Network analysis of R&D technology spillovers effect in the Yangtze River Delta Region

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Abstract. This article evaluates the evolution of inter-city R&D technology spillover in the Yangtze River Delta Region (YRDR) using social network analysis method. Empirical results indicate that the inter-city R&D technology spillovers are sparse, but gradually increasing. Four characteristic cohesive subgroups are formed, subgroup I formed by core cities like Shanghai and Nanjing is the technical sender and the subgroup is closely connected. Nanjing's role as a network bridge has been replaced by Jiaxing.

1. Introduction
China is facing the transition from extensive development driven by factors to intensive sustainable development after more than 30 years of rapid development. Then the central government has determined a new mode of urban agglomeration development in order to find new driving forces and growth points. In 2019, China promulgated the outline of the development plan of Guangdong, Hong Kong, Macao and the Great Bay Area. At the same time, it upgraded the regional integration of the Yangtze River Delta into a national strategy, marking that China's economic development has formally entered a new stage of urban agglomeration-led development. “Leading Enterprises, Technology Diffusion and Public Policy” released by OECD, proposes that knowledge and information diffusion are key to improving regional overall productivity, maintaining economic stability and sustainable growth. There are three national science centers in China: Beijing, Shanghai and Hefei, and the Yangtze River Delta accounts for two-thirds. Therefore, it is of great significance to study the technology spillover and its evolution in this region to promote the integration of urban agglomerations.

Since Schumpeter, economists have argued that technological innovation is a key driver of economic growth [1]. The endogenous growth theory underlines the importance of R&D for the occurrence of innovation [2]. In an open economy, the R&D investment of a country, a region or an enterprise is not only beneficial to its own innovation and technological progress, but also to the technological progress of other countries or regions via technology spillovers due to the knowledge externalities [3].

Scholars have explored international R&D technology spillover from three aspects: international trade [4], FDI [5] and OFDI [6]. However, the externalities of R&D also in the regional economic activities. There are R&D technology spillovers effects among different regions when economic
activities such as trade in goods, personnel turnover, and industry transfer occur due to the gap in different regional economic development and technical progress. Therefore, in recent years, scholars have gradually begun to study the inter-regional technology spillover effect [7,8]. At the present stage, China is vigorously promoting the regional integration and the urban agglomeration construction. All kinds of information flow, knowledge flow, and personnel flow have been moving among different cities, which put cities into the same association web. Therefore, the research on inter-city technology spillovers effects can provide the basis and reference for the construction of urban agglomeration and the development of regional integration. However, there are few studies that put inter-city technology spillover in a whole network and explore the inter-city technology spillover links and its network characteristics by using the social network method. Therefore, this paper takes the 41 cities in the YRDR as the research sample, constructs the inter-city R&D technology spillover network, analyzes its links, structure features, the position and role of node cities in the network, aiming to provide scientific references for the strengthening of technical connection among YRDR cities, and the promotion of the comprehensive technical strength.

2. Materials and Methods

2.1. Data source
As for the definition of YRDR space, there exist a variety of theoretical perspectives. We took the generally accepted mode “3+1” [9], namely the space including Shanghai, Jiangsu, Zhejiang and Anhui provinces. Considering the separation and combination of Chaohu city, together with the data consistency, we analyzed the data related to 41 prefecture-level cities and above.

The paper chooses the year of 2009 and 2014 as the survey years based on the availability and completeness of the data and the proposed time of conception of the YRDR. The R&D expenditure data are from Anhui, Shanghai and Zhejiang statistical yearbook; We calculates the R&D expenditure data of Jiangsu province according to municipal statistical monitoring results and bulletin of scientific and technological progress in Jiangsu province, which published on the website of science and technology department of Jiangsu province (http://kxjst.jiangsu.gov.cn/). The GDP per capita comes from the provincial statistical yearbook, and the geographic distance between cities is the spherical distance between cities, which is calculated by ArcGIS.

2.2. Measure of the inter-city R&D technology spillovers
As for the calculation of the inter-city R&D technology spillovers, the following formula is often applied [4]:

\[ RDS_{it} = \sum_{j \neq i} W_{ij} * RD_{jt} \]  \hspace{1cm} (1)

Where \( RDS_{it} \) refers to the R&D technology spillovers received by city i from other regions; \( W_{ij} \) is the inter-city R&D spillovers weight; \( RD_{jt} \) is the R&D investment expenditure of city j in the period of t.

This paper sets up \( W_{ij} \) considers two factors: 1. Cities closer to each other are more likely to have technology spillover [10]; 2. Cities with closer economic development are more able to absorb technology spillover [11]. Therefore, the calculation formula is as follows:

\[ W_{ij} = w_{ij} * e_{ij} \]  \hspace{1cm} (2)

Where \( w_{ij} \) represents the geographical distance between city i and j, which is measured according to the reciprocal structure of the distance between urban spheres; \( e_{ij} \) is a matrix that describes the difference between regional economic levels, which is denoted by the inverse of the absolute value of per capita GDP in urban i and j.
2.3. Analysis of inter-city R&D technology spillovers network

2.3.1. The evaluation index of overall network structure.

(1) The Network Density means the ratio of the actual links number to the maximum theoretical links number in the inter-city R&D technology spillovers network[12], reflecting the overall tightness of the network. The greater the network density value, the more technology links among cities. As for the intercity R&D technical spillovers network constructed in this article, there exists the maximum number of N (N-1) in theory. If the actual number of R&D technical spillovers in the network is L, then the network density is L/N (N - 1).

