations positively and significantly correlate with the economic proximity matrix gradually. Obviously, the significant level of the correlation coefficient was low, even the coefficient was not significant at the early two periods both

current year and 1 year lag. Then, the inter-regional relations positively and significantly correlate with the economic proximity matrix. That is, if two regions' level of economic development is similar or belong to same group, their relations of technology transaction is strong; if not, their relations is weak. Meanwhile, the correlation coefficient with diagonal valid (including intra-regional relations) is bigger than that with diagonal invalid (excluding intra-regional relations), which indicates that the economic proximity effect within regions was bigger than that across regional borders.

Results of the correlation test support the *Hypothesis 1b*—the economic proximity effect existing in the inter-regional network, in particular, organizations prefer to transact technology with partners from regions with similar level of economic development. It indicates organizations from regions with high or low development level prefer to transact technology with that from regions with high or low development level. Extant literature has realized the phenomenon of technology license like to happen between developed regions (Zhang et al. 2016; Wang et al. 2015), and our results confirmed the economic proximity effect existing the inter-regional network of technology transaction through statistical analysis.

Preferential attachment

The results of the correlation between regions' centrality measures in different periods are in Table 4.

Table 4 shows that regions' centrality measures positively and significantly correlate with their centrality measures in the last year and in the year before last. Results of the correlation test not only support the preferential attachment process of the inter-regional network evolution, in particular, organizations prefer to attach to partners from well-connected regions (having high degree centrality), but also asserts that the positions of regions in the inter-regional network have cumulative advantage. In particular, regions that are close to other regions in the inter-regional network (having high closeness centrality) tend to be close to others in the next periods again, and the regions who entertain the role of brokering (and bridging) in the network (having high betweenness centrality) tend to entertain the role of brokering in the network in next periods again. Results of the correlation test support the *Hypothesis 2a, 2b and 2c*. The preferential attachment is existing in the inter-regional network.

Table 4 Spearman correlation between the regions' centrality measures in different periods

Centrality measures	Continuous years				Separated by 1 year		
	06/07	07/08	08/09	09/10	06/08	07/09	08/10
Number of regions	31	31	31	31	31	31	31
Degree centrality	.796***	.735***	.827***	.846***	.786***	.823***	. 723***
Closeness centrality	.796***	.735***	.827***	.846***	.786***	.823***	. 723***
Betweenness centrality	.723***	.559***	.616***	.778***	.573***	.717***	. 577***

* Correlation is significant at the 0.10 level (2-tailed)

** Correlation is significant at the 0.05 level (2-tailed)

*** Correlation is significant at the 0.01 level (2-tailed)

It is worth to note that looking at the correlation coefficient of each centrality measure values. The correlation coefficient of degree centrality and closeness centrality are same, meanwhile they are bigger than that of betweenness centrality. It indicates that the preferential attachment effect for degree and closeness centrality is more significant than that of betweenness centrality. Over time, the correlation coefficient of degree centrality and closeness centrality remains almost constant (with some fluctuation), and the correlation coefficient was increasing during the continuous periods. But for betweenness centrality, the correlation is fluctuating over time.

Therefore, we may infer that as the inter-regional network grows, degree centrality and closeness centrality becomes increasingly important for attachments or, in other words, regions with high degree centrality and closeness centrality gain more power and influence in the network. An increasing number of links prefer to attach to the regional who are controlling the technology resource or economic demand or close to all other regions in the network. Our results enrich Abbasi et al. (2012)'s work with regarding to collaboration network, in which betweenness centrality becomes increasingly important for attachments or, in other words, an increasing number of nodes prefer to attach to the existing nodes who are controlling the flow of information (communication) by having a brokering (or bridging) role in the collaboration network.

Path dependence

The results of the correlation between the inter-regional relations in different periods are in Table 5.

Table 5 shows that the inter-regional relations in current year positively and significantly correlate with own relations in last year. That is, the level of technology transaction between two regions in current year depended on their transaction in last year or the year before last, and the level of dependence on the last year is higher than that on the year before last (except the inter-regional matrix in 2010). Meanwhile, the correlation coefficient with diagonal valid (including intra-regional relations) is much bigger than that with diagonal invalid (excluding intra-regional relations), which indicates that the path dependence effect of technology transaction within regions was bigger than that across regions. It is worth to note that looking at the correlation coefficient over time. The correlation coefficient of inter-regional matrix in various years was decreasing.