(2) The network centralization is an index used to measure the centralization of the total inter-city R&D technology spillovers network. The higher the value is, and the more concentrated of the network links on few nodes is. The inter-city R&D technology spillovers network is directed, the network centralization is divided into outdegree and indegree centralization. The calculation formula is as follows:

\[ C_{AD} = \frac{\sum_{i=1}^{N} (C_{AD\text{max}} - C_{ADi})}{(N^2 - 3N + 2)} \]  

Where \( C_{AD} \) stands for the network centralization, \( C_{ADi} \) represents the centrality of node i, \( C_{AD\text{max}} \) denotes the maximum node centrality and N is the number of nodes in the network.

2.3.2. Evaluation index of network hierarchical structure.

Cohesive Subgroups Analysis is used to explore whether cities form subgroups due to the technology links, what kind of relationship there is between the subgroups in the inter-city R&D technology spillovers network. In this paper, CONCOR clustering method is used to cluster cities in PRDR. Its essence is an iterative correlation convergence method based on Pearson correlation coefficient. Its basic principle is to calculate the correlation coefficient between each row or column according to the row or column of the original matrix, and then use the correlation coefficient matrix as the input matrix, and continue to calculate the correlation coefficient between each row or column until the matrix is iterated to contain correlation coefficient matrix composed of only 1 and -1 [13].

2.3.3. Evaluation index of network node characteristics.

Betweenness of node, reflects to what extent a city is the intermediary of other cities in the network. If a city is located on the shortest path of other cities, the city has a higher betweenness. For example, if there exist gab shortcuts between city a and b and the number of shortcuts through city c is \( g_{ab}(c) \), \( k_{ab}(c) \) denotes the association ability of c to control city a and b, \( k_{ab}(c) = g_{ab}(c)/g_{ab} \). Its standardized formula is as follows:

\[ Ck_c = \frac{2 \sum_{a}^{N} \sum_{b}^{N} k_{ab}(c)}{N^2 - 3N + 2} \]  

Where \( Ck_c \) indicates the relative betweenness of the node.

3. Results

3.1. The overall characteristics of the R&D technology spillovers of YRDR

(1) The technical links in the YRDR are generally fewer, but they are gradually increasing. In 2009, the number of technology links in the network was 332, and the network density was only 0.2024. In 2014, technology links increased to 725, more than doubling that in 2009, and the network density increased to 0.4421. It shows that the inter-city R&D technology spillovers in YRDR was significantly enhanced.

(2) The technology spillovers senders and receivers are not evenly distributed, but both of them are
moving towards a more balanced direction.

As can be seen in Table 1, the outdegree centralization reflecting the ability of the send out R&D technology spillovers is relatively high, exceeding 57%, which indicates that the technical senders are concentrated in a few cities, and the big cities with economic and technical strength are influential in the inter-city R&D technology spillovers network. According to the status of R&D investment, the top 10 cities represented by Shanghai and Suzhou account for more than 70% of the total regional investment in R&D. The indegree centralization reflecting the ability of the receive R&D technology spillovers is relatively low, which indicates that the technical receiver are evenly distributed, helpful to narrow the technical gap among cities.

Table 1. Network Density and Centralization of inter-city R&D spillovers in 2009 and 2014

| Year | Network Density | Outdegree Centralization | Indegree Centralization |
|------|-----------------|--------------------------|-------------------------|
| 2009 | 0.2024          | 81.75%                   | 38.19%                  |
| 2014 | 0.4421          | 57.19%                   | 29%                     |

3.2. Analysis of the hierarchical structures of the inter-city R&D technology spillovers network

There are four distinctive cohesive subgroups in the R&D technology spillovers network of YRDR. The internal members of the subgroups is unstable, and the formation of each subgroup is characterized by the geographic adhesiveness and economic proximity. Specifically speaking, the cohesive subgroup I represented by Shanghai-Nanjing-Hangzhou is mainly distributed along the Yangtze River and Hangzhou Bay Area, whose members increases steadily, and the influence of technology spillovers increases. The cohesive subgroup II and the cohesive subgroup III showing a strong economic proximity. The former is formed by the following cities like Xuzhou, Yancheng, Taizhou in jiangsu province, Huzhou, Jiaxing, Jinhua, Wenzhou, Taizhou in Zhejiang province and Maanshan, Wuhu; while the latter is formed by the following cities like Lianyungang, Suqian, Quzhou, Lishui, Bengbu, Huaihe, Huainan, Tongling, Xuancheng, Chizhou, Huangshan. For example, in 2014, Yancheng and Wenzhou are geographically far apart, but their per capita GDP are almost the same, amounting to 8.6 thousand USD/person. Meanwhile, their added value of the secondary industry accounted for 46.5% and 47.2% of the local GDP respectively, have similar industrial structure. Therefore, the cohesive subgroup was formed driven by both economic distance and industrial structure. The cohesive subgroup IV formed by the peripheral cities like Anqing, Lv’an are mainly distributed in Anhui province.

In terms of internal subgroup links, the cohesive subgroup I is the benchmark among the four subgroups. In 2014, subgroup I was the most closely connected, 7.77 times as high as subgroup II, 9.92 times as high as subgroup III, and 123.29 times as high as subgroup IV. From the perspective of inter-group links, subgroup I is the main force to send technology spillovers in the network, its net external technology spillover accounted for 54% and 46.5% of the network technology spillover. From
2009 to 2014, technology spillovers of subgroup I has been significantly radiated, and the technology spillovers on the other subgroups increased by 99.32%. In 2009, subgroup IV formed by Lianyungang and other cities was the biggest technical receiver. The net input accounted for 37% of the total network technology spillovers. Absorbing the technology spillovers from the inter-group is helpful to the technological progress of the cities within subgroup IV, thus finding new technical partners, and forming new subgroups. As can be seen from Fig. 1, some members of subgroup IV entered subgroup II and subgroup III respectively in 2014. In 2014, subgroup III became the main technical receiver, and its net input of technology spillovers accounted for 39.58% of the total network, increased by 602% compared with the year of 2009.

3.3 Nodes Characteristics of inter-city R&D technology spillovers network
Nanjing’s intermediary position in the network was replaced by Jiaxing. Nanjing and jiaxing are the largest intermediary cities in two years respectively. In 2009, the average betweenness was 0.796, and Nanjing’s betweenness was the highest, reaching as high as 14.88, 18.6 times as high as the mean in the network, and 2.16 times as high as that of Hefei city, which ranks the second in the betweenness. Therefore, Nanjing is an important hub city in the inter-city R&D technology spillovers network. Once the links with Nanjing is lost, many cities may lose the technical links with other cities. However, Jiaxing became the city which has highest betweenness in the network in 2014, the intermediary role played by Nanjing was replaced by jiaxing. Geographically, jiaxing is close to Shanghai and hangzhou, the total links of Jiaxing with other cities in terms of technology increased by 56.73% during that period. Moreover, Jiaxing’s technical partner increased from 18 to 35. Moreover, Jiaxing is located on the shortcuts of many cities belonging to south of Zhejiang province and north of Jiangsu province. Only through Jiaxing can such cities as Wenzhou, Taizhou, and Jinhua in zhejiang province make technical links with Taizhou, Yancheng and Yangzhou in jiangsu province, thus improving the bridge role of Jiaxing in the network. Nanjing, as a semi-central city in the YRDR, established technical links with most cities in the network in 2009. Therefore, there was less net increase in the technical links with other cities over the period.

Table 2. Centrality of the top 10 cities in 2009 and 2014.

| City     | 2009 Betweenness | 2014 Betweenness |
|----------|------------------|------------------|
| Nanjing  | 14.879           | Jiaying          |
| Hefei    | 6.876            | Shaoxing         |
| Yangzhou | 3.393            | Shanghai         |
| Changzhou| 2.809            | Nantong          |
| Zhongjiang| 2.209           | Shanggai         |
| Mean     | 0.796            | Mean             |

4. Conclusions and Recommendations
Main findings are concluded as follows: (1)The technical links among cities in PRDR were generally few, but it is gradually strengthening. (2) There are four cohesive subgroups characterized by geographical adhesion and economic proximity in the network. Among them, the cohesive subgroup I formed by the core cities such as Shanghai, Nanjing and Hangzhou are the benchmark of intra-group and inter-group connections. (3) Nanjing’s role as a bridge in inter-city R&D technology spillover network has been replaced by Jiaxing, which has more advantageous geographical position. Based on the results, we propose the following suggestions: (1) Increasing R&D investments and rational allocation of R&D resources of cities, enhancing their technical strength and their ability to absorb technology. (2) We should improve infrastructure such as transportation and public knowledge and information platforms in the PRDR, promote exchanges and cooperation in inter-city trade,
technology and human resources, and expand channels for sending and receiving inter-city R&D technology spillovers. At the same time, it is necessary to allocate educational resources rationally, increase the support for the cultivation of talents in marginal cities, and establish the coupling mechanism of talents between cities, so as to provide intellectual support for the transmission and absorption of inter-city R&D technology spillovers.(3) we should pay more attention to the overall interests of the region. Each city in the PRDR should rationally positioned according to its own resource endowment and position in the network, drive the development of the surrounding cities with the central cities, carry out a reasonable functional orientation and orderly division of labor for the big, medium and small cities, achieving dislocation development, complementary advantages, so as to promote the economic and technological integration of the PRDR.

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