Results of the correlation test support the *Hypothesis 3*—the path dependence effect existing in the inter-regional network evolution, in particular, organizations prefer to

Table 5 QAP correlation between the inter-regional networks in different periods

Pearson correlation	Continuous years				Separated by 1 year		
Observed matrix Structure matrix	2006 2007	2007 2008	2008 2009	2009 2010	2006 2008	2007 2009	2008 2010
Diagonal invalid	.829***	.814***	.766***	.733***	.739***	.757***	.779***
Diagonal valid	.966***	.958***	.938***	.897***	.941***	.944***	.907***

* Correlation is significant at the 0.10 level (2-tailed)

** Correlation is significant at the 0.05 level (2-tailed)

*** Correlation is significant at the 0.01 level (2-tailed)

transact technology with past partners, and regions also prefer to transact technology with past collaborative regions. That is, "place dependent" and "relation dependent" were occurrence within the development process of regional innovation, and the inter-regional relations were also history dependence, which confirms that it is possible that a region's innovation development was influenced by those in other regions through inter-regional ties (Martin and Sunley 2006).

Discussion and conclusion

In order to investigate the temporal evolutionary mechanisms of inter-regional network of technology transaction, we examined whether proximity effect, preferential attachment and path dependence coexist in the evolutionary process of inter-regional network.

In particular, the geographic and economic proximity have a relevance effect on inter-regional relations of technology transactions; the positions of a region in the inter-regional network generate further trend to strengthen its position in the next periods; the technology transaction relations between regions determinate on their relations in the next periods. Economic geography as introduced the studies of proximity and interregional relations, and network science has introduced centrality measures as proxies for specific positions of the nodes in a network. In this study of the evolution of the technology transaction relations among regions in China (between 2006 and 2010), we assessed the extent to proximity effect, preferential attachment and path dependence.

The results show that proximity effect, preferential attachment and path dependence have coexisted in the evolutionary process of China's inter-regional network of technology transactions. In particular, the inter-regional relations positively and significantly correlate with the geographical and economic proximity matrix, all regions' three centrality values in current year positively and significantly correlate with their centrality in the last year and in the year before last, and the inter-regional relations in current year positively and significantly correlate with own relations in last two years. This paper contributes to the existing literature by identifying three evolutionary mechanisms of inter-regional network. We find that proximity effect, preferential attachment and path dependence are concurrence in the evolutionary process of China's inter-regional network of technology transactions. This finding suggest that the evolution process of inter-regional network is a very complex process, and one mechanism such as geographical proximity from the perspective of economic geography or preferential attachment from the perspective of network science only could explain a part of the process.

First, besides the geographical proximity, this paper proposes and verifies the economic proximity effect existing the inter-regional network. Our finding agrees with extant literature on geographical proximity, and the physical distance and regional borders still matter for technology transaction (Katz 1994; Maggioni and Uberti 2009; Frenken et al. 2009). We also confirmed that technology transaction favor to happen among regions with similar economic development level (Zhang et al. 2016; Wang et al. 2015). It suggests that the economic proximity between two regions is central to inter-regional relations of technology transaction. According to the empirical result, both geographical proximity and economic proximity influence the inter-regional relation formation. It is worth to note that it is possible that two regions are both geographical proximity and economic proximity, which could generate overlap proximity effect to inter-regional ties.

Second, considering few new nodes (regions) participating into inter-regional network, this paper redefined the preferential attachment behavior during the process of network evolution from the perspective of existing nodes. We found that as the inter-regional network grows, degree centrality and closeness centrality becomes increasingly important for attachments or, in other words, regions with high degree centrality and closeness centrality gain more power and influence in the network. Our results enriched Abbasi et al. (2012)'s work with regarding to collaboration network, in which betweenness centrality becomes increasingly important for attachments.

Third, this paper proposes and verifies path dependence of inter-regional network or "relation dependent". It is possible that a region's innovation development depends on not only its geographical location ("place dependent") (Martin and Sunley 2006), but also its inter-regional relations. It is significance for a region's innovation development strategy and policies. In particular, large numbers of enterprises in other regions depend on Beijing's technology sellers in China. From the perspective of inter-regional network, we need to pay attention to the important role of Beijing in the network, meanwhile we also need to consider how to avoid "path locking" and knowledge homogeneity through fostering more central regions of technology supply like Shanghai and Jiangsu.

Two limitations should be considered in the future study. A limitation of this study remains that we only studied the China's case of technology transaction between 2006 and 2010. Our contribution, therefore, provides mainly a hypothesis. In order to generalize these findings, one would need to investigate other networks like collaboration network, citation network and others. If we could find similar results in China's case, it might help policy and decision makers of regional innovation. In addition, it is possible that proximity effect, preferential attachment and path dependence are correlative phenomenon. For example, the proximity may form inter-regional relations which condition an actor's position in the network; the preferential attachment is that actors' future position depend on their prior position, and inter-regional relations condition a region's position in the network, to some degree, the preferential attachment is also a kind of path dependence. However, our empirical research could not reveal relations of these three mechanisms and identify the primary mechanism. In order to reveal their relations, one would need to investigate full life circle of a network evolution, from formation to development, maturity. It is difficult to investigate China's inter-regional network during a very long period of time due to statistic data issue.

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References

Abbasi, A., Hossain, L., & Leydesdorff, L. (2012). Betweenness centrality as a driver of preferential attachment in the evolution of research collaboration networks. *Journal of Informetrics, 6*(3), 403–412.

Agrawal, A., Kapur, D., & McHale, J. (2008). How do spatial and social proximity influence knowledge flows? Evidence from patent data. *Journal of Urban Economics, 64*(2), 258–269.

Amesse, F., & Cohendet, P. (2001). Technology transfer revisited from the perspective of the knowledge based economy. *Research Policy, 30*(9), 1459–1478.

Arthur, W. B. (1989). Competing technologies, increasing returns, and lock-in by historical events. *The Economic Journal, 99*(394), 116–131.

Balland, P., Boschma, R., & Frenken, K. (2015). Proximity and Innovation: From statics to dynamics. *Regional Studies, 49*(6), 907–920.
Barabási, A. L. (2012). Network science: Luck or reason. *Nature, 489*(7417), 507–508.
Barabási, A. L., & Albert, R. (1999). Emergence of scaling in random networks. *Science, 286*(5439), 509–512.
Barrat, A., Barthélemy, M., & Vespignani, A. (2005). The effects of spatial constraints on the evolution of weighted complex networks. *Journal of Statistical Mechanics: Theory and Experiment, 2005*(05), P05003.
Belussi, F., Sammarra, A., & Sedita, S. R. (2010). Learning at the boundaries in an "Open Regional Innovation System": A focus on firms' innovation strategies in the Emilia Romagna life science industry. *Research Policy, 39*(6), 710–721.
Boschma, R. (2005). Proximity and innovation: A critical assessment. *Regional Studies, 39*(1), 61–74.
Boschma, R. A., & Frenken, K. (2006). Why is economic geography not an evolutionary science? Towards an evolutionary economic geography. *Journal of Economic Geography, 6*(3), 273–302.
Boschma, R., & Frenken, K. (2010). The spatial evolution of innovation networks. A proximity perspective. In R. Boschma & R. Martin (Eds.), *The handbook of evolutionary economic geography*. Cheltenham Glos: Edward Elgar Publishing.
Boschma, R., & Iammarino, S. (2009). Related variety, trade linkages, and regional growth in Italy. *Economic Geography, 85*(3), 289–311.
Boschma, A. R., & Ter Wal, L. J. A. (2007). Knowledge networks and innovative performance in an industrial district: the case of a footwear district in the South of Italy. *Industry and Innovation, 14*(2), 177–199.
Bottazzi, L., & Peri, G. (2003). Innovation and spillovers in regions: Evidence from European patent data. *European Economic Review, 47*(4), 687–710.
Breschi, S., & Lissoni, F. (2001). Localised knowledge spillovers vs. innovative milieux: Knowledge "tacitness" reconsidered. *Papers in Regional Science, 80*(3), 255–273.
Broekel, T., & Boschma, R. (2012). Knowledge networks in the Dutch aviation industry: The proximity paradox. *Journal of Economic Geography, 12*(2), 409–433.
Cantner, U., & Graf, H. (2006). The network of innovators in Jena: An application of social network analysis. *Research Policy, 35*(4), 463–480.
Capello, R. (2009). Spatial spillovers and regional growth: A cognitive approach. *European Planning Studies, 17*(5), 639–658.
Capello, R., & Caragliu, A. (2012). Proximities and the intensity of scientific relations: synergies and nonlinearities. Paper presented at the Tinbergen Institute, Amsterdam, May 7–8. http://www.grupposervizioambiente.it/aisre_sito/doc/papers/Caragliu_Cappello.pdf
Cheyre, C., Klepperdeceased, S., & Veloso, F. (2015). Spinoffs and mobility of U.S. merchant semiconductor inventors. *Management Science, 61*(3), 487–506.
Cohen, W. M., & Levinthal, D. A. (1990). Absorptive capacity: A new perspective on learning and innovation. *Administrative Science Quarterly, 35*(1), 128–152.
Cooke, P., Uranga, M. G., & Etxebarria, G. (1997). Regional innovation systems: Institutional and organisational dimensions. *Research Policy, 26*(4), 475–491.
Cowan, R., & Gunby, P. (1996). Sprayed to death: path dependence, lock-in and pest control strategies. *The Economic Journal, 106*(436), 521–542.
David, A. P. (1985). Clio and the Economics of QWERTY. *The American Economic Review, 75*(2), 332–337.
Ejermo, O., & Karlsson, C. (2006). Interregional inventor networks as studied by patent coinventorships. *Research Policy, 35*(3), 412–430.
Fitjar, R. D., & Rodriguez-Pose, A. (2011). When local interaction does not suffice: sources of firm innovation in urban Norway. *Environment and Planning A, 43*(6), 866–884.
Florida, R. (1995). Toward the learning region. *Futures, 27*(5), 527–536.
Freeman, L. C. (1979). Centrality in social networks conceptual clarification. *Social Networks, 1*(3), 215–239.
Frenken, K., Hoekman, J., Kok, S., Ponds, R., van Oort, F., & van Vliet, J. (2009). Death of distance in science? A gravity approach to research collaboration. In A. Pyka & A. Scharnhorst (Eds.), *Innovation networks: New approaches in modelling and analyzing*. Berlin: Springer.
Fromhold-Eisebith, M. (2004). Innovative milieu and social capital—Complementary or redundant concepts of collaboration-based regional development? *European Planning Studies, 12*(6), 747–765.
Gao, X., Guan, J., & Rousseau, R. (2011). Mapping collaborative knowledge production in China using patent co-inventorships. *Scientometrics, 88*(2), 343–362.

Gertler, M. S., & Levitte, Y. M. (2005). Local nodes in global networks: The geography of knowledge flows in biotechnology innovation. *Industry and Innovation, 12*(4), 487–507.
Grabher, G., & Ibert, O. (2006). Bad company? The ambiguity of personal knowledge networks. *Journal of Economic Geography, 6*(3), 251–271.
Guan, J., Zhang, J., & Yan, Y. (2015). The impact of multilevel networks on innovation. *Research Policy, 44*(3), 545–559.
Guimera, R., & Amaral, L. A. N. (2004). Modeling the world-wide airport network. *The European Physical Journal B-Condensed Matter and Complex Systems, 38*(2), 381–385.
Hassink, R., & Klaerding, C. (2012). The end of the learning region as we knew it; towards learning in space. *Regional Studies, 46*(8), 1055–1066.
Herstad, S. J., Aslesen, H. W., & Ebersberger, B. (2014). On industrial knowledge bases, commercial opportunities and global innovation network linkages. *Research Policy, 43*(3), 495–504.
Hoekman, J., Frenken, K., & Tijssen, R. J. (2010). Research collaboration at a distance: Changing spatial patterns of scientific collaboration within Europe. *Research Policy, 39*(5), 662–673.
Hoekman, J., Frenken, K., & van Oort, F. (2009). The geography of collaborative knowledge production in Europe. *The Annals of Regional Science, 43*(3), 721–738.
Katz, J. (1994). Geographical proximity and scientific collaboration. *Scientometrics, 31*(1), 31–43.
Krätke, S. (2010). Regional knowledge networks: A network analysis approach to the interlinking of knowledge resources. *European Urban and Regional Studies, 17*(1), 83–97.
LeSage, J. P., Fischer, M. M., & Scherngell, T. (2007). Knowledge spillovers across Europe: Evidence from a Poisson spatial interaction model with spatial effects. *Papers in Regional Science, 86*(3), 393–421.
Liu, H., & Jiang, Y. (2001). Technology transfer from higher education institutions to industry in China: Nature and implications. *Technovation, 21*(3), 175–188.
Lundvall, B. A. (1992). *National systems of innovation: An analytical framework*. London: Pinter.
Ma, H., Fang, C., Pang, B., & Li, D. (2014). The effect of geographical proximity on scientific cooperation among Chinese cities from 1990 to 2010. *PLoS One, 9*(11), e111705.
Ma, R., Liu, F., & Sun, Y. (2013). Collaboration partner portfolio along the growth of Chinese firms' innovation capability: Configuration, evolution and pattern. *International Journal of Technology Management, 62*(2/3/4), 152–176.
Maggioni, M. A., & Uberti, T. E. (2009). Knowledge networks across Europe: Which distance matters? *The Annals of Regional Science, 43*(3), 691–720.
Maggioni, M. A., Uberti, T. E., & Usai, S. (2011). Treating patents as relational data: Knowledge transfers and spillovers across Italian provinces. *Industry and Innovation, 18*(1), 39–67.
Martin, R., & Sunley, P. (2006). Path dependence and regional economic evolution. *Journal of Economic Geography, 6*(4), 395–437.
Mathieu, E. J., Heffner, S. T., Goodwin, F. G., Salas, E., & Cannon-Bowers, A. J. (2000). The influence of shared mental models on team process and performance. *Journal of Applied Psychology, 85*(2), 273–283.
Morescalchi, A., Pammolli, F., Penner, O., Petersen, A. M., & Riccaboni, M. (2015). The evolution of networks of innovators within and across borders: Evidence from patent data. *Research Policy, 44*(3), 651–668.
Morgan, K. (2004). The exaggerated death of geography: Learning, proximity and territorial innovation system. *Journal of Economic Geography, 4*(1), 3–21.
Orsenigo, L., Pammolli, F., & Riccaboni, M. (2001). Technological change and network dynamics: Lessons from the pharmaceutical industry. *Research Policy, 30*(3), 485–508.
Porter, M. E. (1994). The role of location in competition. *Journal of the Economics of Business, 1*(1), 35–39.
Porter, M. E. (1998). Clusters and the new economics of competition. *Harvard Business Review, 76*(6), 77–90.
Scott, J. (1991). *Social network analysis: A handbook*. London: Sage Publications.
Sebestyén, T., & Varga, A. (2013). Research productivity and the quality of interregional knowledge networks. *The Annals of Regional Science, 51*(1), 155–189.
Sun, Y., & Cao, C. (2015). Intra-and inter-regional research collaboration across organizational boundaries: Evolving patterns in China. *Technological Forecasting and Social Change, 96*(7), 215–231.
Wang, Y., Pan, X., Ning, L., Li, J., & Chen, J. (2015). Technology exchange patterns in China: An analysis of regional data. *The Journal of Technology Transfer, 40*(2), 252–272.
Wang, Z. Z., & Zhu, J. J. (2014). Homophily versus preferential attachment: Evolutionary mechanisms of scientific collaboration networks. *International Journal of Modern Physics C, 25*(05), 1440014.
Wanzenböck, I., Scherngell, T., & Brenner, T. (2014). Embeddedness of regions in European knowledge networks: A comparative analysis of inter-regional R&D collaborations, co-patents and co-publications. *The Annals of Regional Science, 53*(2), 337–368.

Wennekers, S., Van Wennekers, A., Thurik, R., & Reynolds, P. (2005). Nascent entrepreneurship and the level of economic development. *Small Business Economics, 24*(3), 293–309.
Zhang, G., Duan, H., & Zhou, J. (2016). Investigating determinants of inter-regional technology transfer in China: A network analysis with provincial patent data. *Review of Managerial Science, 10*(2), 345–364.